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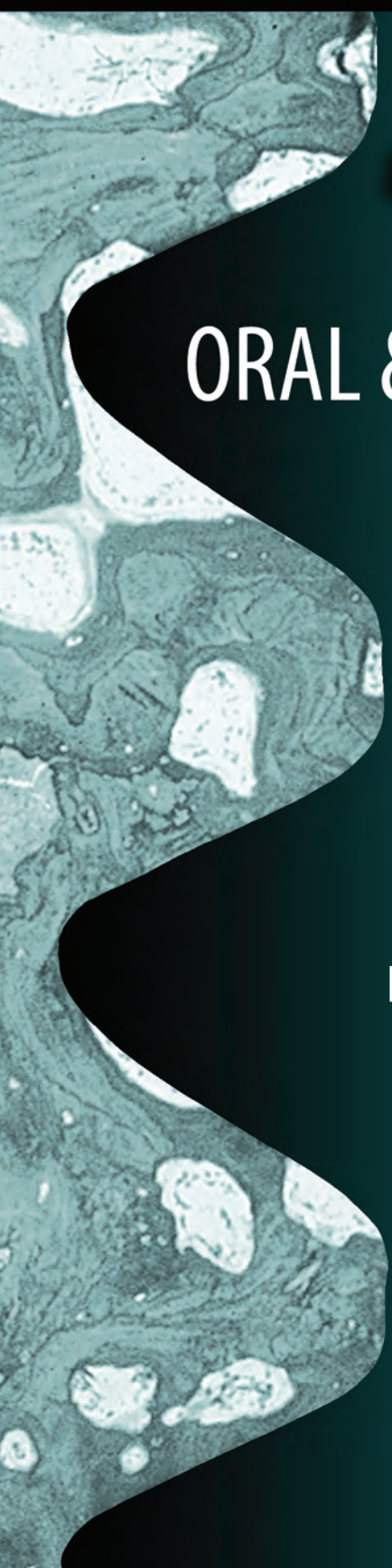

PROCEEDINGS OF THE FOURTH ITI CONSENSUS CONFERENCE

INTRODUCTION

This supplement to *The International Journal of Oral & Maxillofacial Implants* presents the proceedings of the Fourth ITI Consensus Conference, which took place in August 2008 in Stuttgart, Germany. The International Team for Implantology (ITI) is an independent academic association that unites professionals around the world from every area of implant dentistry and related tissue regeneration field. ITI fellows and members, who currently number more than 6,000 in total, regularly share their knowledge and expertise from research and clinical practice at meetings, courses, and congresses with the objective of continuously improving treatment methods and outcomes to the benefit of their patients.

The ITI organizes consensus conferences once every 5 years to discuss and deliberate on the most relevant and topical issues in clinical implant dentistry. The organizing committee, led by the chairman of the ITI Education Committee, invited four group leaders to oversee the task of preparing review papers for discussion at the consensus conference. A team of 15 reviewers and 29 co-reviewers worked tirelessly over a 12-month period to evaluate the current literature and to identify the evidence or lack thereof for a wide range of clinically based topics. At the consensus conference, 15 to 20 clinicians and researchers per group were invited from around the world to participate in the discussions. The four topics and group leaders were as follows:

Group 1: Risk Factors for Implant Therapy
Group Leader: David L. Cochran

Group 2: Emerging Techniques and Technologies in Implant Dentistry
Group Leader: Christoph H. F. Hammerle

Group 3: Implant Loading Protocols
Group Leader: Hans-Peter Weber

Group 4: Surgical Techniques in Implant Therapy
Group Leader: Stephen T. Chen

A total of 15 review papers were presented for discussion at the consensus conference. Each group was given the task of reviewing and agreeing on the content and conclusions of the review papers, and making recommendations in relation to treatment protocols. These deliberations formed the basis for consensus statements and clinical recommendations for each of the topics under consideration. The consensus statements and recommendations were presented at plenary sessions attended by all participants. These statements were discussed extensively and amendments made where required until they were accepted by all conference participants.

The ITI is pleased to be able to present the proceedings of the Fourth ITI Consensus Conference in this special supplement, which should serve to provide clinicians with current and evidence-based information to assist with diagnosis, treatment planning, and management of patients undergoing dental implant therapy. On behalf of the ITI, we wish to thank all the group leaders, reviewers, co-reviewers, and participants who contributed to the success of the consensus conference.

Dieter Weingart
ITI President

Stephen T. Chen
Chairman, ITI Education Committee

ACKNOWLEDGMENTS

The effort and enthusiasm of all staff members of the ITI Center are recognized and greatly appreciated. In addition, we wish to thank Mrs Jeannie Wurz for her assistance and support with the editing of the manuscripts.

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Review Papers Submitted for Discussion:

Systemic Conditions and Treatments as Risks for Implant Therapy
Michael M. Bornstein/Norbert Cionca/Andrea Mombelli

Local Risk Factors for Implant Therapy
William Martin/Emma Lewis/Ailsa Nicol

History of Treated Periodontitis and Smoking as Risks for Implant Therapy
Lisa J. A. Heitz-Mayfield/Guy Huynh-Ba

Mechanical and Technical Risks in Implant Therapy
Giovanni E. Salvi/Urs Brägger

Systemic Conditions and Treatments as Risks for Implant Therapy

Michael M. Bornstein, Dr Med Dent[1]/Norbert Cionca, Dr Med Dent[2]/Andrea Mombelli, Prof Dr Med Dent[3]

Purpose: *To evaluate whether systemic diseases with/without systemic medication increase the risk of implant failure and therefore diminish success and survival rates of dental implants.* ***Materials and Methods:*** *A MEDLINE search was undertaken to find human studies reporting implant survival in subjects treated with osseointegrated dental implants who were diagnosed with at least one of 12 systemic diseases.* ***Results:*** *For most conditions, no studies comparing patients with and without the condition in a controlled setting were found. For most systemic diseases there are only case reports or case series demonstrating that implant placement, integration, and function are possible in affected patients. For diabetes, heterogeneity of the material and the method of reporting data precluded a formal meta-analysis. No unequivocal tendency for subjects with diabetes to have higher failure rates emerged. The data from papers reporting on osteoporotic patients were also heterogeneous. The evidence for an association between osteoporosis and implant failure was low. Nevertheless, some reports now tend to focus on the medication used in osteoporotic patients, with oral bisphosphonates considered a potential risk factor for osteonecrosis of the jaws, rather than osteoporosis as a risk factor for implant success and survival on its own.* ***Conclusions:*** *The level of evidence indicative of absolute and relative contraindications for implant therapy due to systemic diseases is low. Studies comparing patients with and without the condition in a controlled setting are sparse. Especially for patients with manifest osteoporosis under an oral regime of bisphosphonates, prospective controlled studies are urgently needed.* Int J Oral Maxillofac Implants 2009;24(suppl):12–27

Key words: *bisphosphonates, diabetes, implant failure, osseointegration, osteoporosis, systemic disease*

The replacement of missing teeth with endosseous implants for the rehabilitation of edentulous or partially edentulous patients has become a standard of care in the past two decades. This significant progress is based on the concept of osseointegration, first described by the two research groups of Brånemark and Schroeder. Fundamental experimental studies demonstrated that titanium implants regularly heal with direct bone-to-implant contact, a process termed *osseointegration*[1] or *functional ankylosis*.[2] To achieve and maintain osseointegration, indications and contraindications must be carefully balanced, and proper patient selection is thus a key issue in treatment planning.[3] Contraindications can be divided into local and systemic/medical. In a paper prepared for the second ITI (International Team of Oral Implantology) Consensus Conference, Buser and coworkers[4] (2000) proposed to subdivide the general medical/systemic risk factors into two groups:

- Group 1 (very high risk): Patients with serious systemic disease (rheumatoid arthritis, osteomalacia, osteogenesis imperfecta); immunocompromised patients (HIV, immunosuppressive medications); drug abusers (alcohol); noncompliant patients (psychological and mental disorders)

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None of the authors reported a conflict of interest.

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- Group 2 (significant risk): Patients with irradiated bone (radiotherapy), severe diabetes (especially type 1), bleeding disorders (hemorrhagic diathesis, drug-induced anticoagulation), heavy smoking habit

Systemic diseases may affect oral tissues by increasing their susceptibility to other diseases or by interfering with healing. In addition, systemic conditions may be treated with medications or other therapies that potentially affect implants and the tissues carrying them. Several authors have identified diseases for which dental implants are not recommended, or are at least questionable,[3,5–7] but it often remains unclear on what type of evidence these statements are based.

Patients receiving dental implants generally fall into the first two physical status categories of the Classification System of the American Society of Anesthesiology (ASA): P1, a normal healthy patient; or P2, a patient with mild systemic disease.[8,9] For very severe and acute medical problems, calculating the risk of failure in affected subjects seems impossible, simply because patients with such conditions hardly ever receive implants. These patients fall into the ASA physical status categories P3 to P6: patients with severe systemic disease (P3); patients with severe systemic disease that is a constant threat to life (P4); moribund patients who are not expected to survive without an operation (P5); and subjects declared brain dead whose organs may be removed for donor purposes (P6). A recent publication stated that elective dental treatment of patients classified as P4 or higher should ideally be postponed until the patient's medical condition has stabilized and improved to at least P3.[10]

The purpose of this review was to evaluate the impact of systemic diseases, and/or medications used to treat systemic diseases, on the success of dental implant therapy. The analysis was focused on conditions that are not generally considered to be an absolute contraindication. The role of systemic factors in early failures (ie, during the healing period up to initiation of prosthetic treatment) and late failures (ie, after implant loading) was analyzed.

MATERIALS AND METHODS

Literature "Scoping"

To select the most important key words, a preliminary assessment was made of the potentially relevant literature. This was achieved by "scoping" searches, including searching for existing reviews. Incorporating opinions expressed in seven nonsystematic reviews,[3,6,7,11–14] a list of systemic diseases suspected of having a negative impact on the success of osseointegration therapy was generated. Severe and acute medical conditions for which implant therapy has always been considered a contraindication (eg, acute infections, severe bronchitis or emphysema, severe anemia, uncontrolled diabetes, uncontrolled hypertension, abnormal liver function, nephritis, severe psychiatric disease, conditions with severe risk of hemorrhage, endocarditis or myocardial infarction) were excluded from the start.

As the present review paper is also an update of the paper published in 2006 by Mombelli and Cionca,[15] key word selection was additionally based on the search terms used in the former publication. The diseases and conditions retained for further analysis were: scleroderma, Sjögren syndrome, neuropsychiatric disorders/Parkinson disease, lichen ruber planus/oral lichen planus, HIV infection, ectodermal dysplasia, long-term immunosuppression after organ transplantation, cardiovascular disease, Crohn disease, diabetes, osteoporosis, oral bisphosphonate medication, and use of radiotherapy for the treatment of oral squamous cell carcinoma (OSCC).

Review Question and Study Parameters

In patients treated with dental implants, to what extent does a history of scleroderma, Sjögren syndrome, neuropsychiatric disorders/Parkinson disease, oral lichen planus, HIV infection, ectodermal dysplasia, long-term immunosuppression after organ transplantation, cardiovascular disease, Crohn disease, diabetes, osteoporosis, medication with oral bisphosphonates, or irradiated bone due to the treatment of OSCC increase the risk for implant failure?

Implant failure was selected as the primary study parameter, and it was further divided into early and late implant failures.

Search Strategy

Using EndNote X1, 13 MEDLINE searches were conducted based on the process mentioned previously. The search was conducted up to and including March 2008 using the following strategy: *implant* AND (*oral* OR *dental*) AND

1. *Scleroderma*
2. *Sjögren's syndrome* and/or *Sjögren*
3. *Neuropsychiatric disorders* and/or *Parkinson*
4. *Lichen planus*
5. *AIDS* or *HIV*
6. *Ectodermal dysplasia*
7. *Crohn*
8. *Transplantation*
9. *Cardiovascular*

10. *Diabetes* or *insulin therapy* or *glucose intolerance*
11. *Osteoporosis* or *osteoporotic*
12. *Oral bisphosphonates*
13. *Radiotherapy* or *irradiation* or *irradiated*

This search strategy was designed for high recall rather than high precision in the first instance. There were no language restrictions.

Study Selection and Quality-Assessment Procedures

The primary study inclusion criteria were:

- Study includes human subjects with the respective diagnosis.
- Subjects have osseointegrated dental implants.
- Study reports implant failure, survival, and/or success.
- Case series include at least five subjects with the respective diagnosis. If case reports with fewer treated subjects were the only available source of information, they were listed.

Two independent reviewers screened titles and abstracts of the search results (MB, NC). Any disagreement regarding inclusion was resolved by discussion including the third independent reviewer (AM). The full text of all studies of possible relevance was then obtained by two reviewers (MB, NC) for independent assessment of the stated inclusion criteria. Additional studies were sought by scanning the references cited in the retained papers and by personal communication.

The methodological quality was assessed using the levels of evidence proposed by the Oxford Centre for Evidence-based Medicine (http://www.cebm.net/levels_of_evidence.asp), ranging from lowest (level 5, expert opinion without explicit critical appraisal, or based on physiology, bench research, or first principles) to highest (level 1a, systematic reviews with homogeneity of randomized clinical trials).

Data Extraction Strategy

The following data were sought, separately for each condition, for subjects with and without the specific diagnosis (if available): implant type, number of subjects, number of implants, number of subjects with early failures, number of early failing implants, years of follow-up, number of subjects followed up, number of implants followed up, number of subjects with late failures, number of late failing implants. Failures were defined as implants lost, and were subdivided into losses occurring before and those occurring after the functional loading (early and late).

RESULTS AND DISCUSSION

Scleroderma, Lichen Planus, and Ectodermal Dysplasia

No controlled studies were found for scleroderma, oral lichen planus, or ectodermal dysplasia to demonstrate any positive or negative effects on the outcome of implant therapy. For all three conditions only case reports or case series could be identified.

Scleroderma is defined as a multisystem disorder characterized by inflammatory, vascular, and sclerotic changes of the skin and various internal organs, especially the lungs, heart, and gastrointestinal tract. Typical clinical features in the facial region are a masklike appearance (patients look younger), thinning of the lips, microstomia, radial perioral furrowing, sclerosis of the sublingual ligament, and indurations of the tongue.[16] These symptoms cause the skin of the face and lips as well as the intraoral mucosa to become taut, thereby hindering dental treatment and complicating or even preventing the insertion of dental prostheses. Only five case reports with up to two patients treated with dental implants could be found in the literature.[17–21] Therefore, the level of evidence for the efficacy of dental implants in these patients is quite low (level 4).

Oral lichen planus (OLP) is a common T-cell–mediated autoimmune disease of unknown cause that affects stratified squamous epithelium virtually exclusively.[22] OLP has been considered a contraindication for the placement of dental implants possibly because of the altered capacity of the oral epithelium to adhere to the titanium surface.[5] In the literature there are only case reports with up to three patients treated, including symptomatic[23] and asymptomatic[21,24] forms of lichen planus. Nevertheless, OLP is a potentially malignant condition, which in rare cases may result in malignant transformation.[25] Only one case report describing an OSCC originating from OLP in association with dental implants was identified.[26] With the literature available at present (level 4), oral lichen planus as a risk factor for implant surgery and long-term success cannot be properly assessed.

Ectodermal dysplasia (ED) is a hereditary disease characterized by congenital dysplasia of one or more ectodermal structures. Common extra- and intraoral manifestations include defective hair follicles and eyebrows, frontal bossing, nasal bridge depression, protuberant lips, hypo- or anodontia, conical teeth, and generalized spacing.[27] Most search results for ED were case reports demonstrating treatment success with dental implants.[21,28–37] A few larger case series report survival and success rates of implants in such patients[38–42] (Table 1). However, due to the lack of controls, it cannot be determined how these results

Table 1 Implant Failures: Case Series of Patients with Ectodermal Dysplasia Treated with Implants

Study	No. of patients	No. of implants placed		Early failures		Late failures			All failures		Implant failures (no.) by location	
		Maxilla	Mandible	%Subj	%Impl	Y	%Subj	%Impl	%Subj	%Impl	Maxilla	Mandible
Guckes et al (1991)[38]	ND	0	61	ND	10	ND	ND	ND	ND	ND	ND	6
Kearns et al (1999)[39]	6	19	22	16.7	2.4	6	0.0	0.0	16.7	2.4	1	0
Guckes et al (2002)[40]	51	21	243	ND	ND	1.9	ND	ND	27.5	89.8	5	22
Sweeney et al (2005)[41]	14	15	46	35.7	11.4	1	ND	ND	ND	ND	2	4
Umberto et al (2007)[42]	13	15	51	ND	3	3	ND	6.1	ND	9.1	2	4

%Subj = subject-based rate; %Impl = implant-based rate; Y = years of follow-up after restoration; ND = no data available.

compare to those expected in subjects without the condition. All studies reported significantly lower survival and success rates in the maxilla than in the mandible (evidence level 4).

Sjögren Syndrome

Sjögren syndrome (SS) is a chronic autoimmune disease affecting the exocrine glands, primarily the salivary and lacrimal glands. At present, the etiology of SS is far from being understood.[43] The most common symptoms of SS are extreme tiredness, along with dry eyes (keratoconjunctivitis sicca) and dry mouth (xerostomia). Xerostomia can eventually lead to difficulty in swallowing, severe and progressive tooth decay, or oral infections. Currently, there is no cure for SS, and treatment is mainly palliative.[44]

Literature on implant performance in patients with SS is scarce. There are no controlled studies available, and only one case series study with eight patients included was found (level of evidence 4).[45] The eight patients in this study were all women receiving a total of 54 implants (18 in the maxilla, 36 in the mandible) with a machined surface. At abutment connection seven of these implants (12.9%) were found not to be osseointegrated at abutment connection. During the first year of function, two additional implants in the mandible were lost, resulting in an implant-based failure rate of 16.7% (patient-based 50%; four patients out of eight lost at least one implant).

Neuropsychiatric Disorders and/or Parkinson Disease

There is virtually no literature available on implant performance in patients with neuropsychiatric disorders. There are no controlled studies or even case series on defined pathological entities to evaluate implant survival and success in these situations. Only case reports on selected psychiatric diseases or neurologic disabilities—such as Down syndrome, autism, Huntington disease, and schizophrenia—have been published.[46–50] For Parkinson disease, one of a group of extrapyramidal diseases characterized by rigidity and tremor,[51] there are some case reports suggesting that successful implant placement is possible.[52,53] Therefore, the level of evidence for the efficacy of dental implants in these patients is low (level 4). For many neuropsychiatric disorders there is no literature available.

AIDS and/or HIV

The introduction of highly active antiretroviral therapy (HAART) for HIV infection has significantly postponed the outbreak of AIDS-defining diseases, reduced the rates of clinically manifested opportunistic infections and oral HIV-associated mucosal lesions, and extended life expectancy considerably.[54] Several case reports have demonstrated successful implant-prosthetic rehabilitation of these immunocompromised but immunologically stable patients.[55–58] The authors of a recent report conclude that no modification of routine dental treatment is needed in HIV-positive patients, provided that their immune status is stable.[59] Optimized oral hygiene, regular recall intervals, screening for HIV-related oral lesions, and detection of hyposalivation/xerostomia are preventive therapies used to treat HAART side effects. Only one study was found that investigated the short-term clinical outcome of implant placement in a group of HIV-positive patients compared to results with an HIV-negative control group.[60] In this study, 20 HIV-positive subjects and 9 HIV-negative control patients were followed for 6 months after loading of the implants. The success rates for both groups were 100%; no differences in clinical outcome were noted between the two groups (a level 3b study).

Morbus Crohn or Crohn Disease

Crohn disease is an idiopathic chronic inflammatory disorder of the gastrointestinal tract that may also involve the oral cavity. The disease process is characterized by recurrent exacerbations and remissions.[61] The literature regarding the performance of dental implants in patients with Crohn disease is scarce, with

a level of evidence 4.[62] In a retrospective study with observation up to 1 week after second-stage surgery, two of three patients with Crohn disease had implant failures (3 out of 10 inserted implants were lost).[63] The authors speculated that the presence of antibody-antigen complexes might lead to autoimmune inflammatory processes in several parts of the body, including the bone-implant interface. However, in both of these patients with early implant failures, other medical and local risk factors were also present: claustrophobia, smoking, and poor bone quantity.

In a follow-up study, patients treated from 1982 to 2003 were evaluated to assess the influence of systemic and local factors on the occurrence of early implant failures.[64] Crohn disease was significantly related to early implant failure, exhibiting an odds ratio of 7.95 (95% CI of 3.47 to18.24)—the highest odds ratio of all systemic factors evaluated in the study. Unfortunately, the authors did not provide the exact number of patients with Crohn disease treated or the number of implant failures in these patients.

In a recent prospective study from the same group, the influence of various systemic and local factors on the occurrence of early failures was once more evaluated. This time the implants had a modified, oxidized titanium surface.[65] Between November 2003 and June 2005, 11 of 12 implants placed in patients with Crohn disease integrated successfully. Unfortunately, the authors again did not provide the exact number of patients with Crohn disease treated.

Transplantation (Heart/Liver/Renal Transplant)

Patients receiving transplanted organs generally undergo long-term immunosuppressive therapy, usually consisting of cyclosporine A combined with steroids, which have anti-inflammatory properties.[66,67] Several animal studies have demonstrated that cyclosporine may negatively influence bone healing around dental implants and may even impair the mechanical retention of dental implants previously integrated in bone.[68–70] With regard to studies in humans, there is no information available in the literature addressing heart or renal transplantations and the performance of subsequently placed or already present dental implants (evidence level 5). There is one case report describing the placement of two interforaminal implants 6 months after liver transplantation, providing anecdotal evidence of stability 10 years after insertion[71] (evidence level 4).

Cardiovascular

The literature addressing dental implants and their success and failure rates in patients with cardiovascular diseases (CVD) is scarce. In addition, very different pathologies—ranging from recent myocardial infarction to congestive heart failure to atherosclerosis and hypertension—are referred to as CVD. In a preliminary retrospective study with a total of 246 patients receiving dental implants, three different groups were separately analyzed for early implant failures[72]: group I, CVD (39 patients); group II, healthy subjects (98 patients); group III, other systemic disease (109 patients). The patient-based failure rates varied between 12.2% and 13.8% in the three groups, and differences were not statistically significant (evidence level 3b).

One center has published three papers on this subject. The influence of systemic and local factors on implant failure, again only up to 1 week after second-stage surgery, was evaluated in a retrospective analysis of patients receiving implants.[63] CVD was not associated with an increased incidence of early implant failures. In a second retrospective analysis of a much larger patient population, hypertension and cardiac problems also were not significantly related to early implant failure.[64] In a third study, the authors prospectively evaluated the occurrence of early failures of implants with a modified, oxidized titanium surface, again only up to second-stage surgery.[65] Once more, hypertension and cardiac problems were not factors contributing to early implant failure.

A retrospective cohort study including patients consecutively treated with dental implants between 1982 and 2003 revealed that hypertension and cardiac disease were not significant factors associated with implant failure.[73]

Diabetes or Insulin Therapy or Glucose Intolerance

There are two major types of diabetes: Type 1 (previously termed "insulin-dependent") is caused by an autoimmune reaction destroying the beta cells of the pancreas, leading to insufficient production of insulin. Type 2 (previously termed "non–insulin-dependent") is viewed as a resistance to insulin in combination with an incapability to produce additional compensatory insulin.[74] Type 2 diabetes, often linked to obesity,[75] is the predominant form, notably in the adult population in need of implant therapy. Diabetes mellitus is associated with various systemic complications, including retinopathy, nephropathy, neuropathy, micro- and macrovascular disturbances, and impaired wound healing. In the oral cavity, xerostomia, caries, and periodontitis have been linked to diabetes mellitus. The increased susceptibility to periodontitis is thought to be due to a negative influence of diabetes on inflammatory mechanisms and apoptosis, resulting in a deregulated host defense, deficits in wound healing, and microvascular problems (for review, see Taylor and coworkers [2004],[76] Graves et al [2006][77]).

Table 2 Implant Failures: Case Series of Diabetic Patients Treated with Implants

Study	No. of patients	No. of implants placed		Early failures		Late failures			All failures		Implant failures (no.) by location	
		Maxilla	Mandible	%Subj	%Impl	Y	%Subj	%Impl	%Subj	%Impl	Maxilla	Mandible
Abdulwassie and Dhanrajani (2002)[90]	25	113		ND	4.4	3	0.0	0.0	ND	4.4	3	2
Balshi and Wolfinger (1999)[85]	34	118	109	17.6	5.7	0.5	3.3	0.6	18.6	6.7	6	7
Farzad et al (2002)[91]	25	136		12.0	3.7	ND	ND	ND	ND	ND	4	1
Fiorellini et al (2000)[86]	40	131	84	ND	11.2	6	ND	3.3	ND	ND	19	12
Kapur et al (1998)[84]	25	ND	ND	ND	ND	2	0.0	ND	0.0	0.0	ND	ND
Olson et al (2000)[88]	89	ND	178	11.2	6.7	5	ND	ND	15.7	9.0	ND	16
Peled et al (2003)[92]	41	ND	141	ND	1.4	3	ND	1.4	ND	3.4	ND	4
Shernoff et al (1994)[83]	89	ND	178	ND	ND	1	ND	ND	12.4	ND	ND	13

%Subj = subject-based rate.;%Impl = implant-based rate; Y = years of follow-up; ND = no data available.

The present authors have analyzed the literature published up to October 2005 in a previous paper.[15] At that time, a search using the terms *implant* AND (*oral* OR *dental*) AND (*diabetes* OR *insulin therapy* OR *glucose intolerance*) yielded 73 articles. The primary screening excluded 60 of these papers because they either did not report results from humans, did not include diabetic subjects, did not deal with osseointegrated implants, or did not quantitatively report failure/success/survival. Scanning the reference lists of the retained studies yielded one additional paper. Furthermore, one MSc thesis[78] found through personal communication was added. A repetition of the same search in April 2008 yielded a limited amount of additional original data published with regard to diabetes: one case report of successful implants in a diabetic patient,[79] one prospective cohort study,[80] and two papers from the same center presenting retrospective data of a patient population that included diabetic subjects.[64,65]

Data were extracted from 18 articles.[63,64,65,73,78,80–92] Three types of reports were found: *(1)* case series of diabetic patients treated with implants; *(2)* cross-sectional, longitudinal, or retrospective evaluations of groups of subjects treated with implants, including some diabetic patients; and *(3)* one matched control retrospective chart survey (evidence level 3a).

Table 2 lists eight papers, each reporting results from multiple diabetic patients treated with implants. One paper is a 1-year interim report[83] of the same patient population presented with a 5-year follow-up in another publication.[88] From the data in these papers, an attempt was made to calculate early, late, and overall failure rates. However, it was noted that due to incomplete follow-up of subjects in these reports, the numbers of subjects and implants available to calculate early and late failure rates do not always correspond (n indicating the number of treated subjects). Thus, estimated overall failure rates are not identical to the sum of early and late failure rates as presented in Table 2.

Because the data compiled in Table 2 were heterogeneous with regard to the length of time the cases were followed, the proportion of implants and subjects monitored throughout the entire period varied, and large parts of sought information were unavailable, a meta-analysis was not possible. Within the limitations of the collected material, the following trends were recognized: *(1)* more failures in diabetic patients occurred early, and *(2)* the percentage of diabetic patients experiencing failures seemed to be relatively high, but the percentage of failing implants appeared to lie within the normal range.

Nine studies reported data on failures in cohorts including some diabetic subjects. Specific attribution of failures to the diabetic status was not reported in one of them.[82] The other eight studies are listed in Table 3.

Again heterogeneity of the material and the method of data reporting precluded any further analysis. The diabetic patients in general had well-controlled blood glucose levels, at least before and immediately after implant therapy. No unequivocal tendency for subjects with diabetes to have higher failure rates emerged. However, the largest study reporting early and late failures, the retrospective cohort analysis of Moy and coworkers (2005) already mentioned in the context of CVD, included 48 diabetic and 1,092 nondiabetic patients treated consecutively by one surgeon over a period of 21 years.[73]

Table 3 Implant Failures: Studies Including Diabetic (D) and Nondiabetic (non-D) Subjects

Study	No. of patients	No. of implants placed		Early failures		Late failures			All failures		Implant failures (no.) by location	
		Maxilla	Mandible	%Subj	%Impl	Y	%Subj	%Impl	%Subj	%Impl	Maxilla	Mandible
Morris et al (2000)[87]												
D	663	ND	ND	ND	3.5	3	ND	ND	ND	7.8	ND	ND
non-D		ND	ND	ND	2.5		ND	ND	ND	6.8	ND	ND
Moy et al (2005)[73]												
D	48	ND	ND	ND	8	5–10*	ND	ND	ND	14	198	111
non-D	1,092	ND	ND	ND	2		ND	ND	ND	4		
Rutar et al (2001)[89]												
D	1	ND	ND	ND	ND	5–10*	100	100	ND	ND	ND	ND
non-D	44	ND	ND	ND	ND		0	0	ND	ND	ND	ND
Smith et al (1992)[81]												
D	5	59	254	0	0	1–15*	0	0	0	0	9	9
non-D	99			13.5	5.8		0	0	13.5	5.8		
Van Steenberghe et al (2002)[63]												
D	399	ND	ND	0	0	ND	ND	ND	ND	ND	0	0
non-D		ND	ND	ND	2.2		ND	ND	ND	ND	17	10
Accursi (2000)[78]												
D	15	15	45	ND	3.3	1–17*	ND	3.3	20.0	6.7	0	4
non-D	30	29	85	ND	1.8		ND	4.4	16.7	6.1	2	5
Dowell et al (2007)[80]												
D	25	10	29	0	0	ND	ND	ND	ND	ND	ND	ND
non-D	10	6	5	0	0		ND	ND	ND	ND	ND	ND
Alsaadi et al (2008)[65]												
D	283	ND	ND	ND	4.0	ND	ND	ND	ND	ND	74	27
non-D		ND	ND	ND	1.9		ND	ND	ND	ND		

%Subj = subject-based rate; %Impl = implant-based rate; Y = years of follow-up; ND = no data available.
*Cumulative (variable time).

This study indicated a statistically significant increase in the relative risk of implant failure with diabetes (RR 2.75, 95% CI: 1.46 to 5.18, $P < .05$).

The most recent publications were limited to reporting the rate of early failures: 50 implants placed in a cohort of 35 subjects, including 25 patients with diabetes (10 well controlled, 12 moderately controlled, 3 poorly controlled), showed 100% success at the 4-month follow-up.[80] No apparent influence of diabetes on 252 implant failures in 178 patients was noted in the retrospective assessment of Alsaadi and coworkers (2007)[64] including 2,004 subjects treated with 6,946 implants (only odds ratios reported; case numbers not known). In the recent report of the same group, 14 early failing implants in 14 patients out of 283 subjects treated with 720 implants are reported.[65] This data set includes one subject with diabetes type 1, who had an early failure, and reports 4% early failures in patients with diabetes type 2, in comparison to 1.9% in nondiabetic subjects.

At the highest available level of evidence, a group of 15 diabetics, retrospectively identified in a pool of 387 consecutively treated patients, were each matched to two control subjects by age, sex, location of implants (jaw and zone), type of prosthetic restoration, opposing arch, and duration of edentulism.[78] In this study, diabetic patients had no increased risk of implant failure and a similar number of prosthodontic complications compared to matched nondiabetic controls.

The present review focused on failure. In the recent literature, biological complications not necessarily leading to failure, ie, peri-implant mucositis and peri-implantitis, have become an issue of investigation as well. A cross-sectional survey of 212 subjects with 578 implants included 29 diabetics.[93] In diabetic patients, peri-implant mucositis was diagnosed in 59% of the cases and peri-implantitis in 24%. In subjects with no diabetes, the prevalence of mucositis was similar (66%) but peri-implantitis was significantly lower (7%).

Osteoporosis or Osteoporotic

Osteoporosis has been defined as a decrease in bone mass and bone density and an increased risk and/or incidence of fracture. However, it has been noted that subjects without fractures may have also lost a significant amount of bone, while many patients with fractures display levels of bone mass similar to those of control subjects.[94,95] Thus, definitions of osteoporosis

based on reduced bone mass or nonviolent fracture are not perfectly synonymous. In addition, the relationship between skeletal and mandibular or maxillary bone mass is limited.[96–98] The World Health Organization has established diagnostic criteria for osteoporosis based on bone density measurements determined by dual energy X-ray absorptiometry: A diagnosis of osteoporosis is made if the bone mineral density level is 2.5 standard deviations below that in a mean young population.[99]

In October 2005, a search using the terms *implant* AND (*oral* OR *dental*) AND (*osteoporosis* OR *osteoporotic*) yielded 66 articles. The primary screening excluded 54 of these papers because they either did not report results from humans, did not include subjects with osteoporosis, did not deal with osseointegrated implants, or did not quantitatively report failure/success/survival rates. Three papers were case reports of individual osteoporotic females, all successfully treated with osseointegrated implants.[100–102] One paper reported a case of implant failure after therapy with an oral bisphosphonate for osteoporosis.[103] In this report, the patient lost all five implants, which had been inserted to retain a fixed hybrid mandibular prosthesis, approximately 2.5 years after insertion. The patient's initial medical history was significant for osteoporosis, hyperparathyroidism, nephrolithiasis, thyroidectomy, cholecystectomy, hysterectomy, an ankle fracture, and a hip fracture with total hip replacement. Two years after implant placement, therapy for osteoporosis was commenced with etidronate, an oral bisphosphonate known as Didronel. In the following routine appointment, all five implants exhibited massive radiolucency all around the implants. The authors concluded that bisphosphonates should be avoided in patients who have undergone implant placement, and implants should not be placed in patients who require bisphosphonates. This case report is the first article to mention bisphosphonates as a potential risk factor for oral implantology. In light of the current controversy (see next section on bisphosphonates), it is important to note that etidronate is one of the least potent bisphosphonates known today and is administered via an oral route only.

Another paper reported three cases of mandibular fractures following implant placement, two of them in elderly women with advanced mandibular atrophy.[104] Sixteen women, all with a diagnosis of osteoporosis (low bone density or the occurrence of low-trauma fractures), were assessed in one retrospective study with regard to the success of implants placed between 6 months and 11 years previously. The reported overall success rate was 97.0% for maxillary implants and 97.3% for mandibular implants.[105]

The administration of corticosteroids or other endocrinopathies can cause osteoporosis. These drugs are used for a variety of conditions, including, but not limited to, Crohn disease, asthma, pemphigus, and polyarthritis. Cases have been reported in which dental implants were placed, and successfully maintained, under such circumstances.[62,106,107]

In 2005 a number of papers were published evaluating implant therapy, including subjects with and without a diagnosis of osteoporosis. A repetition of the same search in April 2008 yielded two additional papers in this category. They have already been mentioned previously in the context of CVD and diabetes[64,65] and will be discussed below in the context of osteoporosis.

Van Steenberghe and coworkers[63] counted 27 early failures among 1,263 consecutively inserted implants in 399 patients. Two implants were placed in patients diagnosed with osteoporosis and both were a success. In 2007, however, the same center reported a significant association between osteoporosis and early implant failure.[64] In a third paper by the same group, none of their 29 implants placed in patients with osteoporosis failed early, whereas 2% of the implants in nonosteoporotic subjects failed.[65]

Von Wowern and Gotfredsen[108] measured changes in mineral content of the mandibular bone in 7 osteoporotic and 11 nonosteoporotic women 5 years after functional loading of their implants. Although no implant failure was observed in any patient, a significant difference was noted in the marginal bone loss between the two groups. One retrospective study found no difference in failure rates between women receiving (n = 25) or not receiving (n = 91) hormone replacement therapy (HRT).[109] In the study by Moy et al,[73] already discussed in the context of diabetes, postmenopausal hormone replacement therapy (or lack thereof) was also evaluated. Compared to the total of 1,140 patients, the relative risk for implant failure was increased by 2.55 (95% CI: 1.72 to 3.77, $P < .05$) in the 161 women on HRT. Implant failure rates of postmenopausal women, with or without estrogen replacement therapy, were compared to those of premenopausal women by August and coworkers.[110] Postmenopausal women without HRT (n = 168) had the highest maxillary failure rate (13.6%), a rate significantly greater than that of premenopausal women (n = 114) (6.3%). The difference in the maxillary failure rates of HRT-supplemented postmenopausal women (n = 75) (8.1%) and unsupplemented women did not reach statistical significance. Implants placed in the mandible did not show statistically significant differences in the number of failures.

With regard to age, the opposite was found by Dao et al[111] in an informal review of the Toronto implant study patient series (93 women and 36 men, aged 20

to 76 years): The highest failure rates were noted in the youngest age group. The heterogeneity and quality of the data presented in these studies precluded any formal meta-analysis.

Thirty-nine women aged 48 to 70 years, 19 with a densitometric diagnosis of osteoporosis in the lumbar spine and femoral neck and 20 controls with a normal densitometric diagnosis, were compared by Amorim and coworkers.[112] Bone mineral density was measured in the patients and controls by dual-energy x-ray absorptiometry. Eighty-two osseointegrated dental implants were placed in the mandible, 39 of them in the osteoporosis group and 43 in the control group. The loss of one implant (1.2%) could not be attributed to systemic osteoporosis.

Two publications including a collection of cases with failures and a group of control patients with successful implants analyzed factors associated with implant integration failure.[113,114] The analysis by Blomqvist et al[113] included 11 patients with severely atrophied maxillary alveolar processes who had lost 43% of implants placed in a one-stage procedure together with sinus-floor bone grafts. Mean relative bone mass density was significantly lower in these subjects than in 11 control subjects, matched for sex and age, who had received the same reconstructive treatment but no grafts. Becker and coworkers[114] compared a case population of 49 individuals who had experienced implant loss to a control population consisting of 49 successful recall patients. The groups had the same gender distribution but were unmatched for age. Ten patients in the test group and 7 in the control group had a history of osteoporosis. Generalized estimating equations were used to evaluate the likelihood of an individual having at least one implant failure. There was no association between bone density assessed at the radius and ulna and the risk of implant failure. The clinical estimation of local bone quality, however, was related to implant failure, suggesting that a simple visual assessment of bone quality at a site considered for implantation may be more informative than bone density measures obtained at peripheral bones.

Based on the results reported above, the evidence for the efficacy of dental implants in patients with osteoporosis is on the level of multiple case-control studies (level 3a).

Bisphosphonates

Bisphosphonates reduce or even suppress osteoclast function and can therefore be used in the treatment of various disorders causing abnormal bone resorption. The first type of disorders includes malignancies affecting the bone, such as multiple myeloma and bone metastases of breast and prostate cancer.[115] The second type are nonmalignant bone diseases, the most common of which are osteoporosis and Paget disease.[116] Marx first showed a connection between bisphosphonate cancer therapy and osteonecrosis of the jawbones in 2003.[117] He described 36 cases of osteonecrosis: 80.5% in the mandible, 14% in the maxilla, 5.5% in both jaws simultaneously. All affected subjects were being treated with intravenous bisphosphonates, either pamidronate (brand name Aredia) or zoledronate (Zometa). In 28 of these patients the clinical onset was preceded by a tooth extraction. Since then, numerous centers have reported similar observations, with incidences of osteonecrosis as high as 12% for patients treated with intravenous bisphosphonates.[118,119] Today, intravenous bisphosphonate therapy is considered a major risk for jaw necrosis (bisphosphonate-related osteonecrosis of the jaw [BRONJ]).[120] Elective oral surgery, including the insertion of dental implants, is generally contraindicated for subjects on this type of medication.[121–123]

The risk for BRONJ appears to be much lower for oral than for intravenous drug administration,[119] but appears to increase with the duration of bisphosphonate therapy.[120,123] Especially oral administration of the potent aminobisphosphonates with N-containing side groups (alendronate/Fosamax; risedronate/Actonel; ibandronate/Boniva or Bonvivia) over several years has been associated with BRONJ.[122–124]

The use of bisphosphonates in the treatment of osteopenia/osteoporosis requires oral administration of much lower dosages than in the context of cancer therapy. The risk for complications of implant therapy in such patients—implant failure or BRONJ—is currently unknown and the subject of controversy.[120,125] The present literature search yielded only three clinical studies addressing this issue. As these studies are very different in design, they will be discussed individually without a direct comparison.

In a report from 2006 presenting data from two controlled studies, oral bisphosphonate usage was not associated with osteonecrosis of the jaws.[126] In the first study, the effects of alendronate on alveolar bone loss in patients with moderate or severe periodontal disease were explored using a double-blind placebo-controlled design. Patients were randomized to either 70 mg alendronate or a placebo once weekly for 2 years. No BRONJ was observed in this study. The second study was a parallel-arm controlled study of patients with dental implants receiving oral bisphosphonates (alendronate or risedronate) versus control dental implant patients over the course of at least 3 years. After the observation period, 100% of the implants in the test group and 99.2% of the implants in the control group (no bisphosphonates) were con-

sidered successful, thus exhibiting no statistically significant difference between the two groups. Also in this study, no evidence of BRONJ was observed (evidence level 3a).

In a retrospective analysis of private practice case records, patients with a history of oral bisphosphonates (alendronate or risedronate; mean time of drug usage 3.3 years) and treatment with implant placement at the time of tooth removal or in an edentulous area were analyzed for possible side effects.[127] The implants were left to heal for 6 weeks before initiation of prosthodontic restoration. Patients were followed for 12 to 24 months after implant placement, and hard and soft tissue complications were noted. One patient exhibited exposed bone 1 week after implant insertion. No other postoperative sequelae or complications were noted in any patients, and all implants were classified as successful 12 to 24 months postinsertion. The authors concluded that the incidence of BRONJ after an average of 3.3 years of bisphosphonate intake following implant insertion with or without tooth extraction is minimal, and it is comparable to complication rates in patients without a history of oral bisphosphonate therapy (evidence level 4).

The design of the study mentioned above was criticized in a letter to the editor of the *Journal of Periodontology* for the following reasons[128]: the mean duration of oral bisphosphonates before implant placement was relatively short; the dosage of alendronate taken by the included patients was low (only four subjects used 70 mg; the remaining patients used 35 mg); and the sample size, with 61 patients, was small.

A retrospective questionnaire was mailed to 1,319 patients in the United States who received implants in the years 1998 to 2006[129]; 458 of these patients returned the questionnaire (34.7%). Anamnestically, 115 patients receiving 468 implants reported that they had been taking oral bisphosphonates at the time. Of these 468 inserted implants, all but 2 integrated. The 115 patients were asked to come for a clinical visit, and 72 patients presented. In these 72 patients, no BRONJ could be diagnosed. The implant failure rate for patients taking oral bisphosphonates was similar to that observed for a healthy control population. The authors therefore concluded that oral bisphosphonates represent no risk factor for osteonecrosis in implant surgery. Nevertheless, they limited this conclusion to a duration of bisphosphonate intake not longer than 3 years and also warned against simultaneous medication with corticosteroids (evidence level 3b).

Radiotherapy or Irradiation or Irradiated

With regard to cancer, two aspects need to be considered: the effect of the disease and the effect of its treatment on the tissues containing the implants. The cancer may have been treated before the implants were placed, or treatment may become necessary in subjects who already have implants. Furthermore, implants may be inserted in residual or grafted bone. Due to the heterogeneity of disease conditions, combinations of treatments (radiotherapy and chemotherapy), sequence of events, time of follow-up, and parameters used for assessment, it was decided to analyze the risk factor *radiotherapy* for dental implant placement in a descriptive manner, with special emphasis on existing systematic reviews. As pointed out in two reviews, several factors may potentially influence success rates in irradiated patients. They include, but are not limited to: the source, dose, and fractionation of irradiation; concomitant therapies (ie, chemotherapy, hyperbaric oxygen therapy); the anatomic region of implantation; and the timing of medical and dental therapies.[130,131]

In a recent systematic review, the literature from 1990 to 2006 was searched for implant failure rates to compare the outcomes of preimplantation radiotherapy and postimplantation radiotherapy.[132] The authors found similar failure rates for the time points (3.2% versus 5.4%, respectively; evidence level 2c), but cautioned that it was difficult to compare the studies included because of differences in the exact site of implant placement in relation to the region of radiotherapy, in lengths of follow-up periods, in implant systems used, and in the use of prostheses, and because there were other confounding variables, such as systemic disease, smoking, and parafunction. When implants were inserted after radiotherapy, the implant failure rate was lower for the mandible (4.4%) than for the maxilla (17.5%). The authors could not find evidence in the literature to support delaying implant placement after radiotherapy for 6 to 12 months to maximize implant success. No implant failures were found to occur below a radiation dose of 45 Gy.

In a study analyzing the long-term survival rates of 316 dental implants placed in the mandible in 71 patients after radiotherapy and radical surgery, three different groups were evaluated: *(1)* implants in nonirradiated residual bone, *(2)* implants in irradiated residual bone, and *(3)* implants in grafted bone.[133] In this study, the patients were treated with implants after cancer surgery and after receiving a total radiochemotherapy dose of 50 Gy. The survival rates 2, 3, 5, and 8 years after implant insertion were 95%, 94%, 91%, and 75%, respectively. Implants placed in irradiated bone showed significantly lower survival rates than implants in nonirradiated mandibular bone. The survival rates for the three groups com-

pared in this study were 95% (group 1), 72% (group 2), and 54% (group 3). The authors could not show that the amount of time between irradiation and implantation significantly influenced the results.

A retrospective study reported the survival rates of 631 implants inserted in cancer patients over a period of 25 years.[134] This group of irradiated patients was compared to a control group of nonirradiated patients receiving 614 implants at the same clinic during the same period. The mean time of follow-up in this study was 6.3 years, with a range of 0.5 to 23 years. During this period, 147 implants in patients undergoing radiotherapy were lost (23.3%), and 76 implants (12.4%) failed in the control group. High implant failure rates were especially seen after high-dose radiotherapy and a long time after irradiation. Failures occurred in all craniofacial regions, but the greatest risk of implant failures was found for the frontal bone, zygoma, mandible, and nasal maxilla.

In another retrospective study, the survival of dental implants placed in the interforaminal region during oral cancer surgery was evaluated in relation to postoperative radiotherapy.[135] In 48 patients with a squamous cell carcinoma of the oral cavity, a total of 139 implants were placed. Of these patients, 21 (with 61 implants) received postoperative radiotherapy with 10 to 68 Gy on the symphyseal area, while 27 patients (78 implants) were treated with surgery alone. The average time interval between surgery and the commencement of radiotherapy was 6 weeks. The success rate of the dental implants was 97% in the postoperative irradiated group and 100% in the nonirradiated group. The prosthetic success was lower, irrespective of radiation administration, because in 12 patients a denture could not be fabricated due to death of the patient (7 patients), psychological reasons (4), and loss of an implant (1). The authors concluded that postoperative radiotherapy did not negatively affect the osseointegration of implants placed during oral cancer surgery.

Regarding the papers evaluating multiple local and systemic risk factors for dental implant failure (already mentioned above in the context of Crohn disease, diabetes, osteoporosis, and cardiovascular diseases), radiotherapy was identified by two studies as being a statistically significant variable. [63,73] The calculated relative risk of failure for implants due to radiation therapy was 2.73 (95% CI 1.10 to 3.77). Two papers did not find a significant association between implant failure and irradiation of the patient due to cancer in the head and neck region.[64,65]

Besides the problem of implant failure, the risk of induction of osteoradionecrosis is always present.[136–138] Esser and Wagner[137] reported that in their group of 64 patients rehabilitated with a total of 249 implants (71 IMZ and 178 Brånemark implants) in the irradiated maxilla and mandible, osteoradionecrosis occurred in 2 patients in the mandible, and necrosis of soft tissues in the floor of the mouth occurred in 3 patients following implant placement. Osteoradionecrosis resulted in continuity defects of the mandible and loss of the implants in the region. Some authors even state that this severe complication may be underreported in the literature.[131]

To minimize the risk of osteoradionecrosis due to implant placement in irradiated bone and to improve survival and success rates of implants inserted in irradiated jawbones, hyperbaric oxygen (HBO) therapy has been advocated.[139–142] The rationale for the use of HBO therapy is based on its effect on osteogenesis through stimulation of capillary ingrowth, fibroblastic proliferation, collagen synthesis, and capillary angiogenesis.[140,143–145] Therefore, HBO has been recommended for all elective surgery in irradiated tissues, for the prevention and treatment of osteoradionecrosis,[146,147] and to improve osseointegration of implants inserted in patients undergoing radiotherapy.[131,140–142]

Nevertheless, the use of HBO in irradiated patients remains controversial in the literature, with some authors considering it ineffective.[148,149] In a recent systematic review from the Cochrane collaboration, Esposito and coworkers compared the success, morbidity, patient satisfaction, and cost effectiveness of dental implant treatment performed with and without HBO in irradiated patients[150] (evidence level 1b). After screening of the eligible studies, only one randomized controlled clinical trial was identified.[151] In this study, endosseous implants were placed in the anterior part of the mandible either under antibiotic prophylaxis alone (13 patients) or under antibiotic prophylaxis combined with pre- and postsurgery HBO treatment (13 patients). In the HBO group 85.2% of implants survived, and in the non-HBO group 93.3% survived. Interestingly, osteoradionecrosis developed in one patient in the HBO group only. In their systematic review, Esposito and coworkers concluded that HBO therapy in irradiated patients requiring dental implants may not offer any evident clinical benefits.[150]

Combined Risk Factors

When discussing the impact of various medical conditions on implant failure, it is necessary to keep in mind that recorded data may be interrelated. Potential risk factors, particularly those found more frequently in older adults in general—systemic chronic diseases, medications taken on a long-term basis, reduced salivary flow—may not be independent of each other. On the other hand, one single factor alone may not influence the risk measurably, whereas a combination of multiple independent factors may

have a significant impact. This is supported by retrospective investigations showing, for example, that the combination of specific interleukin-1 gene polymorphisms and smoking could be associated with periimplant bone loss, whereas only one of these factors alone is not.[152–154] Established risk factors for osteoporosis include advanced age, smoking, and alcohol consumption, steroid therapy, inadequate calcium intake, genetic predisposition, and menopause.

There have been attempts in recent years to analyze several factors jointly. Ekfeldt and coworkers[155] recorded age, gender, smoking habits, alcohol and other drug abuse, as well as medical conditions such as diabetes, osteoporosis, cytostatic treatment or radiotherapy, impaired immune defense, psychological disorders, and bruxism in 27 subjects with multiple implant failures and 27 matched controls. Patients in the failure group had less favorable bone conditions (bone volume) in general, and bruxism was noted only in this group. But this group also included more subjects with signs of addiction to alcohol, narcotics, and tobacco. In addition, this group also included one subject under cortisone treatment, one with uncontrolled diabetes mellitus, and two psychologically stressed individuals. In the retrospective study of Moy and coworkers,[73] the database of 1,140 implant patients, including 170 with implant failures, was subjected to multiple regression analysis to explore predictors of the number of failed implants per patient. Using this approach, the variables sex, age, implant location, smoking, hypertension, coronary artery disease, asthma, diabetes, steroids, chemotherapy, head and neck radiation therapy, and postmenopausal HRT were evaluated. The only variables identified as having significant predictive value for implant failure were location in the maxillary arch, diabetes, smoking, and head and neck irradiation.

Observations made in case series can reflect cohort effects; for example, results specific to the generation studied that may not be seen in subsequent generations. There may be differences in dental status and dental awareness (today's young generation may reach old age with more and better maintained teeth), changes in dietary patterns and in the use and abuse of substances (based on availability, preferences, and the awareness of side effects), and changes in general health conditions (as environmental hazards shift and new therapies and pharmaceutical products become available). These may account for many differences that we ascribe to aging.[156] It remains to be investigated which changes observed in older subjects today are truly a consequence of the physiological aging process (and not due to other extraneous factors), and thus can be expected to occur in future generations as well.

CONCLUSIONS

On the basis of the data found in the literature, the following can be concluded:

General Conclusions

The level of evidence indicating absolute and relative contraindications for oral implant therapy due to systemic conditions and treatments is low. Many conditions have been listed as potential risk factors, but studies comparing patients with and without the condition in a controlled setting are sparse. In general, the available literature is restricted to case reports and case series.

The problem of positive publication bias exists in case reports and smaller case series.

No data exist for the more severe medical conditions, simply because implant therapy has not been documented.

Specific Conclusions

Based on the published literature it is not possible to distinguish between subtypes of systemic diseases such as diabetes type 1 and 2 or primary and secondary osteoporosis.

The supposition that subjects with diabetes tend to have higher failure rates is equivocal. The only available matched-control retrospective survey indicated no increased risk of failure. The largest study, a retrospective cohort analysis of patients with type 2 diabetes treated by one clinician, indicated a statistically significant increase in the relative risk of implant failure with diabetes.

The density of peripheral bone, as currently used for the diagnosis of osteoporosis, showed only a weak association with the risk of implant failure in two case-control studies.

For bisphosphonate therapy and implant surgery, the duration, route, and the dosage of the medication, as well as the type of bisphosphonate are reported to play an important role in potential bisphosphonate-related osteonecrosis of the jaws. There are not enough data to estimate the risk for oral bisphosphonates in the context of implant therapy, with only one prospective and two retrospective clinical studies available.

A systematic review of implants placed before and after radiotherapy reported failure rates of between 0% and 12.6% for a follow-up period up to 12 years. Osteoradionecrosis following implant placement has been reported in the literature. A recent systematic review found no beneficial effect of hyperbaric oxygen therapy.

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Local Risk Factors for Implant Therapy

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Purpose: *The aim of this review was to determine the effect of several potential local risk factors on implant survival and success (primary outcomes) as well as on mucosal recession, bleeding on probing, and proximal marginal bone loss (secondary outcomes).* ***Materials and Methods:*** *A comprehensive review of the literature was conducted. The selection of publications reporting on human clinical studies was based on predetermined inclusion criteria and was agreed upon by three reviewers. After title and abstract screening of 2,681 publications obtained from the search, 19 articles were deemed to be relevant to the topic and the search criteria.* ***Results:*** *Limited data show that when an implant is placed within 3 mm of the neighboring tooth, proximal bone is at risk. The data regarding the placement of implants into infected sites are still insufficient, but studies have shown that this may be possible. Soft tissue thickness has not been shown to be a risk factor in implant survival. There is also no evidence to support a relationship between the width of keratinized tissue and implant survival. No studies were found that directly related bone density to implant survival. Implant stability was also difficult to examine due to the lack of validated stability measures.* ***Discussion and Conclusion:*** *One critical factor that faced the group during the review of the literature and interpretation of the data was the multifactorial nature of implant therapy. This makes isolation of specific risk factors difficult. Conclusions are limited by the current lack of quality clinical trials in this area.* Int J Oral Maxillofac Implants 2009;24(suppl):28–38

Key words: *dental implants, hard tissue, infection, interdental space, local risk factors, soft tissue*

The use of dental implants to aid in the support of restorations replacing missing teeth has been reported in the literature dating back to the early 1960s.[1–3] Historically, dental implant treatments have had mixed results with regard to survival of the implants and prostheses. The past two decades have seen continual efforts by manufacturers, researchers, and clinicians to improve the success of implant treatment outcomes through evolution in implant designs, materials, and clinical procedures.

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In today's practice, the clinician and patient often evaluate the treatment success of dental implants with reference to duration of function and ultimate esthetic result. When implant failures occur, they are categorized as either early or late, defined as occurring prior to or at abutment connection (early), or after occlusal loading (late).[4,5] The factors involved in the failures at these time points often are not related. Early failures often are associated with a disruption that occurs during the initial healing phase, leading to fibrous scar tissue formation between the implant surface and the surrounding bone.[6] This scar tissue formation can allow epithelial downgrowth to occur, which can lead to implant mobility and eventual implant failure. Late failures are often influenced by a combination of factors, including the microbial environment and prosthetic rehabilitation. In recent years, diagnosis, planning, and clinical techniques that highlight potential risk factors and introduce methods to improve the outcomes of implant osseointegration and restoration have moved to the forefront of educational demands.

Several factors have been shown to have a potential influence on the incidence of dental implant success.[4,7] These factors can be divided into local and systemic risk factors, which may be influential in the early or late phase of implant therapy. A *risk factor* is a characteristic statistically associated with, although

not necessarily causally related to, an increased risk of morbidity or mortality, according to *Stedman's Medical Dictionary*. It is important to understand that this is a statistical relationship and to emphasize that a risk factor does not imply causation. The scope of this paper is the examination of local risk factors in implant dentistry. A *local risk factor* is any situation that could pose a risk to successful osseointegration and restoration of a dental implant at the level of the implant site and surrounding teeth. It would be advantageous for the clinician to be able to identify the role local risk factors play prior to the initiation of treatment, so that the end result is optimal for a given situation.

The placement of dental implants adjacent to natural teeth requires careful measurement of the available restorative space, bone, and proximal root positions. Utilization of a dental implant that encroaches on the adjacent periodontal apparatus or root surface could lead to complications affecting the peri-implant hard and soft tissues, the dental implant, and/or the tooth, resulting in esthetic compromise and loss of the implant or the adjacent tooth.[8] Therefore, careful consideration of available bone coupled with the implant dimension and insertion position is needed to prevent such occurrences. While numerous studies support the use of dental implants in single-tooth rehabilitation, there is little information available on structures adjacent to single-tooth implants.[9] For example, how close can an implant be placed to an adjacent root without causing significant bone loss and subsequent compromise of interdental papillae?

In response to increasing demands to streamline patient care and maximize available bone once condemned teeth are extracted, clinicians have successfully introduced immediate placement of dental implants into the clinical protocol.[10–14] In addition, numerous clinical studies have demonstrated that immediate implant placement into extraction sockets is a successful and predictable clinical method.[12,15–16] As clinicians' experience with immediate implants has increased, questions have arisen regarding whether implants placed into debrided infected sites would show similar outcomes when compared to native sites. At present, data regarding the outcome of implant placement into sites with periapical lesions in humans are scarce.[17]

One of the primary clinical outcomes of implant placement is primary stability, ie, rigid fixation of the implant with the host bone cavity and absence of micromotion.[18–20] There has been limited investigation of the factors that influence primary stability or of its predictability at different sites in the jawbone. The degree of primary stability after implant placement has been related to bone quality, bone volume, implant design, patient characteristics, and surgical technique, among other factors.[21,22] Since many of these factors are present during placement of an implant, it is difficult to isolate the influence of primary stability alone. Various methods have been used to objectively assess the stability of the bone-implant interface at the time of insertion and throughout the osseointegration period, but none have been validated.[23]

With the ever-increasing demands regarding esthetic outcomes with implant therapy, the behavior of the peri-implant soft tissue is at the forefront of discussions. The gingival biotype has often been used to describe soft tissue thickness in a bucco-lingual dimension, and perhaps in the future this will become a more accepted term.[24,25] Soft tissue thickness is an important factor when considering the esthetic zone. Esthetic success is different from dental implant success, the definition of which is still under discussion. The presence of an adequate zone of keratinized mucosa has also been discussed as essential for esthetic success and the long-term survival of dental implants. Lang and Löe[26] have defined an adequate zone of keratinized mucosa as having ≥ 2 mm of masticatory gingiva with ≥ 1 mm of attached gingiva. These different types of tissue may differ in their resistance to bacterial infection, especially at the complex implant-mucosa interface. Few studies have examined the relationship between the width of keratinized mucosa and the health of the peri-implant tissues.[27–30]

While there is literature to support the direct influence some local risk factors may have on implant survival or success, there are also several factors that are anecdotally quoted as having an impact on implant therapy. It is the ongoing task of healthcare professionals to seek evidence-based knowledge such that the highest standard of care can be provided to their patients.

OBJECTIVES

The aim of this review was to determine the effect of several potential local risk factors on implant survival and success (primary outcomes) as well as on mucosal recession, bleeding on probing, and proximal marginal bone loss (secondary outcomes). The following local risk factors were considered: interdental space, infected sites, soft tissue thickness, width of keratinized soft tissue, bone density, and implant stability. It must be noted that this does not represent a comprehensive list of all the local factors related to implant therapy. Other papers within this consensus report address the topic of bone quantity.

As with any study involving the oral cavity, oral hygiene is a key variable. There is substantial evi-

dence that poor oral hygiene is associated with peri-implant disease.[31,32] The authors felt that it was not within the scope of this review to examine this association in any further detail.

The following list highlights the primary and secondary outcome measures that were utilized in this review. The primary outcomes were implant survival and implant success, and all definitions of implant survival and success described in the included studies were considered. However, when there was a lack of consensus regarding a set of universally accepted success criteria, the following clinical and radiographic criteria proposed by Albrektsson et al[33] and adapted by Buser et al[34] and Karoussis et al[35] were used to define implant success:

- Absence of mobility[34]
- Absence of persistent subjective complaints (pain, foreign-body sensation, and/or dysesthesia)[34]
- Absence of recurrent peri-implant infection with suppuration[34]
- Absence of a continuous radiolucency around the implant[34]
- No pocket probing depth (PPD) > 5 mm[36]
- No PPD ≥ 5 mm and no bleeding on probing[36]
- Annual vertical bone loss after the first year of service not exceeding 0.2 mm (mesially or distally)[33,37]

Several secondary outcomes were also considered. These included mucosal recession, bleeding on probing, and proximal marginal bone loss. Although these outcomes individually were not directly related to implant survival or success, they were determined to be significant when considering outcomes in the esthetic zone.

MATERIALS AND METHODS

Search Strategy

Prior to commencing an electronic search, it was necessary to determine the key local risk factors in implant dentistry. Through a group discussion drawing on published articles, textbooks, and clinical experience, the authors generated a list of local risk factors. Once the list had been compiled, an electronic search was performed utilizing MEDLINE (via PubMed) from 1991 through June 2008. The search key words utilized were: (*dental implant* OR *implant*) AND: *local risk factor, risk factor, anatomy, infection, endodontic failure, implant failure, ridge atrophy, hard tissue, soft tissue, bone quality, bone quantity, biotype, success, Periotest,* and *Osstell.* Limits applied during the search were *English*, *dental,* and *clinical journals*.

Hand searching was performed for all offline journals, including *The International Journal of Periodontics & Restorative Dentistry, Journal of Oral and Maxillofacial Surgery, Journal of Oral Implantology, Implant Dentistry, Journal of Periodontology,* and *Dental Clinics of North America*, as well as for bibliographies of articles relevant to the topic.

The search was restricted to clinical trials utilizing conventional and immediate placement and loading protocols for dental implant therapy. Only studies reporting implant and prosthesis survival and/or success outcomes and the secondary outcomes (mucosal recession, bleeding on probing, and peri-implant marginal bone loss) after 12 or more months were included. All levels of the hierarchy of evidence, except for expert opinion, were included. For case reports, only studies with 10 or more patients were included.

Data Extraction

Three reviewers (WM, EL, and AN) independently screened the titles and abstracts of the articles collected from the initial search. After title and abstract screening of 2,681 publications obtained from the search, 189 were selected for full text reading. The selected publications in electronic format (when available) were imported into a reference managing software (EndNote X.0.2 for Macintosh) and distributed to the reviewers. Discrepancies were resolved by discussion. Nineteen articles were deemed to be relevant to the topic and the search criteria.

RESULTS

Interdental Space

According to the inclusion criteria, six papers were found that reported on the effects of implant placement on the proximal marginal bone loss of adjacent teeth (Table 1). Of the six papers found, none were prospective controlled clinical trials or randomized controlled trials; all were prospective clinical trials. Two of the six prospective clinical trials reported on the influence of implant placement on the marginal bone levels of adjacent teeth based on available interdental space. In all of the studies, the cementoenamel junction (CEJ) to the alveolar crest of the tooth surface facing the implant was used as a reference point for measurements. When available, the survival and success rates of the implants and the adjacent teeth were reported.[38–42]

Esposito et al[38] performed a prospective clinical trial of marginal bone loss at tooth surfaces adjacent to single machined-surface implants. A total of 58 adults with 71 implants were followed up to 3 years after restoration. Specified distances were measured,

Table 1 Reported Mean Marginal Bone Loss (MMBL) at Adjacent Teeth at Pre- and Postloading Visits

Study	Study type	Patients/ implants	Location	Preloading	Postloading	Notes
Esposito et al (1993)[38]	PCT	58/71	53 anterior 18 posterior	x = 0.97 ± 1.09 mm	x = 0.32 ± 0.58 mm y = 1	No failures, machined implants
Johnson and Persson (2000)[39]	PCT	76/78	21 anterior 57 posterior	NA	x = 0.3 ± 0.9 mm y = 3	1 failure, machined and rough-surfaced implants
Krennmair et al (2003)[40]	PCT	78/78	27 anterior 51 posterior	NA	xa = 1.6 ± 0.6 mm xp = 0.4 ± 0.3 mm *P* < .05 y = 3	1 failure, no loss of adjacent teeth, rough-surfaced implants
Gotfredsen (2004)[42]	PCT	20/20	18 anterior 2 posterior	xe = 0.13 ± 0.58 mm x = 0.57 ± 0.48 mm	xe = 0.35 ± 0.45 mm x = 0.22 ± 0.38 mm y = 5	No failures, rough-surfaced implants
Cardaropoli et al (2006)[41]	PCT	11/11	11 anterior	x = 0.2 ± 1.1 mm	x = 0.4 ± 0.9 mm y = 1	No failures, machined implants

PCT = prospective clinical trial; x = MMBL at adjacent teeth; xe = MMBL when implants placed in extraction sockets; xa = MMBL at adjacent teeth in anterior locations; xp = MMBL in posterior locations; y = years.

as were marginal bone levels around implants and tooth surfaces in magnified standardized intraoral radiographs. The results showed a loss of marginal bone support at tooth surfaces adjacent to inserted implants during the interval between preoperative examination and crown delivery (mean 0.97 mm, SD 1.09 mm) that exceeded the loss during subsequent years (mean 0.32 mm, SD 0.58 mm). The largest bone loss was observed when implants were placed next to maxillary lateral incisors (mean 1.40 mm, SD 1.46 mm). A strong correlation was found between bone loss at adjacent teeth and a horizontal distance from implant body to tooth of < 3 mm ($P = .0001$). With decreasing distance the bone loss increased, especially in the maxillary incisor region. The authors reported an implant survival rate of 100%.

Another prospective clinical trial by Krennmair et al[40] analyzed the status of teeth adjacent to single-tooth dental implants placed in anterior (27 implants) and posterior (51 implants) regions of the mouth. Seventy-eight single-tooth implants and 148 adjacent teeth were followed for a mean of 58 months, including evaluation of implant survival rate and proximal bone loss. Radiographic bone loss was determined from orthopantomograms and/or radiographs based on the paralleling technique and by comparing the primary postoperative radiograph with the most recent one. The differences in proximal bone crest height between implant placement and follow-up were calculated, and the amount of bone height loss was compared between anterior and posterior regions. The authors reported one implant failure and no loss of adjacent teeth over the evaluation period, for a 99% success rate. There was a significant horizontal distance from the implant edge to the adjacent teeth between the anterior (mean 1.5 mm, SD 0.6 mm) and posterior (mean 2.8 mm, SD 0.8 mm; $P < .05$) regions. There was also a significant difference in proximal crestal bone loss when anterior (mean 1.6 mm, SD 1.0 mm) and posterior (mean 0.4 mm, SD 0.3 mm; $P < .05$) regions were compared. A multivariate regression analysis showed a significant influence of the horizontal distance on the proximal bone loss in the anterior region (correlation 0.676; $P = .0032$), but not in the posterior region (correlation 0.05; $P = .29$).[40]

Johnson and Persson[39] conducted a prospective clinical trial evaluating marginal bone levels around machined implants and hydroxyapatite-coated implants and their neighboring teeth over a 3-year period. At machined surface sites, there was a statistically significant change in marginal bone height between baseline and 1 year ($P < .01$), with the radiographic bone levels showing a 1-year mean loss of 0.6 mm (SD 0.1 mm) on the mesial surface and 0.7 mm (SD 0.2 mm) on the distal surface of the adjacent teeth. There was no significant change in marginal bone levels between years 1 and 2, years 1 and 3, or years 2 and 3. The authors reported a 3-year survival rate of 98.3%.

Gotfredsen[42] conducted a 5-year prospective clinical trial of 20 patients who received single-tooth implants placed into extraction sockets after 4 weeks of healing (group A; n = 10) and healed sites, 12 weeks postextraction (group B; n = 10). An implant survival rate of 100% over a period of 5 years was reported. At crown placement, the mean marginal bone loss on neighboring teeth was 0.13 mm (SD 0.58 mm) in group A and 0.57 mm (SD 0.48 mm) in group B, which represented a significant correlation between the groups. After 5 years, the mean loss of

marginal bone on neighboring teeth was 0.35 mm (SD 0.45 mm) for group A and 0.22 mm (SD 0.38 mm) for group B, with no significant correlation.

Cardaropoli et al[41] conducted a prospective clinical trial to evaluate dimensional alterations of the peri-implant tissues of eleven single-implant restorations from the time of placement to 1 year postloading. Radiographic measurements of proximal bone levels on the neighboring teeth were performed at crown placement and at 1 year postloading. The mean radiographic interproximal bone level was 1.9 mm (SD 1.1 mm) at the time of second-stage surgery, increased to 2.1 mm (SD 1.1 mm) at the time of crown placement, and was 2.5 mm (SD 0.8 mm) at the 1-year follow-up ($P > .05$). The authors reported no implant failures during the study period.

Infected Sites

For the purpose of this review, an *infected site* is defined as one exhibiting signs or symptoms of pain, periapical radiolucency, fistula, suppuration, or a combination of these. The search identified two papers (one prospective controlled clinical trial, one prospective clinical trial) that examined the survival outcomes of implants placed into infected sites utilizing immediate implant placement. One prospective randomized clinical trial was also identified that provided implant success rates on immediate and delayed implant placement into infected sites.

Siegenthaler et al[17] examined the survival of immediate implants that replaced teeth exhibiting periapical pathology. In this prospective controlled clinical trial, one group of 17 patients was treated with immediate implant placement in order to replace teeth that exhibited periapical pathology, while the control group of 17 patients had immediate implant placement in sites with no pathology. The authors defined the inclusion criteria for the test group on the basis that the tooth to be extracted and replaced by an implant exhibited periapical pathology, with signs or symptoms including pain, periapical radiolucency > 1 mm, fistula, suppuration, or a combination. One surgeon carried out a standard surgical protocol: upon removal of the tooth, the site was carefully debrided of all granulation tissue and carefully rinsed. Upon achieving primary stability with implant positioning, guided bone regeneration with a deproteinized bovine bone mineral (Bio-Oss spongosia particles, Geistlich) was applied to the horizontal deficit between the implant surface and bone wall and then covered with a resorbable collagen membrane (Bio-Gide, Geistlich). Implants were allowed to heal in both transmucosal and semisubmerged positions. Patients were prescribed a 5-day regimen of penicillin (Clamoxyl 750 mg tid) and diclofenac (Voltarene 50 mg bid). Implants were loaded after 3 months. Five patients were removed from the study (four test and one control) due to the inability to obtain primary stability of the implant during placement. The remaining difference between the test and control group numbers was not statistically significant based on a Fisher exact test. The remaining implants showed a 100% survival rate at 12 months. The authors concluded, within the confines of their study, that when primary stability is achieved for implants placed into extraction sockets exhibiting periapical pathology, there is no statistical difference in survival or complication rates versus those implants placed in sites of removed pathology.

Villa et al[43] examined immediate and early function of implants placed in the extraction sockets of maxillary infected teeth. The pilot study followed 33 patients over one year who had implants placed in infected extraction sites by one surgeon. The authors defined the infected teeth as possessing clinical or radiographic evidence of advanced endodontic and periodontal lesions or root fracture judged to be no longer recoverable and unable to support a fixed prosthesis. The surgical protocol included complete debridement of the extraction socket and placement of the dental implant with primary stability. Grafting was performed to fill socket deficits greater than 1 mm with autogenous bone (when possible) or a demineralized bovine bone (Bio-Oss). Various reasons for tooth extraction were reported: periodontal (n = 55), endodontic (n = 15), and root fracture (n = 6). Implants were placed utilizing various surgical techniques (47 flap elevation, 29 flapless) based on the clinical presentation. Implants were distributed in the maxilla into single sites (n = 12), and multiple sites for partial (n = 9) and complete (n = 12) reconstruction. Seventy-six implants were placed directly into infected sites, while 24 were placed in sites without pathology. Provisional prostheses were placed within 36 hours of the surgery; 20 were in occlusal function and 14 remained out of occlusal contact. An implant was classified as surviving if *(1)* it fulfilled its purported function, *(2)* it was stable when tested individually, *(3)* no pain or signs of infection were detected during clinical examination, and *(4)* no radiographic signs of peri-implant pathology were observed. The author reported a 1-year overall survival rate of 97.4%, with 97.9% in sites with flap elevation and 96.6% in sites with flapless surgery.

With regard to delayed placement into previously infected sites, Lindeboom et al[44] carried out a prospective randomized trial on 50 patients with 50 implants followed up for 1 year. Patients with a tooth demonstrating radiographic signs of chronic apical periodontitis were randomized into two groups (n =

Table 2 Reported Bleeding on Probing (BOP) and Mean Alveolar Bone Loss in Relation to Keratinized Mucosa

Study	Study type	Patients/ implants	Implants/width of keratinized mucosa	BOP	Mean alveolar bone loss
Bouri et al (2008)[30]	Cross-sectional	76/200	A 110/≥ 2 mm B 90/< 2 mm	*B > A (P < .01)	*B > A (P < .001)
Wennström et al (1994)[28]	Cross-sectional	39/171	A 108/≥ 2 mm B 63/< 2 mm	B > A	Not examined
Chung et al (2006)[29]	Retrospective cross-sectional	69/339	A 225/≥ 2 mm B 84/< 2 mm	Not examined	A = B

*Statistically significant.

25 each): *(1)* immediate placement (IP) and *(2)* delayed placement (DP), 3 months post extraction. Primary stability at the time of implant placement was an inclusion criterion for the study. In the IP group, implants were placed following thorough degranulation of the socket, and bone augmentation utilizing ground corticocancellous bone harvested from the trigonum retromolar or chin regions was performed to cover the buccal surface and implant. A bioresorbable collagen membrane (Bio-Gide) was placed to cover the graft and implant. In the DP group, implant placement was carried out after 12 weeks of healing. All implants were submerged and allowed to heal without loading for 6 months. Implant success criteria included: no clinical implant mobility at second-stage surgical procedures or follow-up evaluations, no radiographic evidence of peri-implant radiolucency, no signs or symptoms of infection, and no bone loss in excess of the bone loss criteria reported by Albrektsson et al.[33] Thirty-two implants were placed in the anterior maxilla and 18 implants in the premolar region. Every patient required augmentation of the buccal bone (autograft) at the time of implant placement. Cumulative implant success rates after 6 months were 92% in the IP group and 100% in the DP group. At the 1-year follow-up, all implants remained in function.

Soft Tissue Thickness

During data extraction, there were no papers found that reported a correlation between soft tissue thickness and implant survival, so the secondary outcome measure of mucosal recession was used. There were several studies found that evaluated mucosal recession around dental implants over various time periods, but unfortunately they were not correlated with soft tissue thickness at the time of implant placement.[17,41,43–48] One paper was identified that described this secondary outcome related to soft tissue thickness at the time of implant placement.

Evans and Chen[49] examined esthetic outcomes of immediately placed implants. They evaluated the outcome of implants placed by gingival biotype. They classified the biotype as being either thick or thin according to criteria referenced by Müller et al.[24] For a thin tissue biotype, a periodontal probe could be seen through the gingival tissue of the labial sulcus; for a thick biotype, a periodontal probe was not visible. Of the 42 patients in their study, 24 were classified as having a thin biotype. They demonstrated slightly greater mucosal recession than those classified as having the thick tissue biotype (1.0 ± 0.9 mm vs 0.7 ± 0.57 mm, respectively); however, this was not statistically significant (P = .187). Facial tissue recession of 1 mm or greater was measured in 40.5% sites; those with a thin tissue biotype had a greater frequency of recession of 1 mm or more (45.8%) compared with thick sites (33.3%). If the implants were also located toward the facial aspect, 85.7% of thin biotypes had recession compared with 66.7% of thick biotypes.

Width of Keratinized Soft Tissue

In this review of the literature, no studies were found that directly related the width of keratinized tissue to implant survival. Therefore, secondary outcomes (bleeding on probing, marginal bone loss) were evaluated as they related to the width of keratinized tissue. A summary of these findings can be found in Table 2.

Bouri et al[30] performed a cross-sectional study of 76 patients with 200 implants that had been restored for a minimum of 12 months to determine whether the width of keratinized mucosa around dental implants has an effect on the health of the surrounding soft and hard tissues. One hundred ten implants (group A) were found to have ≥ 2 mm of keratinized tissue and 90 implants (group B) had < 2 mm. Multivariable logistic and linear regression analyses were used to examine whether the width of keratinized tissue is independently associated with bleeding on probing and mean alveolar bone loss. The findings showed implants in group B to have significantly more bleeding on probing than implants in group A (odds ratio 2.37; 95% CI 1.04–5.83). Implants in group B also showed significantly higher mean alveolar bone loss than implants in group A; however, this was based on comparisons of nonstandardized radiographs.

In a clinical investigation, Wennström et al[28] evaluated the soft tissue conditions around implants in relation to the width of masticatory mucosa. They found that although 61% of 171 implants in their study had no attached mucosa adjacent to the implant, this did not appear to have a detrimental effect on the plaque control or the peri-implant health of the tissue when measured by bleeding on probing. They concluded that a lack of an attached portion of masticatory mucosa did not compromise the maintenance of health of the peri-implant soft tissue.

In a retrospective cross-sectional clinical study of 69 patients from two centers, Chung et al[29] investigated the relationship between the presence or absence of keratinized mucosa and the long-term maintenance of 339 endosseous root-form implants with different surfaces. Probing depths and radiographic evaluation were recorded. They found inflammation and plaque accumulation to be statistically higher in keratinized and attached mucosa widths < 2 mm, whereas the absence of adequate keratinized/attached mucosa had little or no impact on alveolar bone level.

Roos-Jansåker et al[50] performed a longitudinal clinical study looking at 218 patients and 999 implants with a follow-up of 9 to 14 years postrestoration, in which they attempted to determine the factors that allowed development of peri-implant lesions. They defined mucositis as sites with a probing depth ≥ 4 mm and bleeding on probing. The bleeding scores were divided into three categories: 0% to 20%, 21% to 60%, 61% to 100%. They reported that the amount of keratinized mucosa was significantly associated with mucositis ($P = .008$ multivariate) as well as a bone level loss of ≥ 3 threads ($P = .03$ multivariate).

Bone Density

During the data extraction, no studies were found that directly related bone density to implant survival or success.

Implant Stability

A number of obstacles were encountered in reviewing the literature on implant stability and survival. Most important was the lack of objective measures of implant stability.

Esposito et al[51] performed a thorough review of the literature, which included randomized controlled trials looking at implant success rates in immediate, early, and conventionally loaded root-form implants. They concluded that a high degree of primary implant stability seems to be one of the prerequisites for successful immediate/early loading.

Orenstein et al[52] conducted a prospective multicenter clinical study of 3,111 implants in 800 patients in which they evaluated the 3-year postplacement survival of 89 implants (HA-coated) that exhibited clinical mobility at the time of placement. Mobility was assessed during the surgical procedure by gently applying pressure to the implant to see if it could be depressed or rotated. The degree of and/or reason(s) for mobility were not documented. The use and type of augmentation material at the time of surgery, if any, were documented. Survival was defined as clinically stable and free of associated pain and/or infection. Survival rates were reported for two periods: from placement to 36 months and from prosthetic loading to 36 months. The latter eliminated early failures and resulted in higher survival rates. Implant survival was 78.8% from placement to loading and 95.9% from prosthetic loading to 36 months. Implant mobility at placement was significantly related to 3-year survival ($P < .001$).

Although the following papers may not deal with implant survival directly, they are mentioned below because they provide information on the currently available methods for measuring implant stability.

Molly[53] performed a review of the literature to evaluate bone density and primary stability in implant therapy. The search included publications from 1988 to January 2006, which resulted in a total of 24 articles that met the inclusion criteria. Four systems were used to measure primary implant stability. The author concluded that there was no evidence that the Periotest (Medizintechnik, Gulden) device provided any means of defining primary stability or that any single measurement provided any predictive value of implant outcome. The Osstell (Integration Diagnostics) device uses resonance frequency association to measure implant stability, and again the author concluded that there was no evidence to support a single measurement having any predictive value for implant outcome. Osseocare (Nobel Biocare) provides a measure of insertion torque, and again there was no evidence that this provided a valid means of defining primary stability. The lack of any correlation of radiofrequency analysis (RFA) to insertion torque has also been confirmed by other authors.[54]

Radiofrequency analysis has been shown to have some use when comparing measurements of the same implant over a period of time and implants of the same system. Balshi et al[55] evaluated 344 Brånemark implants (Nobel Biocare) that were immediately loaded. They looked at radiofrequency measurements taken at the time of implant placement and 30, 60, and 90 days following surgery. They found that RFA measurements showed a decrease in bone-implant stability in the first month which then increased over the second and third months. While a critical value for primary implant stability cannot be determined, information from implant stability measurements taken in

the postsurgical phase may be useful in identifying some of the factors that influence implant survival, such as bone quality and loading protocols.

Turkyilmaz et al[56] performed a clinical study evaluating 108 patients with 230 implant sites in which presurgery bone density was evaluated from a computed tomography (CT) scan, insertion torque was recorded using the Osseocare machine, and primary implant stability was measured using radiofrequency measurements from the Osstell machine. The authors found statistically significant correlations between the radiofrequency values and bone density and insertion torque values. They concluded that the use of a preoperative CT might help predict primary implant stability prior to implant insertion.

DISCUSSION

This review was one of four with the task of determining risk factors in implant therapy in preparation for the International Team for Implantology Consensus Conference in Stuttgart, Germany. The groups were assigned one of four topics: *(1)* systemic, *(2)* local, *(3)* smoking and periodontitis, and *(4)* mechanical and technical risk factors. Verification of these risk factors can be beneficial for treatment planning, establishing treatment protocols, and potentially improving clinical outcomes. The challenge of the review process was collecting enough information to generate appreciable conclusions. Most studies had retrospective or prospective designs that lacked controls, whereas case studies had short follow-up periods and limited numbers of subjects. Another concern faced in interpreting the data was that different implant success criteria were used, complicating the comparison and compilation of the results.

One critical factor that faced our group during the review of the literature and interpretation of the data was implant design. There is a lack of comparative information on the influence of current and past implant designs (implant body, thread pitch, surface characteristics, prosthetic connection, length and diameter) on clinical outcomes in variable clinical situations.

Interdental Space

When exploring the available interdental space as a local risk factor in implant dentistry, the reviewers attempted to determine the time point at which the position of the dental implant influenced the bone crest on the teeth adjacent to the implant. This is an important risk factor, as several implant-body dimensions are commercially available and selection of the improper size implant for a given interdental space can have a negative effect on the support for the interdental papillae, potentially leading to a negative esthetic result. Esposito et al[38] reported a strong correlation between bone loss at adjacent teeth and the horizontal distance of the implant body to the tooth when this was < 3 mm ($P = .0001$). It must be emphasized that their study examined the radiographic parameters of bone loss, which cannot evaluate the true position of the periodontal attachment on the root surface. Their study also did not evaluate the connective tissue attachment, which may be of greater clinical significance in the esthetic zone. Based on these outcomes, there is a need for clinical and histologic studies that evaluate the conditions of the teeth adjacent to implants more thoroughly. The implants that were placed had 4.1-mm platforms, and the authors reported the strongest correlation for marginal bone loss in the lateral incisor position, where the horizontal distance between the implant body and the adjacent tooth was at a minimum. However, the authors reported that this reduced distance could explain only 17% of the variation of bone loss. In a similar study, Krennmair et al[40] also reported significant differences in the proximal crestal bone loss between the anterior and posterior regions of the mouth, and that the horizontal distance significantly influenced the proximal bone loss in the anterior region. Based on their outcomes, the authors encouraged utilization of papilla-protecting surgical methods in cases in which a narrow horizontal distance is to be expected. Lekholm and Jemt[57] considered patients with a horizontal gap of 7 mm or more to be routine cases, whereas gaps of 5 to 6 mm should be regarded as the minimal space for standard 4.1-mm implant platforms. It would be worthwhile to examine the smaller-diameter implants (3.0 to 3.5 mm) available on the market in these limited interdental space situations.

Infected Sites

Several studies have shown the placement of implants into fresh extraction sockets to be a successful and predictable procedure.[10–16] Although this procedure has gained in popularity, several factors continue to play an important role in its success, including surgical technique, achieving primary stability, and augmentation when necessary. Varying indications for immediate implant placement have moved into the forefront of implant dentistry, one of the most popular being placement in infected sites. Data regarding the outcome of implant placement in sites with periapical lesions in humans remain scarce.[17] A question that arose during this review process was whether placement of an implant into an infected, debrided site could pose a local risk to implant success or survival.

In an animal study using histomorphometric analysis of implants immediately placed into sites

with periapical pathology versus control sites, no significant difference was found in the percentage of bone-to-implant contact between the two groups.[58] Hence, it was concluded that in the animal model, periapically infected sites are not contraindicated for immediate implant placement.

The three reviewed papers[17,43,44] reported survival rates ranging from 92% to 100% at 12 months. While the follow-up time was short, the authors of the current proceedings felt that the survival rates were comparable to results reported in noninfected sites.[59–69] Based on this review, we stress that at a minimum, this procedure requires sites to be completely debrided and implant placement to have achieved primary stability to offer the potential for osseointegration and subsequent implant survival. Further long-term controlled clinical trials are needed to investigate this approach.

Soft Tissue Thickness

Our search did not identify sufficient evidence to make firm conclusions with regard to soft tissue as a risk factor in implant therapy. In terms of tissue quality, it was noted that there was an increased risk of recession where a thin tissue biotype was present.[49] However, recession is a multifactorial condition that is also dependent on bone present and the three-dimensional position of the implant. More studies were identified relating to the quantity of soft tissue; however, conflicting evidence exists as to whether the presence of keratinized, attached mucosa is essential for maintenance of health of peri-implant soft tissue.[17,41,43–48]

Width of Keratinized Soft Tissue

This review was unable to find a relationship between the width of keratinized soft tissue and implant survival. It is often recommended that implants be surrounded by keratinized tissue to improve their long-term prognosis. Many authors strongly advocate techniques to increase the width of keratinized tissue; however, there is no evidence to support this.[29] In fact, other studies have shown that the presence of keratinized tissue around an implant is not essential for maintenance of peri-implant health.[28] Until a high-quality trial is performed, there will continue to be controversy over whether the presence of keratinized tissue surrounding an implant is a prerequisite for long-term implant survival.

Bone Density

A number of limitations should be taken into account when reviewing the literature on bone density. Molly[53] highlighted this challenge in a review paper examining bone density and primary implant stability. The author reported that bone quality is often referred to in the literature as bone density, but this cannot be taken for granted because many factors are important when discussing bone quality—among them, metabolism, cell turnover, mineralization, maturation, intercellular matrix, and vascularity. Each of these factors may have an influence on implant outcomes. It has also been highlighted that the "gold standard" for bone density measurement is a histologic and morphometric analysis.[53] The utility of the currently available measurements of bone density for the prediction of implant success has not been assessed. This makes isolation of bone density as a risk factor for implant therapy difficult.

Bone quality has been studied in the implant literature; it includes a classification by Lekholm and Zarb[70] that was introduced more than 20 years ago and is still widely used. It categorizes the quality and quantity of bone in different groups based on the amount of cortical and cancellous bone at the implant site. This assessment employs a radiographic and clinical analysis resulting in a scale from 1 to 4. In view of the highly subjective nature of this classification, studies have utilized bone density in an effort to quantify the bone. However, an evaluation of the literature demonstrates that there is an obvious need for standardization of bone density in order to evaluate implant outcomes.

Implant Stability

There is currently no validated measure of implant stability. Various methods to measure implant stability have been described, such as subjective evaluation,[52] resonance frequency analysis,[71] and insertion torque.[72] However, as Molly[53] discussed, there is no evidence that these methods can be used to define primary stability or that any single measurement provides any predictive value of implant outcome. The primary stability of the implant at placement will remain a critical factor in the survival of an implant, but until there is an accurate and reproducible measure of implant stability, the critical level needed to ensure implant survival will be undefined.

CONCLUSIONS

Limited data (2 PCT) exist evaluating the available interdental space as a risk factor for implant survival. Two clinical studies (both prospective clinical trials) show that as the proximity of the implant to the neighboring tooth decreases (< 3 mm), the proximal bone loss at adjacent teeth could increase following implant placement.

There is evidence regarding the placement of dental implants into infected sites exhibiting apical

pathology. Two clinical trials (one prospective randomized clinical trial and one prospective randomized trial) have shown survival rates greater than 92% when the implants were placed in debrided sockets and had primary stability.

There is no evidence supporting soft tissue thickness as a risk factor in implant survival. While the secondary outcome of mucosal recession is important, there was no significant correlation with tissue thickness and recession around dental implants (retrospective clinical study).

In a recent systematic review, methods of assessing bone density and implant stability were not validated and therefore these factors cannot be linked with implant survival.

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History of Treated Periodontitis and Smoking as Risks for Implant Therapy

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Purpose: *The aim of this review was to evaluate a history of treated periodontitis and smoking, both alone and combined, as risk factors for adverse dental implant outcomes.* ***Materials and Methods:*** *A literature search of MEDLINE (Ovid) and EMBASE from January 1, 1966, to June 30, 2008, was performed, and the outcome variables* implant survival, implant success, occurrence of peri-implantitis *and* marginal bone loss *were evaluated.* ***Results:*** *Considerable heterogeneity in study design was found, and few studies accounted for confounding variables. For patients with a history of treated periodontitis, the majority of studies reported implant survival rates > 90%. Three cohort studies showed a higher risk of peri-implantitis in patients with a history of treated periodontitis compared with those without a history of periodontitis (reported odds ratios from 3.1 to 4.7). In three of four systematic reviews, smoking was found to be a significant risk for adverse implant outcome. While the majority of studies reported implant survival rates ranging from 80% to 96% in smokers, most studies found statistically significantly lower survival rates than for nonsmokers.* ***Conclusions:*** *There is an increased risk of peri-implantitis in smokers compared with nonsmokers (reported odds ratios from 3.6 to 4.6). The combination of a history of treated periodontitis and smoking increases the risk of implant failure and peri-implant bone loss.* Int J Oral Maxillofac Implants 2009;24(suppl):39–68

Key words: *implant success, implant survival, peri-implantitis, periodontitis, smoking, tobacco*

As an increasing number of patients receive implants to replace missing teeth lost due to periodontitis, the question arises as to whether a history of periodontitis affects implant outcomes. In addition, the effect of cigarette smoking must be considered with respect to implant loss, increased risk of peri-implant disease, and peri-implant marginal bone loss.

The aim of this review paper was to evaluate the association of cigarette smoking and a history of treated periodontitis with implant outcomes. The paper addresses the available evidence for these two factors, both alone and combined, as potential risk factors for adverse implant outcome.

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MATERIALS AND METHODS

Search Strategy

A literature search was performed of two databases—MEDLINE (Ovid) and EMBASE—from January 1, 1966, to June 30, 2008. The search strategy included the following terms ([*dental implants* or *oral implants* or *endosseous implants* or *implant-supported prosthesis*] AND [*smoking* or *tobacco*]) OR ([*dental implants* or *oral implants* or *endosseous implants* or *implant-supported prosthesis*] AND [*periodontitis* or *periodontal diseases* or *periimplant$*]). Articles in the English, French, and German languages were considered, and the search resulted in 1,491 articles. Titles and abstracts were screened, and the full texts of publications reporting implant outcomes in smokers, or in patients with a history of periodontitis, were obtained. The articles were then evaluated for adherence to one of the following inclusion criteria:

- Systematic reviews addressing smoking and/or history of treated periodontitis as a risk factor for adverse implant outcome
- Longitudinal or cross-sectional cohort studies reporting implant outcomes where the periodontal history/status of the subjects was clearly defined, ie, with a subgroup of patients with and without a history of treated periodontitis

- Longitudinal or cross-sectional studies reporting implant outcomes in patients with a history of treated periodontitis
- Longitudinal or cross-sectional cohort studies of implant outcomes where the smoking status/history of the subjects was clearly defined, ie, with subgroups of smokers and nonsmokers
- Longitudinal or cross-sectional studies reporting implant outcomes in smokers

Case series articles of fewer than 10 patients were excluded. In addition, the bibliographies of systematic review papers were hand searched.

Implant Outcomes

The following four outcomes were evaluated:

- *Implant survival.* This refers to the presence of an implant with or without complications. If reported, the time of implant loss was described as early (prior to loading) or late (after loading) loss. Where authors included additional criteria for implant survival, these descriptions were recorded. Implant survival was expressed as cumulative survival rates following life table analysis, or survival rates.
- *Implant success.* This refers to the presence of an implant in the absence of complications of either a biologic or technical nature. Various authors have proposed a range of success criteria. In this review all descriptions of success criteria were included. Implant success was expressed as cumulative success rates following life table analysis, or success rates.
- *Occurrence of peri-implantitis.*
- *Radiographic peri-implant marginal bone loss.*

RESULTS: HISTORY OF TREATED PERIODONTITIS

A total of 47 publications were included in this section of the review. Table 1 describes the characteristics of retrospective and prospective cohort studies (19 publications, 17 studies) including subgroups of patients with and without a history of treated periodontitis. Table 2 describes the characteristics of retrospective and prospective studies (20 publications, 18 studies) reporting on implant outcomes in patients with a history of treated periodontitis.

There have been eight recent systematic reviews addressing implant outcomes in patients with a history of treated periodontitis versus nonperiodontitis patients.[1–8] The systematic reviews vary in methodology and inclusion criteria. Two papers carried out meta-analyses,[3,6] while six reported that meta-analysis was not possible due to heterogeneity of study characteristics. Some systematic reviews assessed the quality and risk of bias in the included studies.[2,3,6,8] A high to medium level of bias was indicated. The studies included in the individual systematic reviews are identified in Tables 1 and 2.

Summary of Study Characteristics

The studies identified in this section of the review (Tables 1 and 2) vary considerably in study design, making comparisons of outcomes difficult. Variables found to be inconsistent among studies included patient population with respect to periodontal status, length of follow-up, survival data, success data, marginal bone loss, occurrence of peri-implantitis, confounding factors, maintenance care, implant characteristics, and surgical procedure for implant placement. Details follow below.

Patient Population with Respect to Periodontal Status. The definitions of periodontitis and nonperiodontitis patients differed among studies. For example, Hardt et al described an age-related bone score (history of radiographic bone loss) as a measure of susceptibility to periodontitis.[9] Other authors compared patients who had lost teeth due to periodontitis with patients who had lost teeth due to nonperiodontal reasons.[10,11] Three studies included immediate implants placed in patients with periodontitis and nonperiodontitis-related tooth extraction.[12–14]

Where a description of the type of periodontitis was given, the type of periodontal disease was usually described as chronic periodontitis. In other studies it was described as either chronic or aggressive periodontitis according to the current classification (International Workshop for Classification of Periodontal Diseases and Conditions 1999).[15] One study used the term *recalcitrant periodontitis*.[16] A number of studies did not report the type of periodontitis.

All studies indicated that patients in the periodontitis group received periodontal treatment prior to implant placement. However, the details of the treatment provided (surgical versus nonsurgical) and the periodontal status of the remaining teeth were infrequently reported.

Length of Follow-up. The length of follow-up varied from 6 months to 14 years. The majority of studies had medium-term follow-up of between 1 and 5 years. In nine studies patients were followed for 10 years or more.

Survival Data. Most studies reported implant survival as presence of retained implants over the observation period. A number of studies reported cumulative survival rates following life table analysis. Some studies reported implant survival from the time of implant placement, while others reported from the

Table 1 Cohort Studies, Including a Subgroup of Nonperiodontitis Patients (NP) and a Subgroup with a History of Treated Periodontitis (P), Evaluating a History of Treated Periodontitis as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Watson (1999)[26]	Prosp	P: CP NP	7 19	33 implants total	CSR 100% CSR 100%	CSR 100% CSR 58%	4 y	HA surface Success criteria: bone loss ≤ 4 mm, or bone loss < 1/3 of implant length Heavy smokers excluded (> 20 cigarettes per day) SPT: NR
Brocard (2000)[31] bcdef	Prosp	P NP	147 297	375 647	NR NR	CSR 74.7%* CSR 88.8%	7 y	TPS surface Success criteria: absence of pain, absence of infection, absence of mobility, absence of bone loss 132 smokers (light smokers 5 cigarettes per day) Regular SPT
Hardt (2000)[9] cdefh	Retrosp	P NP	25 25	100 92	92% 96.7%	NR NR	5 y	Turned surface Posterior maxilla History of periodontitis defined by age-related bone score Bone loss > 2 mm from time of abutment connection: P: 64%, NP: 24%, *P < .001 2 mm bone loss from abutment connection to 5 years: P: 62%, NP: 42%, P < .055 Smoking: NR SPT: NR
Karoussis (2003)[11] bcdefh	Prosp	P NP	8 45	21 91	CSR 90.5% CSR 96.5%	CSR 71.4%* CSR 94.5%	10 y	TPS surface (hollow screw) Incidence of peri-implantitis; NP: 5.8%, P: 28.6% * Clinical success (PD ≤ 5 mm, BOP negative) Regular SPT P: 47.6% of implants in smokers NP: 19.78% of implants in smokers No statistically significant difference in outcome between smokers and nonsmokers
Evian (2004)[19] def	Retrosp	P: CP NP	77 72	77 72	79.2%* 91.7%	NR NR	10 y	HA surface Immediate/delayed implant placement Implant failure defined as advanced bone loss, infection, or pain Implant failure was statistically significantly associated with a history of periodontitis Regular SPT Smoking: NR
Rosenberg (2004)[25] bdf	Retrosp	P NP	151 183	923 588	90.6% 93.7%	90.6% 93.7%	Up to 13 y	HA-coated, SLA, TPS, AE, turned surface Peri-implantitis reported as failure occurring after 1 y of loading A higher percentage of late failure (25.6%) occurred in P group compared to NP group (5.4%). This was more evident in the HA-coated implants SPT: 3 monthly Smoking: NR

Table 1 continued Cohort Studies, Including a Subgroup of Nonperiodontitis Patients (NP) and a Subgroup with a History of Treated Periodontitis (P), Evaluating a History of Treated Periodontitis as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Hanggi (2005)[30] g	Retrosp	P: AP P: CP NP	16 33 19	201 total	NR	NR	3 y	TPS, SLA surface Regular SPT 15 smokers Tendency for more bone loss in AP patients (P = .058) NS Smoking had no effect on bone loss Poor oral hygiene had a significant effect on bone loss
Mengel (2005)[32] bdefgh	Prosp	P: AP P: CP NP	15 12 12	77 43 30	95.7% 100% 100%	95.7% 100% 100%	3 y	Turned, AE surface Nonsmokers At baseline all treated periodontal patients had PPD ≤ 3 mm, no BOP Regular SPT More bone loss in AP group
Mengel (2005)[33] bgh	Prosp	P: AP NP	10 10	15 11	100% 100%	NR	3 y	Turned surface Nonsmokers Implants in AP group were placed in regenerated bone
Mengel (2007)[41]	Prosp	P: AP NP	5 5	36 7	91.67% 100%	83.3% 100%	10 y	Turned surface Regular SPT Smoking: NR Statistically significant greater bone loss in AP group
Ferreira (2006)[18] c	Retrosp	P NP	30 182	578 total	NR	NR	Mean 42 mo	Partially dentate patients Nonsmokers Patient level: 26.4% peri-implant health; 64.6% peri-implant mucositis; 8.9% peri-implantitis Implant level: 62.6% peri-implant mucositis; 7.44% peri-implantitis Multivariate analysis: increased risk for peri-implant disease History of periodontitis OR 3.1 (95% CI: 1.1 to 3.5) Gender (male) OR 2.7 (95% CI: 2.1 to 6.3) Plaque score OR 14.3 (95% CI: 9.1 to 28.7) Periodontal BOP ≥ 30% sites affected OR 3.3 (95% CI: 2.1 to 5.6) Uncontrolled diabetes OR 1.9 (95% CI: 1 to 2.2)
Roos-Jansåker (2006) [17]	Retrosp	P NP	94 62	NR	16 events* 2 events	NR	9–14 y	Statistically significant relationship between implant loss and periodontal bone loss at remaining teeth
Roos-Jansåker (2006) [29] cf								History of periodontitis significantly related to peri-implantitis OR 4.7 (95% CI: 1 to 22) No organized SPT 52 smokers
Wagenberg (2006)[14] c	Retrosp	P NP	891 total	122 1803	91.8%* 96.3%	NR	1–16 y	Turned, rough surface Immediate implant placement Immediate implants placed following extraction due to periodontitis were 2.3 times more likely to fail than following non-periodontitis extraction P = .02 No statistically significant difference between smokers and nonsmokers

Table 1 continued Cohort Studies, Including a Subgroup of Nonperiodontitis Patients (NP) and a Subgroup with a History of Treated Periodontitis (P), Evaluating a History of Treated Periodontitis as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Rosenquist (1996)[13] c	Retrosp	P NP	51 total	62 49	NR	92% 95.8%	1–67 mo (mean 30.5 mo)	Turned surface Immediate implant placement Success criteria: Albrektsson et al (1986) Incidence of infection occurred in 5 patients; in 4 patients the reason for tooth extraction was periodontitis
Cune (1996)[10]	Retrosp	P NP	102 233	375 total	NR	CSR 58% CSR 78%	Up to 3 y	Turned surface Definition of survival (interpreted as success) included absence of severe inflammation, progressive bone loss, chronic pain related to implant, injury of the mental nerve, implant mobility, damage of the implant beyond repair, implant loss; gingival index of 3 at any of the four assessed sites around the implant
Polizzi (2000)[12] ch Same cohort as Grunder (1999)[86] 3-year data	Prosp	P NP	143 total	62 49	NR	NR	5 y	Turned surface Regular SPT Smoking: NR Immediate implants (82%) or after a short healing period of 3 to 5 weeks (18%) Correlation between implant failure and periodontitis as a reason for tooth extraction 14 of 17 patients with failure had periodontitis-related extraction (not statistically significant) 3-year results show 10.2% of implants placed following tooth loss due to periodontitis failed
Cordaro (2005)[100] h	Retrosp	P NP	9 10	37 53	100% 98.2%	NR	24–94 mo	TPS, turned surface Implant-tooth-supported prostheses (rigid, nonrigid connection) Smoking reported Periodontal group < ⅔ of periodontal support remaining

CP = chronic periodontitis; AP = aggressive periodontitis; NR = not reported; SPT = supportive periodontal therapy; OR = odds ratio; BOP = bleeding on probing; TPS = titanium plasma sprayed; SLA = sandblasted large grit acid etched; HA = hydroxyapatite; AE = acid etched; Prosp = prospective; Retrosp = retrospective; CSR = cumulative survival/success rate.
*Statistically significant difference as reported by the author.
a Study included in systematic review by Van der Weijden et al.[8]
b Study included in systematic review by Karoussis et al.[11]
c Study included in systematic review by Schou et al.[6]
d Study included in systematic review by Quirynen et al.[4]
e Study included in systematic review by Klokkevold and Han.[3]
f Study included in systematic review by Ong et al.[2]
g Study included in systematic review by Al-Zahrani.[1]
h Study included in systematic review by Schou.[7]

Table 2 Studies Including Patients with a History of Treated Periodontitis Evaluating a History of Treated Periodontitis as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Nevins (1995)[16] de	Retrosp	59	132 Mandible 177 Maxilla	97% Mandible 98% Maxilla	NR	1–8 y	Recalcitrant periodontitis Turned surface Regular SPT
Ericsson (1986)[101] bh	Prosp	10	41	100%	NR	6–30 mo	Treated for advanced periodontitis Combined implant-tooth connection Turned surface Regular SPT Smoking: NR
Ellegaard (1997)[102] bdeh	Prosp	19 56	31 Tioblast 93 TPS	100% 97.8%	76.3% 57%	36 mo 60 mo	Treated periodontal patients with tooth loss due to periodontal disease Smokers 64% Regular SPT Success criteria: no bone loss ≥ 1.5 mm
Schwartz-Arad (1998)[103] h	Prosp	22	213	98.5% CSR	NR	5 y	Immediate implants/implant placement in healed sites Regular SPT
Daelemans (1997)[104] h	Retrosp	33	121	93%	NR	3–80 mo (mean 40 mo)	Tooth loss due to periodontitis Turned surface Implants in posterior maxilla + sinus lift and graft Smoking: NR Supra-structure 98% survival
Sbordone (1999)[105] bh	Prosp	25	42	100%	NR	3 y	Patients treated for moderate to advanced periodontitis AE surface Regular SPT Smoking: NR
Buchmann (1999)[106] h	Prosp	50	167	100%	NR	Up to 5 y	Sinus augmentation + simultaneous implant placement Turned surface Smoking: NR Regular SPT
Yi (2001)[107] deh	Prosp	39	125	100%	100%	3 y	Patients treated for severe periodontitis Turned surface Regular SPT Smoking: NR Success criteria PPD < 6 mm
Mengel (2001)[34] bdegh	Prosp	CP 5 AP 5	12 36	100% 94.4%	100% 88.8%	3 y 5 y	Regular SPT Smoking: NR Bone loss up to 3 y was significantly higher in AP patients
Leonhardt (2002)[35] Same cohort as Leonhardt (1993)[108] beh	Prosp	15	57	94.7%	NR	10 y	Partially dentate patients treated for advanced periodontitis Turned surface Regular SPT Smoking: NR 61% implant sites BOP Mean bone loss 1.7 ± 1.2 mm

Table 2 continued Studies Including Patients with a History of Treated Periodontitis Evaluating a History of Treated Periodontitis as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Feloutzis (2003)[75] h	Retrosp	90	182	96.15%	NR	2–12 y (mean 5.6 y after loading)	Chronic periodontitis TPS surface Regular SPT Smoking history reported (39 nonsmokers, 23 former smokers, 14 heavy smokers) IL-1 genotype recorded
Baelum (2004)[20] bdeh	Prosp	108 32	201 1-stage/TPS 57 2-stage/Tioblast	78% 97%	60% 69%	Up to 10 y	All patients had undergone periodontal surgery Regular SPT Smoking was associated with increased implant failure, HR = 2.6 Success criteria: bone loss < 1.5 mm Number of teeth remaining and % bone remaining at implant insertion influenced bone loss ≥ 3.5 mm
Wennström (2004)[109] bdeh	Prosp RCT	51	149	97.3%	NR	5 y	Partially dentate patients treated for moderate to advanced CP Turned surface/Tioblast Smokers 17 Regular SPT (individualized) Mean bone loss at 5 y: 0.41 mm No difference between implant surfaces
Jansson (2005)[74] h	Retrosp	766	1091 Maxilla 705 Mandible	97% 92%	NR	Up to 10 y	Turned surface Smoking reported Regular SPT Analysis of patients with implant failure and relationship to smoking and interleukin 1 (IL-1) genotype
Ellegaard (2006)[42] Same cohort as Ellegaard (1997)[102] bdh	Prosp	68	262	59% TPS 97% Tioblast	53% TPS 82.5% Tioblast	Up to 10 y	Tioblast TPS Non-grafted sinus implants/conventional implants Regular SPT 57% smokers Success criteria: bone loss < 1.5 mm Implant survival significantly influenced by: smoking, patient having ≥ 20 teeth
Malo (2007)[81]	Retrosp Prosp	81 103	165 268	91% CSR 96% CSR	NR NR	5 y 3 y	Turned, oxidized surface Immediate implant placement and function Smokers included Standardized surgical and maintenance protocol

Table 2 continued Studies Including Patients with a History of Treated Periodontitis Evaluating a History of Treated Periodontitis as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Machtei (2007)[80]	Prosp	20	49	90%	NR	1 y	Patients treated for CP; AE surface Immediate implant placement and immediate restoration/loading Regular SPT; Smokers included (4 patients)
Machtei (2008)[79]	Retrosp	56	79	83.5%	83.5%	7–78 mo	Previously failed implant sites All patients had a history of periodontitis Regular SPT; AE, turned surface; 3 of 15 implants (20%) in smokers failed 10 of 64 implants (15.6%) in nonsmokers failed. No statistically significant difference between implant survival in smokers and nonsmokers

CP = chronic periodontitis; AP = aggressive periodontitis; NR = not reported; SPT = supportive periodontal therapy; BOP = bleeding on probing; TPS = titanium plasma sprayed; SLA = sandblasted large grit acid etched; HA = hydroxyapatite; AE = acid etched; Prosp = prospective; Retrosp = retrospective; CSR = cumulative survival/success rate; PPD = pocket probing depth, HR = hazard ratio.
* Statistically significant difference as reported by the author.
a Study included in systematic review by Van der Weijden et al.[8] b Study included in systematic review by Karoussis et al.[11] c Study included in systematic review by Schou et al.[6] d Study included in systematic review by Quirynen et al.[4] e Study included in systematic review by Klokkevold and Han.[3] f Study included in systematic review by Ong et al.[2] g Study included in systematic review by Al-Zahrani.[1] h Study included in systematic review by Schou.[7]

time of loading. Some studies distinguished between early and late implant loss, while others reported on overall implant loss. The statistical unit of analysis was implant-based in the majority of studies, while others presented a patient-based analysis.[17–19]

Success Data. The definition of success varied among studies. Some studies defined their own success criteria using different thresholds for probing depths, bleeding on probing, and bone loss.[11,20,21] Other studies used published success criteria, based on clinical and radiographic parameters, as defined by various authors.[22–24] The baseline reference time point for success varied from the time of implant placement[25] to the time of loading[26] to 1 year of function.[11] Success was based on the implant as the unit of analysis for all studies.

Marginal Bone Loss. Marginal bone loss was recorded in most studies from the time of insertion of the prosthesis; however, Karoussis et al[27] measured from 1 year after loading. There were also variations in radiographic reference points due to the differences in implant designs. Few studies reported the use of standardized radiographs.

Occurrence of Peri-implantitis. Few studies reported on the occurrence of peri-implantitis, and definitions of peri-implantitis were inconsistent. Karoussis et al[11] reported on the incidence of peri-implantitis, whereas the other studies reported on the prevalence of implants or patients with peri-implantitis.[18,28]

Confounding Factors. There was inconsistency in reporting of, and adjustment for, confounding factors such as diabetes and smoking. Multivariate analyses accounting for confounding factors were performed in three studies.[17,18,29] Other studies performed univariate or bivariate analyses on smokers within the population.[11,30,31] Several studies eliminated smoking as a confounding factor by including only nonsmokers in the study population.[18,30,32,33]

Maintenance Care. The frequency of supportive periodontal therapy varied among studies and was not always reported. Furthermore, the maintenance regimen was infrequently described.

Implant Characteristics. The type of implant surface (turned, acid etched, hydroxyapatite coated, sandblasted acid etched, titanium plasma sprayed) and configuration (threaded implant, hollow screw, hollow cylinder) varied between studies.

Surgical Procedure for Implant Placement. There was variation between and within studies in the implant placement procedures with respect to the anatomical position of the implant, submerged or nonsubmerged placement, placement in regenerated bone, use of simultaneous bone-augmentation procedures, implant placement in conjunction with sinus

elevation, immediate implant placement, and immediate implant loading.

Main Findings of the Systematic Reviews

Ong et al (2008). This systematic review evaluated whether implant outcomes (survival, success, bone-level change, peri-implantitis) of partially dentate patients who had been treated for periodontitis were different from those of periodontally healthy patients.[2] Nine studies were included, but no meta-analysis was performed due to the heterogeneity of the chief study characteristics. Of the five studies presenting implant survival data, four reported higher implant survival for nonperiodontitis patients.[9,11,17,19] Two of these studies found a statistically significant difference in survival associated with the patient's periodontal status.[17,19]

Of the five studies presenting data on implant success, four reported more favorable results for patients without a history of periodontitis than for those with treated periodontitis.[11,25,31,32] Only one study, Karoussis et al,[11] showed statistical significance.

Occurrence of peri-implantitis was reported in three studies.[11,25,28] Roos-Jansåker et al[29] and Karoussis[11] reported a statistically significantly greater frequency of peri-implantitis in treated periodontitis patients than in nonperiodontitis patients.

Longitudinal radiographic bone loss around implants was associated with a history of treated periodontitis in all five studies reporting bone levels, but was statistically greater in only one study.[9]

The conclusions of this systematic review were that there is some evidence that patients treated for periodontitis may experience more implant loss and implant complications than nonperiodontitis patients. The authors concluded that the evidence was stronger for the effect on implant survival than for the effect on implant success.

Klokkevold and Han (2007). This study compared implant outcomes in patients with a history of treated periodontitis versus nonperiodontal patients.[3]

Implant Survival. A meta-analysis was performed combining results from three cohort studies[9,11,32] and reporting survival data for patients both with and without a history of periodontitis. No statistical difference in implant survival between the two patient groups was found. In a further meta-analysis, data from 10 studies including patients with a history of treated periodontitis were combined. The pooled estimate of implant survival was 0.95 (95% CI: 0.918 to 0.982), or 95%. When survival data from the three studies in nonperiodontitis patients were combined, the pooled estimate was 0.971 (95% CI: 0.948 to 0.994), or 97% survival at the last reported visit.

Implant Success. In a further meta-analysis including four cohort studies,[11,19,31,32] a statistically significant difference in success rates of implants placed in patients with and without a history of treated periodontitis was found ($P = .013$). The pooled estimate of the difference in implant success rates was 0.1105 (95% CI: –0.2006 to –0.0203). In other words, there was an 11.05% better implant success for patients without a history of periodontitis. Eight studies with implant success data in patients with a history of treated periodontitis were combined in a meta-analysis to give a pooled estimate of 0.89 (95% CI: 0.823 to 0.957), or 89% success. Four studies with success data in healthy patients were combined in a meta-analysis resulting in a pooled estimate of 0.892 (95% CI: 0.812 to 0.972), or 89% implant success. The authors concluded that a history of treated periodontitis does not seem to adversely affect implant survival, but that these patients may experience more complications and a lower success rate, particularly over longer periods.

Karoussis et al (2007). This review identified seven short-term (< 5 years) and eight long-term (≥ 5 years) prospective studies addressing the prognosis of osseointegrated implants in partially dentate patients with a history of treated periodontitis.[5] No meta-analysis was performed. Four of the 15 studies were cohort studies including both periodontitis and nonperiodontitis patients.[11,25,31,32] The authors concluded that there were no statistically significant differences in either short-term or long-term implant survival between patients with a history of treated periodontitis and nonperiodontitis patients. When evaluating success criteria, the authors concluded that patients with a history of treated chronic periodontitis exhibited significantly greater long-term probing pocket depth and marginal bone loss and a higher incidence of peri-implantitis compared with periodontally healthy subjects.

Quirynen et al (2007). This systematic review investigated the relationship between susceptibility to periodontitis and peri-implantitis.[4] Seventeen studies were included in the review; however, no meta-analysis was possible due to heterogeneity of study designs. Four of the five cohort studies comparing patients with and without a history of treated periodontitis reported a higher incidence of late implant loss and/or marginal bone loss in patients with a history of treated periodontitis. When implants with a very rough surface were used[11,19,25] or when supportive periodontal therapy was not provided,[9] the number of implant losses was almost three times higher for patients with a history of treated periodontitis. The authors concluded that in patients with a history of treated periodontitis who had implants with minimally/moderately rough surfaces and

received supportive periodontal therapy, the implant failure rates and marginal bone loss remained low. The authors also discussed that due to the lack of assessment of confounding factors (such as smoking, oral hygiene, and diabetes), definitive conclusions could not be drawn.

Schou et al (2006). This systematic review[6] included two controlled studies with at least 5 years of follow-up assessing the outcome of implant therapy in patients with previous tooth loss due to periodontitis.[9,11] Data from a total of 33 patients with tooth loss due to periodontitis and 70 patients with nonperiodontitis-associated tooth loss were combined in meta-analyses. There was no significant difference in the survival of implants after 5 and 10 years. However, there were significantly more patients with peri-implantitis in the group with periodontitis-associated tooth loss during the 10-year follow-up period, with a risk ratio of 9 (95% CI: 3.94 to 20.57). There was also significantly more marginal bone loss observed in patients with periodontitis-associated tooth loss after 5 years, with a mean difference of 0.5 mm (95% CI: 0.0 to 0.94). The authors concluded that the results of the analyses should be interpreted with caution due to the small sample size and the fact that quality assessment of both studies revealed a high risk of bias.

Schou (2008). This subsequent systematic review by Schou[7] included prospective and retrospective studies assessing implant treatment in partially and totally edentulous patients with a history of periodontitis-associated tooth loss and at least 1 year of follow–up. Studies evaluated implant outcomes, suprastructure outcomes, and the health status of periodontal tissues. The authors concluded that while implant survival is high in individuals with periodontitis-associated tooth loss, the high incidence of peri-implantitis might jeopardize the long-term outcome of implant treatment in periodontitis-susceptible patients.

Van der Weijden et al (2005). This systematic review evaluated the long-term (≥ 5 years) outcomes of implants placed in partially edentulous patients with a history of treated periodontitis.[8] Of the four selected papers, two were cohort studies,[9,11] and two were observational studies evaluating only patients with a history of treated periodontitis.[34,35] Meta-analysis was not performed. The authors concluded that implant survival and success might be different in patients with and without a history of treated periodontitis.

Al-Zahrani (2008). This systematic review addressed the survival and success of implants placed in patients treated for aggressive periodontitis.[1] Nine studies were included, four of which were case reports including fewer than 10 patients.[36–39] The remaining five studies included one short-term observational report[40] and four comparative studies.

Of the four comparative studies, Mengel et al[34] reported on survival of 36 implants in five patients treated for generalized aggressive periodontitis (followed for 5 years) and 12 implants placed in five patients treated for advanced chronic periodontitis (followed for 3 years). The implant survival was 100% for the chronic periodontitis patients and 89% for the aggressive periodontitis patients. There was significantly more bone loss around implants in the aggressive periodontitis patients.[34]

Mengel and Flores-de-Jacoby[32] compared survival of implants placed in 12 periodontally healthy patients, 12 patients treated for chronic periodontitis, and 15 patients treated for aggressive periodontitis. The 3-year survival rate was 100% for implants placed in healthy and chronic periodontitis patients and 97.4% in aggressive periodontitis patients.[32]

In another publication, Mengel and Flores-de-Jacoby[33] compared 10 patients with treated aggressive periodontitis who had implants placed in regenerated bone, and 10 periodontally healthy patients who had implants placed in nonregenerated bone. The authors reported 100% survival after 3 years, with more bone loss around implants in the treated aggressive periodontitis patients.[33]

Hanggi et al found a trend for more marginal bone loss at implants placed in patients treated for aggressive periodontitis than at implants placed in patients treated for chronic periodontitis or nonperiodontal patients.[30]

In summary, two of the four comparative studies reported lower implant survival rates, and three of four studies reported more bone loss, for implants in patients with a history of treated aggressive periodontitis. The authors concluded that implant outcomes in patients with a history of treated aggressive periodontitis are less favorable than those in nonperiodontal patients.

Main Findings of Cohort Studies in Patients With and Without a History of Treated Periodontitis (Table 1)

Of the 11 studies presenting implant survival data, nine reported higher survival in patients without a history of periodontitis. Three cohort studies found statistically significantly lower implant survival rates in patients with a history of treated periodontitis than in patients with no history of periodontitis.[14,17,19]

Implant survival in patients with a history of treated periodontitis ranged from 79.2% to 100%. The majority of studies reported survival rates > 90% in patients with a history of treated periodontitis.

Of the eight studies presenting implant success data, seven reported higher implant success for patients without a history of treated periodontitis. Only one study found a statistically significant difference in implant success between patients with and without a history of treated periodontitis.[11]

Implant success in patients with a history of treated periodontitis ranged from 58% to 100%.

Of the four studies that reported on peri-implantitis,[11,18,25,29] three found a statistically significantly greater risk of peri-implantitis in patients with a history of treated periodontitis.[11,18,29] Reported odds ratios ranged from 3.1 to 4.7.

Longitudinal radiographic bone loss around implants was associated with a history of treated periodontitis in all seven studies reporting bone levels, and was statistically significantly greater compared to patients without a history of treated periodontitis in two studies.[9,41]

Four studies including a total of 46 patients with a history of treated aggressive periodontitis reported greater marginal bone loss compared to patients without a history of treated periodontitis.[30,32,33,41]

Main Findings of Prospective and Retrospective Studies in Patients with a History of Treated Periodontitis (Table 2)

Implant survival in patients with a history of treated periodontitis ranged from 59% to 100%.

The majority of studies (17 of 18) reported high implant survival rates ≥ 90% for implants with turned or moderately rough surfaces.

All studies reported regular supportive periodontal therapy.

In the two studies where both very rough surface and moderately rough surface implants were used, lower survival rates (59% to 78%) were observed for the implants with very rough surfaces.[20,42] Only six studies reported implant success data, ranging from 53% to 100%. Success criteria differed between studies.

RESULTS: SMOKING

A total of 88 publications were included in the review of the evidence available for smoking as a risk factor for adverse implant outcomes. Table 3 describes the characteristics of the 59 cohort studies evaluating implant outcomes in a subgroup of smokers and nonsmokers. Study design, sample sizes, and implant outcomes expressed as survival and success rates are described. Risk of failure in smokers, expressed as odds ratios for implant-related data and patient-related data, both with and without augmentation procedures, are presented. Where odds ratios are presented, they were obtained from the original paper or from the systematic reviews if indicated.

Table 4 includes seven studies evaluating smoking as a risk for peri-implantitis and soft tissue complications. Table 5 includes 22 prospective or retrospective studies evaluating smoking as a risk for peri-implant bone loss.

Four recent systematic reviews, all including meta-analyses, have evaluated cigarette smoking as a risk factor for adverse implant outcome. Three of the four reviews found smoking to be a significant risk factor.[3,43,44] The studies included in the individual systematic reviews are identified in Table 3.

Summary of Study Characteristics

Variation in study design, inclusion criteria, and data analyses makes it difficult to compare the studies presented in Tables 3, 4, and 5. The following study characteristics contributed to the heterogeneity among studies: study design, the patient population with respect to smoking status, length of follow-up, survival data, success data, peri-implant marginal bone loss, occurrence of peri-implant disease, confounding factors, maintenance care, implant characteristics, and procedures for implant placement. Details follow below.

Study Design. The majority of studies were retrospective in design, while 14 were prospective. Retrospective studies have less validity than prospective clinical trials due to issues of selection bias and confounding factors. Furthermore, retrospective studies rely on the completeness of data entered in the patient's chart.

Patient Population with Respect to Smoking Status. The studies used a range of definitions for smokers, nonsmokers, and former smokers. In some studies smokers were defined as smoking one or more cigarettes per day, while other studies used a threshold of 10 cigarettes per day. Other studies had categories of smoking including light, moderate, and heavy, depending on the number of cigarettes smoked per day. One study classified nonsmokers as subjects who had never smoked or who had stopped smoking at least 1 year before implant treatment.[45]

Length of Follow-up. The length of follow-up varied from before implant loading up to 20 years. The majority of studies had a follow-up time of between three and six years.

Survival Data. Most studies reported implant survival as presence of retained implants over the observation period. However, Bain and Moy, in one of the first studies to report a significant difference in implant survival between smokers and nonsmokers, defined implant failure as implant loss or bone loss greater than 50% of the implant length.[46] A number of studies

Table 3 Cohort Studies, Including a Subgroup of Smokers (S) and Nonsmokers (NS), Evaluating Smoking as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Bain (1993)[46] abc	Retrosp	S NS	540 total	390 1,804	89%* 95%	NR	Up to 6 y	Turned surface Failure defined as implant loss or bone loss > 50% implant length Implant data without taking into consideration augmentation (b) OR 2.54 (95% CI: 1.74 to 3.72) *P* = .0001
De Bruyn (1994)[49] abc	Retrosp	S NS S NS	16 45	78 166	91.83% 98.8% 86.06% 97.58%	NR	Prior to loading 1 y	Maxilla Turned surface Implant data without taking into consideration augmentation (b) OR 5.46 (95% CI: 1.57 to 19.02) *P* = .014 Patient-related data without augmentation (b) OR 6.89 (95% CI: 1.54 to 31.57) *P* = .013
Gorman (1994)[50] ab	Retrosp	S NS	82 228	646 1,420	93.5%* 96.7%	NR	Prior to loading	Surface: NR Implant data without taking into consideration augmentation (b) OR 2.03 (95% CI: 1.32 to 3.11) *P* = .001 Patient-related data without augmentation (b) OR 2.92 (95% CI: 1.46 to 5.86) *P* = .057
Wang (1996)[84] ac	Retrosp	S NS	30 total	14 69	84.62% 84.29%	84.62% 84.29%	3 y	HA/turned surface No statistically significant difference in survival between S and NS OR 0.98 (95% CI: 0.19 to 5.02) *P* = 15.66
Bain (1996)[78] ac	Prosp	S SQ NS	78 total	13 34 176	61.54% 88.24% 94.32%	NR	< 1 y	Turned surface SQ: Smoking cessation protocol Implant data without taking into consideration augmentation (b) OR 3.93 (95% CI: 1.50 to 10.34) *P* = .007
Minsk (1996)[111] ac	Retrosp	S NS	380 total	157 570	89.17% 90.88%	NR	6 y	Turned surface, TPS, AE 80 different operators OR 1.21 (95% CI: 0.68 to 2.16) *P* = .49
Watson (1998)[112] c	Prosp	S NS	43 total	64 75	NR	52% CSR 87% CSR	3–6 y	HA surface, cylindrical implants Overdentures Success criteria: ≤ 4 mm bone loss
Minsk (1998)[113] bd	Retrosp	S NS	116 total	126 324	90.47% 92.59%	NR	7 y	Postmenopausal women Implant data without taking into consideration augmentation (b) OR 1.46 (95% CI: 0.9 to 2.36) *P* = .079
Grunder (1999)[86] bc	Prosp	S NS	19 55	55 164	100% 98.2%	NR	5 y	AE surface No statistically significant difference between S and NS All failures prior to loading Implant data without taking into consideration augmentation (b) OR 0.42 (95% CI: 0.05 to 3.41) *P* = .357
Keller (1999)[60] abc	Retrosp	S NS/FS	8 20	32 73	60.7% 94.5%	NR	12 y	Turned surface Sinus graft and implant placement OR 2.03 (95% CI: 0.59 to 7.03) *P* =.210 (b)

Table 3 continued Cohort Studies, Including a Subgroup of Smokers (S) and Nonsmokers (NS), Evaluating Smoking as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
De Bruyn (1999)[85] ab	Prosp	S NS	10 13	30 32	80% 71.9%	NR	7 y	Turned surface Maxilla No statistically significant difference between S and NS Implant data without taking into consideration augmentation (b) OR 0.64 (95% CI: 0.19 to 2.08) *P* = .327 Patient-related data without augmentation (b) OR 0.29 (95% CI: 0.04 to 1.94) *P* = .195
Jones (1999)[114] abc	Retrosp	S NS	19 44	126 217	91.27%* 97.7%	NR	5 y	HA-coated/TPS surface Implant data without taking into consideration augmentation (b) OR 4.06 (95% CI: 1.38 to 11.96) *P* = .007 Patient-related data without augmentation (b) OR 12.2 (95% CI: 2.24 to 66.88) *P* = .012
Wilson (1999)[115]	Retrosp	S NS	27 35	NR	NR	NR	Up to 10 y	Turned, TPS surface 27 patients with implant loss compared to 38 patients with no loss Implant failure defined as implant loss or 50% bone loss Smoking was statistically significantly related to implant failure with a RR of 2.5 (95% CI: 1.12 to 5.56) *P* = .025
Watson (1999)[26]	Prosp	S NS	26 total	10 23	100% 100%	70% 91.3%	3–4 y	HA surface, cylindrical implants Single-implant restorations Success criteria: ≤ 4 mm bone loss
Berge (2000)[47] b	Prosp	S NS	NR	61 55	65.5%* 87.2%	NR	Mean 11.4 y	Ceramic implants Implant data without taking into consideration augmentation (b) OR 3.60 (95% CI: 1.39 to 9.33) *P* = .005
Schwartz-Arad (2000)[116] b	Retrosp	S NS	43 total	6 50	83% CSR 90% CSR	NR NR	Up to 5 y (mean 15 mo)	Immediate implants in molar sites 15 teeth extracted due to periodontitis HA/turned surface No statistics performed between NS and S Implant data without taking into consideration augmentation (b) OR 1.80 (95% CI: 0.17 to 18.64) *P* = .511
Wallace (2000)[56] ab	Retrosp	S NS	17 39	72 115	83.33% 93.04%	NR	4 y	Turned surface Implant data without taking into consideration augmentation (b) OR 2.68 (95% CI: 1.04 to 6.91) *P* = .037 Shorter implants (≤ 10 mm) more susceptible to failure in smokers
Lambert (2000)[55] abc	Prosp	S NS/FS	NR	959 1,928	91.14%* 94.01%	NR	3 y	HA-coated/noncoated Early implant failure: implants in smokers 2.6 times more likely to fail from time of uncovering to before insertion of prosthesis Implant data without taking into consideration augmentation (b) OR 1.53 (95% CI: 1.14 to 2.05) *P* = .004
Olson (2000)[64] b	Retrosp	S FS NS	29 total	51 30 35	94.1% 96.6% 100%	NR	5–71 mo	HA, turned surface Sinus grafts and simultaneous or staged implant placement Failures associated with smoking history (b) OR 9.45 (95% CI: 1.14 to 78.11) *P* = .014

Table 3 continued Cohort Studies, Including a Subgroup of Smokers (S) and Nonsmokers (NS), Evaluating Smoking as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Geurs (2001)[61] abc	Retrosp	S NS/FS	NR	62 267	88.71%* 95.34%	NR	3 y	Sinus graft and implant placement (b) OR 2.6 (95% CI: 0.99 to 6.83) *P* = .051
Widmark (2001)[62] abc	Prosp	S NS Sinus graft: S NS	8 12 3 13	44 53 23 78	79.55% 88.68% 26.09% 89.75%	NR	3–5 y	Turned surface Severely resorbed maxilla Maxilla/± sinus graft Implant data without taking into consideration augmentation (b) OR 5.30 (95% CI: 2.53 to 11.12) *P* = .0001 Nongrafted sites Maxilla (b) OR 2.01 (95% CI: 0.65 to 6.18) *P* = .169 Grafted sites (b) OR 20.0 (95% CI: 6.33 to 63.2) *P* = .0001
Kronström (2001)[59] b	Retrosp	S NS	12 68	NR	NR	NR	Up to second-stage surgery	Turned surface Smokers (10 to 20 cigarettes/day) Early implant failure 40 patients with early implant failure and 40 patients with no failure. No significant difference between smokers and nonsmokers in implant failure. 9 of the 12 smokers had implant failure (75%) 31 of the 68 nonsmokers had implant failure (45.5%) Patient-related data without augmentation (b) OR 3.58 (95% CI: 0.89 to 14.39) P = .057
Mayfield (2001)[63] b	Retrosp	S NS	3 12	13 42	43% 100%	43% 100%	4–6.5 y	Turned, TPS surface Implants placed in augmented and non-augmented bone All failed implants were in augmented bone in 2 smokers (b) Patient-related data OR 41.7 (95% CI: 3.56 to 486.9) *P* = .001
Eckert (2001)[117]	Retrosp	S NS	55 total	7 68	NR	NR	Mean 10 mo	Turned surface Multivariate Cox analysis Implant failure Current smoker: HR 2.4 History of smoking: HR 0.8
Kan (2002)[45] abc	Retrosp	S NS/FS	16 44	70 158	82.86% 93.04%	65.30% 82.70%	Up to 5 y	HA/turned surface Grafted sinus and implant placement (simultaneous and staged approach) (b) OR 2.76 (95% CI: 1.16 to 6.62) *P* = .02
Schwartz-Arad (2002)[66] ab	Retrosp	S NS	89 172	380 402	96% 98%	44% 69%	Up to 3 y	Surface: NR Immediate and delayed implant placement Success: Number of complications including cover screw exposure Implant data without taking into consideration augmentation (b) OR 2.66 (95% CI: 2.66 to 3.48) *P* = .0001
Kumar (2002)[57] b	Prosp	S NS	72 389	269 914	97% 98.4%	97% 98.4%	Prior to loading	Smokers: ≥ 10 cigarettes/day SLA surface Early implant failure: Implant data without taking into consideration augmentation (b) OR 1.84 (95% CI: 0.77 to 4.38) *P* = .164

Table 3 continued Cohort Studies, Including a Subgroup of Smokers (S) and Nonsmokers (NS), Evaluating Smoking as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
van Steenberghe (2002)[51] b	Prosp	S NS	NR	156 1,107	94.87% 98.28%	NR	Up to abutment connection	Turned surface Early implant failure: One-third of early implant failures occurred in smokers Implant data without taking into consideration augmentation (b) OR 3.0 (95% CI: 1.33 to 7.20) $P = .013$
Ortorp (2002)[118] b	Prosp	S NS	43 83	729 total	NR	NR	3 y	Turned surface 10 of 15 patients with failures were smokers Smokers experienced significantly more failures than nonsmokers ($P < .006$) Patient-related data without augmentation (b) OR 4.73 (95% CI: 1.50 to 14.9) $P = .007$
Penarrocha (2002)[87] b	Retrosp	S NS	34 80	441 total	NR	NR	3 y	TPS surface 7 of the 34 smokers had implant failures 10 of the 80 nonsmokers had implant failures Patient-related data without augmentation (b) OR 1.82 (95% CI: 0.63 to 5.25) $P = .203$
Chuang (2002)[125]	Retrosp	S NS	57 497	2,349 total	NR	NR	Up to 8 y	HA, TPS surface Patients with a history of periodontitis Univariate analysis: Implant failure HR 2.7 Multivariate Cox regression analysis Implant failure HR 3.1
Beschnidt (2003)[88] b	Prosp	S NS	76 total	51 163	92.15% 93.25%	NR	3 y	Turned surface No significant difference between smokers and nonsmokers Implant data without taking into consideration augmentation (b) OR 1.18 (95% CI: 0.36 to 3.87) $P = .789$
Karoussis (2003)[11] abc	Prosp	S NS	12 41	28 84	92.86% 96.24%	64.28% 77.38%	10 y	TPS surface hollow screw No significant difference between S and NS for survival, success or incidence of biologic complications Patients with and without history of periodontitis were included Implant data without taking into consideration augmentation (b) OR 2.08 (95% CI: 0.33 to 13.12) $P = .367$
Baelum (2004)[20]	Retrosp	140	258	NR	NR	NR	10 y	TPS surface Regular SPT Cox proportional hazard model Implant failure HR smoking 2.6 (95% CI: 0.9 to 7.6)
Ortorp (2004)[120] Same cohort as Ortorp (2002)[118]	Prosp	S NS	43 83	729 total	97.67%* 99.04%	NR	5 y	Edentulous patients Turned surface Statistically significantly more implants failed in smokers than nonsmokers on the patient level ($P < .01$) as well as on the implant level ($P < .05$)

Table 3 continued Cohort Studies, Including a Subgroup of Smokers (S) and Nonsmokers (NS), Evaluating Smoking as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Kourtis (2004)[121]	Retrosp	S NS	405 total	853 839	NR	NR	Up to 12 y (mean 4.6 y)	TPS surface Regular recall 10% immediate implants Significantly greater implant loss in smokers $P < .001$
van Steenberghe (2004)[67] b	Prosp	S NS	13 32	150 total	NR	NR	1 y	Immediate implant loading Turned surface 2 of 13 smokers (15.3%) had implant failures 4 of 32 nonsmokers (12.5%) had implant failures Patient-related data without augmentation (b) OR 1.27 (95% CI: 0.2 to 7.97) $P = .567$
Moheng (2005)[122] b	Prosp	S NS	15 78	266 total	NR	NR	1 y	TPS 4 of 15 smokers had failures 3 of 78 nonsmokers had failures $P < .01$ Multivariate analysis: Implants were more likely to fail in smokers RR 14.4 Patient-related data without augmentation (b) OR 9.09 (95% CI: 1.79 to 46.18) $P = .012$
Moy (2005)[123]	Retrosp	S NS	173 967	4,680 total	NR	NR	6 mo–21 y	Turned surface Univariate analysis: Implant failure RR 1.56 ($P = .03$) Stepwise logistic regression: Implant failure RR 1.39 ($P = .03$)
Jansson (2005)[74]	Retrosp	S NS	10 12	40 66	65% 72.73%	NR	10 y	Smoking did not significantly affect implant survival Authors reported a trend toward higher implant loss in smokers: 14 of 40 implants were lost in smokers 18 of 66 implants were lost in nonsmokers Synergistic effect of smoking and IL-1 genotype
Lemmerman (2005)[89]	Retrosp	S NS	30 346	1,003 total	NR	NR	Up to 15 y	Turned, AE surface, TPS ± bone augmentation, sinus elevation No statistical correlation between smoking and implant failure Authors reported a trend toward more failures in heavy smokers (data not shown)
Wagenberg (2006)[14]	Retrosp	S NS	891 total	323 1,602	94.4% 96.3%	NR	6 y (mean 71 mo)	Immediate implant placement ± graft ± immediate loading Turned/rough surface No significant difference between S and NS ($P = .342$) No difference in implant survival between rough and turned surface implants in smokers

Table 3 continued Cohort Studies, Including a Subgroup of Smokers (S) and Nonsmokers (NS), Evaluating Smoking as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Ellegaard (2006)[42]	Retrosp	S NS	68 total	262 total	NR	NR	Up to 10 y	Nongrafted sinus implants TPS, Tioblast surface Patients with a history of periodontitis Regular SPT Implant failure: HR smoking = 2.2
DeLuca (2006)[69]	Retrosp	S NS/FS S NS/FS	104 285 104 285	494 1,045	94.74%* 96.94% 96.1% 98.02%	NR	Prior to loading 20 y	Turned surface Multivariate survival analysis: Smoking at time of surgery was a significant factor Early failure RR 1.69 Late failures: A positive smoking history (> 25 pack years) was a significant factor for late implant failures OR 2.01 Multivariate survival analysis: Smoking history was a statistically significant factor RR 1.91 Patients who were smokers at the time of surgery had a statistically significantly higher overall failure rate (23.08%) than nonsmokers (13.33%)
Roos-Jansåker (2006)[17] Roos-Jansåker (2006)[29]	Retrosp	S FS NS	57 81 80	999 total	NR	NR	9–14 y	Smoking was associated with: Peri-implant mucositis (OR 2.8) Bone loss (OR 10) Peri-implantitis (OR 4.6) Smoking was not statistically significantly associated with implant failure
Noguerol (2006)[52]	Retrosp	S > 20 S 10–20 S < 10 NS	316 total	239 166 184 521	89% 98.2% 96.2% 95.8%	NR	10 y	Turned surface Early implant failure Bivariate model: Smoking had a statistically significant effect on early implant failure Multivariate model: Early implant failure: smoking > 20 cigarettes per day OR 2.5 (95% CI: 1.3 to 4.79) Perio and nonperio patients included: Analysis showed a tendency for more early failures in patients treated for periodontitis
Peleg (2006)[65]	Retrosp	S NS	226 505	627 1,505	97.4% 98.1%	NR	9 y	HA, rough surface Sinus augmentation and simultaneous implant placement No statistically significant difference in implant failure between smokers and nonsmokers
Mundt (2006)[72]	Retrosp	S FS NS	159 total	215 247 294	85% 90.4% 96.4%	NR	120 mo	Statistically significant difference between NS and FS ($P = .036$) NS and S ($P < .001$) FS and S ($P = .003$) Multifactorial Cox regression model for 1 implant per patient: Significant association between duration of smoking and increased risk of implant failures ($P = .036$) Cox regression analysis considering correlation of implant observations within the same patient: Smoking duration was significant ($P = .004$) Clustering of failures within smokers

Table 3 continued Cohort Studies, Including a Subgroup of Smokers (S) and Nonsmokers (NS), Evaluating Smoking as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Doyle (2007)[124]	Retrosp	S NS	10 186	10 186	72.9%* 95%	48.5*% 74.8%	1 y	Single implants Included immediate implant placement Smokers had significantly fewer successes and more failures
Aykent (2007)[125]	Retrosp	S NS	34 total	38 68	89.48% 100%	CSR 75.8% CSR 97.7%	Up to 12 y	HA, TPS surface (hollow screw/hollow cylinder/solid screw) Overdentures and fixed prostheses Smokers recorded as smoking > 10 cigarettes per day Success criteria—no biologic complication Deeper probing depths and higher sulcus bleeding index in smokers ($P < .05$)
Alsaadi (2007)[53]	Retrosp	S < 10 S 10–20 S > 20 NS	2,004 total	227 320 369 6,030 6,946 total	95.15% 94.69% 92.95% 96.72%	NR	Up to abutment connection 6 mo	Turned surface Early implant failure A significant difference between heavy smoking (> 20 cigarettes/day) and no smoking groups OR 2.72 (95% CI: 1.63 to 4.54) $P < .001$
Sanna (2007)[68]	Prosp	S NS	13 17	212 total	81.2% CSR 98.9% CSR	NR	5 y	Flapless placement /immediate loading Oxidized surface Smoking defined as > 10 cigarettes per day
Machtei (2007)[80]	Prosp	S FS NS	4 3 13	13 6 30	90% overall	NR	1 y	Patients with a history of periodontitis AE surface Smoking did not significantly affect implant outcome
Streitzel (2007)[110]	Prosp	S NS	15 118	59 short implants total	80%* 100%	NR	Up to 55 mo	Short implants (11 mm, 9 mm) ± augmentation AE surface Significant influence of smoking on implant survival for short implants
Sanchez-Perez (2007)[70]	Retrosp	S LS MS HS NS	40 23 11 6 26	95 44 25 26 70	84.2% 90.9% 88% 69.23% 98.57%	NR	5 y	AE surface Regular follow-up Statistically significant difference in implant failure among groups except between HS and MS S/NS OR 13.1 LS/NS OR 7.0 MS/NS OR 9.5 HS/NS OR 31.1
Alsaadi (2008)[53]	Prosp	S NS	283 total	95 623	94.44% 98.88%	94.44% 98.88%	Up to abutment connection 6 mo	Oxidized surface Early implant failure Authors reported smokers had a tendency for more early implant failures than nonsmokers No statistically significant difference.
Alsaadi (2008)[54]	Retrosp	S < 10 S 10–20 S > 20 NS	19 20 22 351	1,514 total	89.86% 85.45% 93.94% 93.8%	NR	2 y	Turned/oxidized surface Smoking habits were not statistically significant in relation to implant loss $P = .28$

Table 3 continued Cohort Studies, Including a Subgroup of Smokers (S) and Nonsmokers (NS), Evaluating Smoking as a Risk Indicator for Reduced Implant Survival and Success

Study (first author and year of publication)	Design	Patients studied	No. of patients	No. of implants	Implant survival	Implant success	Follow-up	Comments
Sverzut (2008)[58]	Retrosp	S NS	76 5,741	197 1,431	97.19% S 96.62% NS	NR	Before loading	Univariate and bivariate analysis showed no statistical significance for early implant failure in conjunction with smoking
Machtei (2008)[79]	Retrosp	S NS FS	15 35 6	79 total	80% 84.4%	NR	7–78 mo (mean 29.9 ± 2 mo)	Previously failed implant sites AE, turned surface History of periodontitis Regular SPT 3 of 15 implants (20%) in smokers failed 10 of 4 implants (15.6%) in nonsmokers failed No significant difference between implant survival in smokers and nonsmokers ($P = .48$)
Anitua (2008)[126]	Retrosp	S NS	221 839	1,299 4,488	98.9%* 99.3%	NR	2–59 mo (median 54 mo)	Moderately rough surface Implants placed with and without augmentation Smoking was statistically significantly correlated with lower implant survival rate $P < .013$ 69.6% of patients with failures had a history of periodontitis

FS = former smokers; HS = heavy smoker; LS = light smoker; MS = moderate smoker; TPS = titanium plasma sprayed; AE = acid etched; HA = hydroxyapatite; OR = odds ratio; RR = relative risk; HR = hazard ratio; CI = confidence interval; NR = not reported; SQ = smoking cessation protocol; mo = months; y = years.
*Statistically significant difference between smokers and nonsmokers as reported by authors.
When the authors did not report success and/or survival rates, they were calculated from the data available in the original papers.
Odds ratios, where presented, were obtained from the original paper or from the systematic review by Strietzel et al[110] if indicated (b).
a Study included in systematic review by Hinode et al.[43]
b Study included in systematic review by Strietzel et al.[110]
c Study included in systematic review by Klokkevold and Han.[3]

reported cumulative survival rates following life table analysis. Some studies reported implant survival from the time of implant placement, whereas others reported from the time of loading. Therefore, some studies distinguished between early and late implant loss, while others reported on overall implant loss.

Success Data. The majority of studies did not report success rate as an outcome variable. In those studies reporting implant success, success criteria varied, and included absence of exposure of cover screw during the healing phase, absence of a biologic complication, and probing depth and/or marginal bone loss thresholds.

Peri-implant Marginal Bone Loss. Marginal bone loss was recorded in most studies from the time of insertion of the prosthesis. However, Karoussis et al measured from 1 year after loading.[27] There were also variations in radiographic reference points due to the differences in implant designs. Few studies reported the use of standardized radiographs.

Occurrence of Peri-implant Disease. Only seven studies reported on the occurrence of peri-implantitis and/or peri-implant mucositis, and definitions were inconsistent among studies.

Confounding Factors. Relatively few studies documented or accounted for confounding factors in their analysis of the effect of smoking. Factors including diabetes and a history of periodontitis were infrequently reported. Patient-related analyses accounting for patient dependence and thereby excluding cumulative effects of individual risk factors were performed only in some studies.

Maintenance Care. The frequency of supportive periodontal therapy and the maintenance regimen was infrequently reported among studies.

Implant Characteristics. The type of implant surface and configuration used was not always reported. The majority of studies included implants with turned or moderately rough surfaces. Some studies included hydroxyapatite-coated implants and implants with a very rough surface. One study used a ceramic implant.[47]

Procedures for Implant Placement. In the studies reviewed there was a wide variation between and within studies in implant placement procedures with respect to the anatomical position of the implant, submerged or nonsubmerged placement, placement in regenerated bone, use of simultaneous bone augmentation procedures, implant placement in conjunction with sinus elevation, immediate implant placement, flapless implant placement, and immediate implant loading. This makes direct comparisons between the studies difficult, as the placement protocols may represent significant confounding factors.

Main Findings of Systematic Reviews

Strietzel et al (2007). In this systematic review, any patient who smoked was classified as a smoker.[44] Meta-analyses combining results of 29 studies were performed. The meta-analyses showed a significantly increased risk of implant failure among smokers both for implant-related (odds ratio 2.25, 95% CI: 1.96 to 2.59) and patient-related (odds ratio 2.64, 95% CI: 1.70 to 4.09) data compared to nonsmokers. Smokers receiving implants with accompanying bone augmentation procedures also had an increased risk of implant failure (odds ratio 3.61, 95% CI: 2.26 to 5.77) compared to nonsmokers. The systematic review showed a significantly increased risk of biologic complications (peri-implantitis) in smokers. The authors concluded that smoking is a significant risk factor for adverse implant outcomes.

Klokkevold and Han (2007). This systematic review identified 19 articles with implant outcome data, and concluded that smoking adversely affects implant survival and success.[3]

Implant Survival. Fourteen studies included implant survival data. A meta-analysis found the pooled estimate for implant survival in smokers was 0.897 (95% CI: 0.87 to 0.924), or 89.7%, at the last reported visit. The pooled estimate for implant survival in nonsmokers was 0.9333 (95% CI: 0.91 to 0.956), or 93.3%, at the last reported visit. The pooled estimate of the difference in implant survival between smokers and nonsmokers was 0.0268 (95% CI: 0.011 to 0.0426), or 2.68% better survival for nonsmokers. This difference was statistically significant.

Implant Success. Seven studies with implant success data were included. The pooled estimate for implant success in smokers was 0.77 (95% CI: 0.661 to 0.879), or 77.0%, at the last reported visit. The pooled estimate for implant success in nonsmokers was 0.91 (95% CI: 0.866 to 0.954), or 91%, at the last reported visit. The pooled estimate of the difference in implant success rates between smokers and nonsmokers was 0.1128 (95% CI: 0.0341 to 0.1915), or 11.28% better success for nonsmokers ($P = .005$).

Bone Quality. In this systematic review, further analyses were performed to investigate the effect of bone quality on the survival and success of implants in smokers compared to nonsmokers. The review found 7.43% better implant survival for nonsmokers than for smokers with implants placed in soft bone (described as loose trabecular bone by the authors). Nine studies reported on implant survival data in all bone types. Analyses showed 2.01% better implant survival for nonsmokers compared to smokers ($P = .0093$). The authors concluded that the effect of smoking on implant survival seems more pronounced in soft bone. Five studies reported implant

Table 4 Clinical Studies Evaluating Smoking as a Risk Indicator for Peri-implantitis and Soft Tissue Complications

Study (first author and year of publication)	Design	No. of subjects/ No. implants	Implant surface	Follow-up	Findings
Haas (1996)[92]	Retrosp	Smokers 107 (366 implants) Nonsmokers 314 (1,000 implants)	TPS Turned	Mean 22 mo	In the maxilla smokers had statistically significantly greater BOP, probing depths, peri-implant mucosal inflammation, bone loss $P < .01$ No statistically significant difference between smokers and nonsmokers in the mandible
McDermott (2006)[127]	Retrosp Cohort	677 subjects (results based on 677 implants) 10.3% of patients were smokers	TPS HA-coated Uncoated	Up to 8 y (median 13.1 mo)	Multivariate analysis for inflammatory complications (including peri-implantitis) showed smoking was statistically significant Hazard ratio: 3.26 (95% CI: 1.7 to 6.10) 69 of 677 implants had inflammatory complications
Karoussis (2003)[11]	Prosp	Smokers 28 Nonsmokers 84	TPS	10 y	No statistically significant difference between smokers and nonsmokers in biologic complications S: 17.86% NS: 6.02%
Gruica (2004)[76]	Retrosp	Smokers 53 Nonsmokers 127	TPS	≥ 8 y	Statistically significantly greater risk for smokers to develop peri-implantitis, draining sinus, suppuration, and bone loss
Roos-Jansåker (2006)[29]	Retrosp	218 total 57 smokers 81 former smokers 80 never smokers N implants = 999	Turned	9–14 y	Smoking was statistically significantly associated with: Peri-implant mucositis OR 2.8 (95% CI: 1.2 to 6.2) Bone level OR 10 (95% CI: 4.1 to 26) Peri-implantitis OR 4.6 (95% CI: 1.1 to 19)
Laine (2006)[73]	Retrosp	Smokers 78 Nonsmokers 42 N implants = 365	Turned	≥ 2 y	Former smokers and current smokers were considered smokers Majority of patients had lost teeth due to periodontitis Peri-implantitis defined as bone loss ≥ 3 threads, BOP/pus Smoking represented a statistically significant risk factor for peri-implantitis OR 3.6 (95% CI: 1.5 to 8.8) $P = .004$
Weyant (1994)[128]	Retrosp	598 patients Partially dentate 42% Number of smokers not reported 2,098 implants (15 different types of cylinder implants)	HA-coated and Uncoated	4 y	Statistically significantly more soft tissue complications in smokers Soft tissue complications: 11.9% of smokers 6.8% of nonsmokers Bivariate analysis OR 1.8 for smoking

TPS = titanium plasma sprayed; HA = hydroxyapatite; Retrosp = retrospective; Prosp = prospective; mo = months; y = years; OR = odds ratio; CI = confidence interval.

Table 5 Clinical Studies Evaluating Smoking as a Risk Indicator for Peri-implant Bone Loss

Study (first author and year of publication)	Design	No. of subjects/ No. implants	Implant surface	Follow-up	Findings
Haas (1996)[92]	Retrosp	107 smokers (1,366 implants) 314 nonsmokers (1,000 implants)	TPS, Turned	22 mo	Statistically significantly more bone loss in smokers (maxilla) compared with nonsmokers $P < .01$ Bone loss mean ± SD— S: mesial 4 ± 2.45 mm NS: mesial 1.52 ± 1.35 mm S: distal 3.9 ± 2.43 mm NS: distal 1.76 ± 1.46 mm
Lindquist (1996)[129]	Prosp	47 patients (273 implants)	Turned	15 y	Statistically significantly greater bone loss in smokers
Lindquist (1997)[71]	Prosp	21 smokers 24 nonsmokers 266 implants	Turned	10 y	At 10 years 3 implants failed – survival 99% Statistically significantly greater bone loss in smokers Dose effect relationship between cigarette exposure and bone loss
Carlsson (2000)[130]	Prosp	21 smokers 23 nonsmokers	Turned	15 y	Edentulous patients Smokers lost statistically significantly more peri-implant bone in the mandible
Feloutzis (2003)[75]	Retrosp	14 heavy smokers (20 cigarettes/day) 14 moderate smokers (5–19 cigarettes/day) 23 former smokers (> 5 years) 39 nonsmokers	TPS	5.6 y	Statistically significantly more bone loss in heavy smokers compared to nonsmokers $P < .02$ Median bone loss NS: 0.18 mm Median bone loss HS: 1.98 mm
Ortorp (2004)[120] Same cohort as Ortorp (2002)[118]	Prosp	43 smokers 83 nonsmokers	Turned	5 y	No statistically significant differences in bone levels between smokers and nonsmokers $P > .05$
Karoussis (2004)[27]	Prosp	89 patients (179 implants)	TPS	10 y	Smokers (most smoked more than 10 cigarettes per day) Multiple linear regression analysis: Statistically significantly greater bone loss in smokers $P < .0001$
Penarrocha (2004)[131]	Retrosp	16 smokers (47 implants) 26 nonsmokers (61 implants)	SLA	1 y	Statistically significantly more bone loss in smokers than nonsmokers $P < .05$
Wennström (2004)[82]	Prosp	13 smokers 32 nonsmokers	Tioblast	5 y	Multiple regression analysis: Statistically significantly more bone loss in smokers $P < .05$
Galindo-Moreno (2005)[132]	Prosp	63 smokers 122 nonsmokers	Turned, HA, TPS	3 y	Bivariate analysis: Statistically significantly more bone loss in smokers $P = .0165$ Mean bone loss S: 1.36 ± 0.04 mm Mean bone loss NS: 1.25 ± 0.02 mm
Nitzan (2005)[133]	Retrosp	59 smokers (271 implants) 102 nonsmokers (375 implants)	NR	1–7 y (mean 3.8 y)	A higher incidence of marginal bone loss in smokers that was more pronounced in the maxilla Nonsmokers had a higher radiographic success rate than smokers: 97.8% versus 97.1%; $P < .001$ In the maxilla, heavy smokers had the greatest bone loss (0.1897 ± 0.1825 mm), followed by moderate smokers (0.1223 ± 0.156 mm), and nonsmokers (0.046 ± 0.070 mm); $P < .001$
Schwartz-Arad (2005)[134]	Retrosp	8 smokers (50 implants) 53 nonsmokers (277 implants)	NR	37.9 mo	Statistically significantly more bone loss in smokers; $P < .0001$ Bone loss was increased in 56% of smokers compared to 23.8% of nonsmokers

Table 5 continued Clinical Studies Evaluating Smoking as a Risk Indicator for Peri-implant Bone Loss

Study (first author and year of publication)	Design	No. of subjects/ No. implants	Implant surface	Follow-up	Findings
Aalam (2005)[135]	Retrosp	16 smokers 58 nonsmokers	AE, Turned, Oxidized	2 y	Smokers (smoked more than 10 cigarettes per day) No statistically significant difference in bone loss between smokers and nonsmokers
DeLuca (2006)[136] Same cohort as DeLuca (2006)[69]	Retrosp	146 nonsmokers 54 smokers 96 positive smoking history 108 never smoked	Turned	20 y	No statistically significant difference between smokers and nonsmokers in the first year of loading. A positive smoking history was a significant factor for bone loss in subsequent years; $P < .048$ Positive smoking history: 0.073 ± 0.263 mm bone loss Nonsmokers: 0.041 ± 0.124 mm bone loss
Roos-Jansåker (2006)[29]	Retrosp	57 smokers 81 former smokers 80 never smokers 999 implants	Turned	9–14 y	Smoking was statistically significantly associated with bone loss OR 10 (95% CI: 4.1 to 26) $P < .001$
Herzberg (2006)[137]	Retrosp	21 smokers 39 nonsmokers 212 implants	Turned	6–56.5 mo (mean 21.7 mo)	Sinus graft and simultaneous or delayed implant placement Smoking had a statistically significant effect on bone loss; $P < .01$ S: 0.24 mm/year NS: 0.09 mm/year
Norton (2006)[138]	Retrosp	7 smokers 47 nonsmokers 173 implants	Tioblast	21–91 mo (mean 3 y)	Sinus grafts included No statistically significant difference in mean marginal bone loss between smokers (0.84 mm) and nonsmokers (0.5 mm)
Watzak (2006)[139]	Retrosp	9 smokers 22 nonsmokers 124 implants	Turned Anodized	Mean 33 mo	Turned, anodized surface Smoker defined as smoking > 10 cigarettes per day Statistically significantly more bone loss in smokers Smokers: 1.46 ± 0.16 mm Nonsmokers: 1.14 ± 0.09 mm $P = .01$
Chung (2007)[140]	Retrosp	7 smokers 62 nonsmokers 339 implants	Turned, AE, TPS	3–24 y (mean 8.1 y)	Statistically significantly more bone loss in smokers, $P < 0.05$ Smokers: 0.32 mm Nonsmokers: 0.12 mm Annual bone loss was 2.7 times greater in smokers
Tandlich (2007)[141]	Retrosp	17 smokers 65 nonsmokers/former smokers 265 implants	Rough (not specified)	≥ 30 mo	Logistic regression analysis Smoking was a statistically significant predictor of bone loss OR 1.95 (95% CI: 0.05 to 1.29) $P = .04$
Sanna (2007)[68]	Prosp	13 smokers 17 nonsmokers	Oxidized	Up to 5 y (mean 2.2 y)	Flapless placement/immediately loaded Smokers defined as smoking > 10 cigarettes per day Mean marginal bone loss— Smokers: 2.6 ± 1.6 mm Nonsmokers: 1.2 ± 0.8 mm No statistical analysis
Fransson (2008)[142]	Retrosp	40 smokers 42 nonsmokers 482 implants	Turned	9–14 y	Patients with progressive bone loss at one or more implants Progressive bone loss Logistic regression analysis: OR smoking 2.2 (95%CI: 1.5 to 3.3) $P = .0002$

Odds ratios, where presented, were obtained from the original paper.
AE = acid etched; TPS = titanium plasma sprayed; Retrosp = retrospective; Prosp = prospective; OR = odds ratio; CI = confidence interval; y = years; mo = months.

success data for both smokers and nonsmokers when implants were placed in all bone types. Analyses showed 11.76% better implant success for nonsmokers ($P = .019$).

Hinode et al (2006). In this systematic review, 19 studies were combined in a meta-analysis, and the strength of the relationship between smoking and implant failure was assessed by odds ratios.[43] Implant failure was defined as loss of the implant or progressive bone loss exceeding 50% of the implant length. Meta-analysis showed an increased risk (odds ratio 2.17, 95% CI: 1.67 to 2.83) for implant failure in smokers compared to nonsmokers. In this review, studies were separated according to the length of follow-up, with mean observation periods of less than 1 year (10 studies), more than 1 year but less than 5 years (16 studies), and greater than 5 years (3 studies).

Bain et al 2002. This meta-analysis examined the effect of smoking on implant outcomes.[48] Clinical studies that monitored the performance of two implant surfaces—a turned surface and an acid-etched surface—were included. Nine prospective studies were included, with a total of 2,614 implants with a turned surface and 2,274 implants with an acid-etched surface. For the turned-surface implants, the 3-year cumulative success rate (CSR) for the 2,117 implants in the nonsmoking group was 92.8%. The corresponding CSR for the 492 implants in the smoking group was 93.5%. The 3-year CSR for the 1,877 acid-etched surface implants in the nonsmoking group was 98.4%. For the 397 implants in the smoking group, the CSR was 98.7%. No statistically significant difference was observed between smoking and nonsmoking patients.

Influence of Smoking on Early Implant Survival

Early failure rates, prior to loading, were evaluated by De Bruyn and Collaert, who reported early implant failure of 9% in smokers versus 1% in nonsmokers.[49] Analyzing the data on a patient basis, 31% of smokers experienced implant loss in this early healing period, compared to 4% of nonsmokers. The difference was statistically significant. Similarly, Gorman et al reported a higher early implant failure rate of 6.5% for smokers versus 3.31% for nonsmokers.[50] Twenty-two percent of smokers had implant failures, compared to 9% of nonsmokers. Van Steenberghe et al also reported significantly more early failures in smokers compared to nonsmokers.[51] Noguerol et al reported that early implant failure (before loading) was significantly associated with smoking habits.[52] Multivariate analysis found a significant effect of smoking > 20 cigarettes per day (odds ratio 2.5, 95% CI: 1.3 to 4.79).

In a retrospective study of 6,946 turned surface implants placed in 2004 patients, a significant difference in early implant failure between heavy smokers (> 20 cigarettes per day) and nonsmokers was found.[53] In a cross-sectional analysis, Alsaadi et al investigated potential factors associated with early implant failure.[54] Implants with an oxidized surface were placed in 283 patients and followed up to abutment connection. The overall failure rate was low (1.9%). The authors reported that due to the low failure rate, statistical analysis of risk factors was difficult. However, a tendency for more failures to occur in smokers than nonsmokers was reported. Data from a large prospective study showed no influence of smoking on early implant failure (placement to uncovering), but found more failures in smokers in the time between uncovering of the implant and before insertion of the prosthesis.[55]

In contrast, Wallace et al found no statistically significant effect of smoking in the early healing phases following implant placement.[56] Similarly, Kumar et al[57] and Sverzut et al[58] found no statistically significant difference in early failure rates between smokers and nonsmokers. Kronström et al evaluated variables associated with early implant failure.[59] Forty patients with early implant failure and 40 patients matched for age and gender with successful osseointegrated titanium implants were studied. The authors found that antibody avidity to *Tanerella forsythia* and antibody titre to *Staphylococcus aureus* were associated with early implant loss, while smoking was not a significant factor.

Effect of Smoking on Implants Placed Following Sinus Floor Elevation and Augmentation

Seven studies reported on implant outcomes in smokers and nonsmokers following sinus floor elevation and grafting.[45,60–65] Six of these studies reported a higher failure rate for implants in smokers. In contrast, one study reported no statistically significant difference in failure rate between smokers and nonsmokers for implants placed simultaneously with sinus grafts.[65] Overall, implant survival in smokers ranged from 26.09% to 94.1% in the studies reviewed.

Effect of Smoking on Outcomes Following Immediate Implant Placement

Schwartz-Arad et al evaluated the effect of smoking in patients who received immediate (288 implants) and delayed (671 implants) implant placement.[66] More complications were reported in smokers than nonsmokers, regardless of the time of implant placement. A higher incidence of complications was found among smokers who received immediate implants ($P < .05$) compared with smokers who received delayed implants.

Wagenberg and Froum (2006) evaluated the effect of smoking following immediate implant placement.[14] Survival rates were 94.4% for smokers and 96.3% for nonsmokers following 6 years of function. There was no statistically significant difference in implant survival between smokers and nonsmokers.

Effect of Smoking on Outcomes Following Immediate Implant Loading

Implant outcomes in 45 patients who were rehabilitated following an immediate loading protocol in the mandible were evaluated following 1 year of loading.[67] Implant failures occurred in 2 of 13 smokers and 4 of 32 nonsmokers. There was no statistically significant difference in implant survival between smokers and nonsmokers.

In a study evaluating flapless implant placement and immediate loading, lower implant survival and more marginal bone loss were reported in smokers (defined as > 10 cigarettes per day) compared to nonsmokers.[68]

Dose Effect of Cigarette Smoking

While there was inconsistency in the definition of a smoker between studies, a number of authors attempted to evaluate the dose effect of cigarette smoking. Schwartz-Arad et al divided the smoking patients into two subgroups according to the number of cigarettes smoked per day (mild smoker ≤ 10/day; heavy smoker > 10/day) and the duration of smoking (mild smoker ≤ 10 years; heavy smoker > 10 years).[66] Both groups of smokers were found to have significantly more complications than nonsmokers. The number of complications increased as the number of smoking years increased. In this study all complications, including exposure of a cover screw during early healing, were recorded.

DeLuca et al found a relationship between the number of cigarettes smoked and early implant failure. Failure rates of 3.51%, 4.82%, and 5.56% were found for individuals who smoked ≤ 5 cigarettes per day, 6 to 14 cigarettes per day, and ≥ 15 cigarettes per day, respectively.[69] A positive smoking history (individuals who had > 25 pack years smoking history) was a significant factor for late implant failure (odds ratio 2.01, $P = .035$). Similarly, Alsaadi et al reported a greater incidence (7.05%) of early implant failures in heavy smokers (> 20 cigarettes per day) compared to patients who smoked 10 to 20 cigarettes per day (5.31%) and those who smoked < 10 cigarettes per day (4.85%).[53]

Sanchez-Perez et al also stratified smokers according to the number of cigarettes smoked per day (never smoked or had quit at least 10 years prior, light smoker < 10 cigarettes per day, moderate smoker 10 to 20 cigarettes per day, heavy smoker > 20 cigarettes per day).[70] Cigarette smoking involved a 15.8% risk of implant failure, with an odds ratio of 13.1. Light smokers or moderate smokers had a 10.1% relative risk of implant loss, whereas heavy smokers increased this risk to 30.8%.[70] Lindquist et al reported a dose-effect relationship between tobacco use and peri-implant marginal bone loss over a 10-year period.[71]

Mundt et al considered the duration of smoking in the analysis of long-term implant survival.[72] Current smokers had a 15% implant failure rate, compared to 9.6% for former smokers and 3.6% for nonsmokers. The number of years of smoking was statistically significantly associated with an increased risk of implant failures. Long-term smoking significantly increased the hazard ratio of implant failure from 1.5 for patients who had smoked for < 10 years to 5.36 for patients who had smoked for > 40 years.[72]

Influence of Interaction Between Smoking and Genetic Factors on Implant Outcome

A number of studies have investigated the effect of smoking on implant outcome in patients with specific interleukin (IL-1) polymorphisms.[73–76] A retrospective study investigated the relationship between IL-1 gene polymorphisms and peri-implant bone loss and peri-implant mucosal inflammation in both smokers and nonsmokers.[75] Of the 90 Caucasian patients, 31.1% were IL-1 genotype positive. Patients were stratified according to smoking history. There were 14 heavy smokers (20 cigarettes per day), 14 moderate smokers (5 to 19 cigarettes per day), 23 former smokers (smoking cessation > 5 years), and 39 nonsmokers. Significant differences in marginal bone loss between heavy smokers and nonsmokers were found for the IL-1 genotype-positive group but not for the IL-1 genotype-negative group. The authors suggested that there is a synergistic effect of smoking and the carriage of the IL-1 gene polymorphism resulting in an increased risk for peri-implant bone loss.

Gruica et al also investigated the impact of the IL-1 genotype and smoking status on peri-implant tissues in a retrospective study of 292 implants which had been in function for at least 8 years. Late biologic complications were observed around 51 implants in 34 patients, while 241 implants had survived without any biologic complications. An association between heavy smokers with a positive IL-1 genotype and peri-implantitis was observed.[76] Jansson et al also found a statistically significant synergistic effect of IL-1 genotype and smoking, and reported an increased risk of early implant failure.[74]

In a study examining the influence of the IL-1 receptor antagonist genotype, Laine et al found a statistically significant association of this genotype with peri-

implantitis.[73] In the multivariate analysis, this study also reported a statistically significant association between smoking and peri-implantitis (odds ratio 3.6, 95% CI: 1.5 to 8.8; $P = .004$), where smokers were classified as individuals who were current or former smokers.

Effect of Smoking on the Outcomes of Peri-implantitis Treatment

In a 5-year follow-up study of patients treated for advanced peri-implantitis, cigarette smoking was found to have a negative effect on treatment outcome. Six of the seven implants that failed due to persistent peri-implantitis were in smokers.[77]

Effect of a Smoking Cessation Protocol on Implant Outcomes

There is one study evaluating the effect of a smoking cessation protocol on implant outcomes.[78] Bain reported that smokers had 1.69 times higher incidence of early implant failures compared to patients who had never smoked or who had stopped smoking at least 1 week prior to and 8 weeks following implant surgery.[78]

RESULTS: SMOKING COMBINED WITH A HISTORY OF TREATED PERIODONTITIS

A number of studies have evaluated the effect of smoking in patients who have a history of treated periodontitis.[20,42,74,75,79–83] Hazard ratios for implant failure of 3.1,[83] 2.6,[20] and 2.2[42] have been reported in smokers with a history of treated periodontitis. In patients with a history of treated periodontitis, Jansson et al reported that smoking resulted in statistically significantly higher early implant failure rates in smokers compared to nonsmokers.[74]

Feloutzis et al reported statistically significantly greater bone loss in patients with a history of treated chronic periodontitis who smoked more than 20 cigarettes per day compared to those who didn't smoke or who were former smokers.[75] Similarly, Wennström et al found that patients with a history of treated periodontitis who were smokers had more bone loss than similar nonsmokers.[82] Malo et al reported a 1-year mean bone loss of 1.0 ± 1.0 mm at implants placed in immediate function in 81 patients with a history of treated periodontitis.[81] In the same study, 45 patients with a history of treated periodontitis who smoked had a mean bone loss of 1.2 ± 0.9 mm.

Machtei et al[80] found no statistically significant difference in implant failure between smokers and nonsmokers who received dental implants for immediate fixed restorations and had a history of treated periodontitis. Machtei et al[79] evaluated implants placed in previously failed sites in patients with a history of treated periodontitis and found no statistically significant difference between smokers and nonsmokers.

Main Findings of Cohort Studies with Subgroups of Smokers and Nonsmokers (Table 3)

1. Of the 59 studies reporting on implant survival, the majority reported a statistically significantly higher survival rate for implants placed in nonsmokers compared with smokers. Only 17 studies reported no significant difference between smokers and nonsmokers.[11,14,17,54,58,59,65,74,79,80,84–90]
2. The majority of studies showed implant survival rates in smokers of 80% to 96%.
3. Implant survival rates in smokers ranged from 61.54% to 100% in nonaugmented bone without sinus elevation.
4. Odds ratios for implant failure in smokers ranged from 2.03 to 6.89.
5. Six of seven studies showed that cigarette smoking is detrimental to the success and survival of implants placed in grafted maxillary sinuses.
6. In smokers, the implant success rates ranged from 43% to 98.3%.
7. Six cohort studies reported a dose effect of cigarette smoking.
8. There are limited data on the survival and success rates of implants in former smokers.
9. There is conflicting evidence that smoking adversely affects initial osseointegration as measured by early implant failures.

Main Findings of Cohort Studies Evaluating Risk of Peri-implantitis (Table 4)

1. Of the six studies reporting on the occurrence of peri-implantitis, five reported a statistically significantly higher risk for smokers compared to nonsmokers.[29,73,76,91,92] Reported odds ratios ranged from 3.6 to 4.6.
2. Studies reporting on the occurrence of peri-implantitis had a follow-up ranging from 1 to 14 years.

Main Findings of Cohort Studies Evaluating Risk of Marginal Bone Loss (Table 5)

1. Of the 22 studies reporting on marginal supporting bone loss, 18 reported a statistically significantly greater risk of bone loss over time in patients who smoked.
2. Odds ratios for progressive bone loss ranged from 1.95 to 10 in smokers.
3. Studies reporting on marginal bone loss had a follow-up time ranging from 1 to 24 years.

DISCUSSION AND CONCLUSIONS

Our current understanding from the literature is that there are similarities between the etiology and pathogenesis of periodontitis and peri-implantitis (Heitz-Mayfield and Lang 2009, in preparation). Therefore, it is perhaps not surprising that many of the studies identified in this review report lower implant survival and/or success rates in individuals with a history of treated periodontitis compared to individuals without a history of periodontitis. While implant placement in patients with a history of treated periodontitis is not contraindicated, with the majority of studies reporting implant survival > 90% over a period of 3 to 16 years, there is an increased risk of peri-implantitis (reported odds ratios 3.1 to 4.7).

The same putative pathogens associated with periodontitis have been identified in high numbers and proportions in peri-implantitis sites.[93–95] Microbial colonization following implant placement has been shown to occur within a short period of time, and the composition of the microbiota within the peri-implant sulcus is similar to that found at neighboring teeth in partially dentate patients.[40,96,97] This underlines the importance of successful treatment of periodontitis prior to implant placement and individualized maintenance care following implant treatment. The definition of successful periodontal treatment and the influence of the periodontal status of the dentition at the time of implant placement need to be addressed in future research.

Smoking is a risk factor for general health and oral health. Smoking has a long-term chronic effect on many aspects of the inflammatory and immune systems. The deleterious effects of smoking include impaired wound healing, reduced collagen production, impaired fibroblast function, reduced peripheral circulation, and compromised function of neutrophils and macrophages.[98] The biologic processes involved in osseointegration and maintenance of peri-implant bone levels are likely affected by tobacco smoking, providing an explanation for the lower implant survival and success in smokers.

While cigarette smoking is not an absolute contraindication for implant placement, with the majority of studies reporting implant survival in the range of 80% to 96%, smokers should be informed that there is an increased risk of implant loss and peri-implantitis (reported odds ratios for peri-implantitis 3.6 to 4.6). Future studies are required to assess the effect of dose and duration of cigarette smoking on implant outcomes.

The link between smoking and periodontitis is well established. Smokers have a greater risk for progression of periodontitis.[99] As patients who have a history of periodontitis may also be smokers, multivariate analyses are required to appropriately assess these risk factors. Further research is required to determine the risk of cigarette smoking and a history of periodontitis combined.

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Mechanical and Technical Risks in Implant Therapy

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Purpose: *To systematically appraise the impact of mechanical/technical risk factors on implant-supported reconstructions.* ***Material and Methods****: A MEDLINE (PubMed) database search from 1966 to April 2008 was conducted. The search strategy was a combination of MeSH terms and the key words:* design, dental implant(s), risk, prosthodontics, fixed prosthodontics, fixed partial denture(s), fixed dental prosthesis (FDP), fixed reconstruction(s), oral rehabilitation, bridge(s), removable partial denture(s), overdenture(s). *Randomized controlled trials, controlled trials, and prospective and retrospective cohort studies with a mean follow-up of at least 4 years were included. The material evaluated in each study had to include cases with/without exposure to the risk factor.* ***Results:*** *From 3,568 articles, 111 were selected for full text analysis. Of the 111 articles, 33 were included for data extraction after grouping the outcomes into 10 risk factors: type of retentive elements supporting overdentures, presence of cantilever extension(s), cemented versus screw-retained FDPs, angled/angulated abutments, bruxism, crown/implant ratio, length of the suprastructure, prosthetic materials, number of implants supporting an FDP, and history of mechanical/technical complications.* ***Conclusions:*** *The absence of a metal framework in overdentures, the presence of cantilever extension(s) > 15 mm and of bruxism, the length of the reconstruction, and a history of repeated complications were associated with increased mechanical/technical complications. The type of retention, the presence of angled abutments, the crown-implant ratio, and the number of implants supporting an FDP were not associated with increased mechanical/technical complications. None of the mechanical/technical risk factors had an impact on implant survival and success rates.* Int J Oral Maxillofac Implants 2009;24(suppl):69–85

Key words: *clinical studies, oral implants, prosthodontics, risk factors*

Medical interventions involving surgical procedures for the insertion of devices such as stents, hip or knee prostheses, orthopedic devices, or dental implants are associated with risk. Before undergoing such interventions, the risks for failure or complications and chances of survival or success need to be carefully weighed by patients and professionals. A qualitative description of risk would relate a greater overall risk to a greater loss and greater likelihood that an event occurs.

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In medicine, a risk factor is a variable associated with an increased risk of disease or infection. Risks are correlational and not necessarily causal. Risk factors are evaluated by comparing the risk of those exposed to the potential risk factor to those not exposed. For the purpose of the present review, mechanical and technical risks were defined as follows:

- *Mechanical risk:* Risk of a complication or failure of a prefabricated component caused by mechanical forces.
- *Technical risk:* Risk of a complication or failure of the laboratory-fabricated suprastructure or its materials.

Mechanical and technical risks play a major role in implant dentistry. They may lead to increased rates of repairs and remakes, and to a waste of time and financial resources, and may even affect the patient's quality of life.

During treatment planning, constellations known to be associated with increased risk should be avoided. Risks associated with different treatment options must also be related to the financial consequences, especially when considerable price differences exist between the prosthetic options.

A series of systematic reviews were launched to estimate and compare the failure/complication rates to be expected with various types of fixed reconstructions on teeth and implants.[1–8] With some of the reconstructions, considerably increased rates of failures were estimated to occur over 10 years of function[6]: fixed dental prostheses (FDPs) with cantilever extensions on teeth (19.6%), combined tooth-implant-supported FDPs (22.3%), and resin-bonded FDPs (35.0%).

The protocols of the systematic reviews mentioned above were designed to include publications reporting on the prosthetic failure and complication rates with a particular design of a reconstruction, ie, full-arch FDPs on implants/teeth, short-span FDPs on implants and teeth, and single crowns, over at least 5 years.

Excluding multiple other factors that may mask a correlation with a particular risk factor seems to be difficult when combining data from cohort studies being performed at various centers. According to the definition of "risk factor" mentioned above, long-term studies that evaluated and compared the risk of those patients/reconstructions exposed to a certain risk factor to those not exposed to that risk factor in the same environment are of particular interest.

Therefore, the aim of this review was to systematically screen the literature for information answering the following focused question: Which mechanical/technical risk factors have an impact on implant-supported reconstructions?

MATERIALS AND METHODS

Search Strategy

A search in the MEDLINE (via PubMed) database from 1966 up to and including April 2008 was performed. Publications in English, German, French, and Italian in peer-reviewed journals were considered; abstracts were excluded. The search strategy applied was a combination of MeSH terms and free text words, including the following key words: *design*, *dental implants/risk*, *prosthodontics*, *fixed prosthodontics*, *fixed partial denture(s)*, *fixed reconstruction(s)*, *oral rehabilitation, bridge(s), removable partial denture(s),* and *overdenture(s)*.

A complementary manual search from 1986 up to April 2008 was carried out in the following journals: *Journal of Oral Rehabilitation*, *Journal of Prosthetic Dentistry*, *International Journal of Prosthodontics*, *International Journal of Periodontics & Restorative Dentistry*, *Clinical Oral Implants Research,* and *International Journal of Oral & Maxillofacial Implants*. In addition, the reference lists of articles selected for inclusion in this review were screened.

Selection Criteria

Randomized controlled trials (RCTs), controlled trials, and prospective and retrospective cohort studies with a mean follow-up time of at least 4 years were included. The material evaluated in one study had to include cases with the risk factor and cases without exposure to the risk factor.

The following inclusion criteria were used:

- Mean follow-up time ≥ 4 years
- At least five patients included
- Studies on fully and partially edentulous patients
- Studies on fixed and/or removable implant-supported dental prostheses
- Studies on fixed dental prostheses with cantilever extension(s)
- Studies on implant-supported single-unit crowns
- Studies on implant- and/or tooth-implant-supported reconstructions
- Studies on cylindrical and/or cylindrical-conical solid-screw implants
- Clinical examination at the follow-up visits
- Detailed information on the characteristics of the implants and their supported reconstructions

The following exclusion criteria were used:

- Animal studies
- in vitro studies
- Studies based on patients' records, surveys, questionnaires, or interviews
- Studies focusing exclusively on finite element analysis (FEA)
- Studies focusing exclusively on implant length and/or diameter
- Studies focusing exclusively on patient-centered outcomes
- Reviews
- Case reports
- Abstracts

Validity Assessment

Two reviewers (UB and GES) screened titles and abstracts identified through the search for possible inclusion. The discrepancies were resolved by discussion. Publications of potential interest were obtained in order to evaluate the full text. Both reviewers screened the included publications independently using the inclusion criteria. Again, any disagreement was resolved by discussion between the two reviewers.

Data Extraction

Collectively, the outcome variables included:

- Implant-related mechanical and technical risk factors
- Abutment-related mechanical and technical risk factors
- Suprastructure-related mechanical and technical risk factors

Depending on the presence or absence of a specific mechanical or technical risk factor, survival and success rates of implants, abutments, and related suprastructures were extracted from the publications. *Survival* was defined as presence of the implant, abutment, and/or its suprastructure in situ in its original extension at follow-up examination with or without complications. *Success* was defined as presence of the implant, abutment, and/or suprastructure in situ without any mechanical or technical complications during the entire follow-up period.

From the included papers, the following information was extracted: the number of patients examined, the mean age of the patients, the mean observation time, the number of implants restored, the implant system used, the designs of the reconstructions under examination, and the study design applied. Finally, the major findings related to harm to the suprastructure, prosthetic components of the implant systems, peri-implant tissues, implants, and results of statistical analyses were noted and grouped according to potential risk factors.

RESULTS

Of the 3,568 titles resulting from the online search, 111 were selected for full text review after reading the abstract. From the 111 full-text articles, 33 were included for data extraction. Two additional articles were included based on a manual search (Fig 1).

The data from 35 publications were grouped according to 10 risk factors identified after screening the literature:

- Type of retentive elements supporting overdentures
- Cantilever extension(s) on fixed dental prostheses (FDPs)
- Cemented versus screw-retained FDPs
- Angled/angulated abutments
- Bruxism
- Crown-to-implant ratio
- Length of the suprastructure
- Prosthetic materials
- Number of implants supporting an FDP
- History of mechanical/technical complications

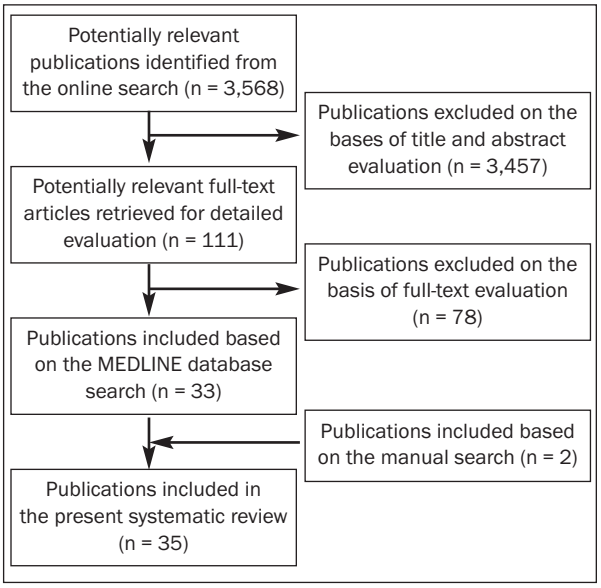

Fig 1 Selection process used to identify the included publications.

Retentive Elements of Overdentures (Tables 1 and 2)

Eight studies dealing with mandibular overdentures in which the allocation of patients to different treatment groups was performed in a randomized manner were identified (Table 1). Naert et al compared 12 patients with Dolder bars to 12 patients with ball attachments and 12 patients with magnets.[9] At 5 years, the highest retention measured by means of a dynamometer amounted to 1,240 g in the bar group, followed by 567 g in the ball attachment group, and only 110 g in the magnet group.[9] When questions about prosthesis stability and cleaning comfort were ranked on a scale from very bad (1) to excellent (9), mean rankings were statistically significantly lower in the magnet group compared to the ball and bar groups. Patient satisfaction related to chewing comfort and phonetics did not change significantly over the 5 years. In the magnet group, however, a significant decrease in general satisfaction and in satisfaction with denture stability was noted ($P < .03$).

In a later publication by Naert et al,[10] unfortunately no detailed information related to prosthetic complications over 10 years of observation was presented. Similar failure rates for the implants were noted in the three groups of overdentures.

Gotfredsen et al found less frequent events for patients receiving ball attachments (19 cases, 0.6 events per year) than for patients receiving a round

Table 1 Randomized Controlled Trials with Edentulous Mandibles Restored with Various Overdenture Designs on Different Implant Systems: Results after 5 and 10 Years of Observation

Study	Year	No. of patients	Mean age, y (range)	Mean observation time	No. of implants	Implant system	Overdenture design	Type of study	Summary of results
Naert et al[10]	1999	36	63.7 (36–85)	60 mo	72	Nobel Biocare	12 Dolder bar 12 magnet 12 ball	Prospective randomized RCT	Retention of denture: bar > ball > magnet Reduction of retention in % of original value similar Complications: magnet > ball > bar More hyperplasia with bar More ulcers with ball Satisfaction: comfort with stability significantly reduced with magnet No risk factor for implant loss
Gotfredsen et al[11]	2000	26	64 (52–78)	60 mo	52	Astra Tech	11 round bar 19 ball	Prospective randomized RCT	Complications per year per patient 1.0 for bar, 0.6 for ball No risk factor for implant loss
Meijer et al[12]	2004	90	54.0 (38–77) 56.6 (35–79) 52.8 (38–74)	60 mo	180	30 IMZ 30 Nobel Biocare 30 Straumann	All Dolder bar (90)	Randomized (envelope) RCT	No risk factor for implant loss
Timmerman et al[15]	2004	110/103	39–87	8.3 y	274	Straumann	36 ball 37 bar on 2 implants 37 bar on 4 implants	Randomized RCT	Satisfaction with retention, stability decreased with ball No difference in change of satisfaction Two implants with bar best solution NR
Meijer et al[13]	2000	61	59 ± 11	5 y	122	29 IMZ 32 Nobel Biocare	61 round bars w/ Ackermann clips	Computerized balancing	Multiple prosthetic revisions Precision attachment system in the overdenture with frequent fractures and loosenings Implant survival: IMZ 93%; Nobel Biocare 86%
Visser et al[16]	2005	60	NR	60 mo	180	IMZ	30 two implants and bar, 30 four implants and bar	Prospective comparative	Tendency for more prosthetic aftercare with two implants and bar More soft tissue complications with four implants and bar No difference in satisfaction No risk factor for implant loss
Meijer et al[14]	2004	61	59±11 55±12	120 mo	122	29 IMZ 32 Nobel Biocare	61 round bars w/ Ackermann clips	Randomized computer-model RCT	Very high incidences of technical/prosthetic complication and failures Measured by clinical implant performance score: similar scores for the two systems No risk factor for implant loss
Naert et al[10]	2004	36	63.7 (36-85)	120 mo	72	Nobel Biocare	12 Dolder bar 12 magnet 12 ball	Prospective randomized RCT	No more information on technical prosthetic complications compared to Naert et al 1999 No risk factor for implant loss

NR = not reported; RCT = randomized controlled trial.

Table 2 Further Studies on Reconstructions of Edentulous Jaws

Study	Year	No. of patients	Mean age, y (range)	Mean observation time	No. of implants	Implant system	Designs of reconstruction	Study design	Findings
Bergendal and Engquist[17]	1998	49	66	62 mo	115	Nobel Biocare (12–106 mo) 8-y life table	Round bar/ball 18 maxillary/ 32 mandibular RCT	Random assignment	Risk of complication: old components, new components Bone anchorage–lever arm was a risk factor More denture fractures with bar versus ball (no framework) More implant loss in maxilla (25%) versus mandible (0%) No risk factor for implant loss
Dudic and Mericske-Stern[18]	2002	119	63 (40–90)	9.3 y (5–15 y)	258	Straumann	75 round bar or ball versus 44 rigid bar	Consecutive patients	No significant difference in time to change of retention mechanism between resilient and rigid Rate of prosthetic maintenance service = event per patient per year at 5 years (no significant difference between the 2 retention systems) For resilient: more complications with retainers, more denture base resin fractures, hyperplasia, relining For rigid: fracture of bar extension, retightening of female part Rates at 5 years similar, advantage for rigid related to time needed for service. No risk factor for implant loss
Nedir et al[19]	2006	55	NR	8-y life table	145	Straumann	41 ball/14 bar	Consecutive patients	Event rate per year: 1.5 with ball, recurrent events 0.9 mm with bar Free of complications 57.1% with bar, 24% with ball ($P < .04$)
Oetterli et al[20]	2001	90/70	67.8 (41–89)	60 mo	180	Straumann	Supportive surface, bent clipbars, U-shaped extension bars, mandible βo: angle between axis connecting implants and mandibular hinge axis	Consecutive patients	Supportive surface and position of implant as well as retention mechanism No risk factor for implant loss
Ferrigno et al[21]	2002	233	59.4 (35–79)	10-y life table	1286	Straumann	Maxilla: full-arch prosthesis 55; Milled bar 19; Dolder bar 16 Mandible: full-arch prosthesis 40; Milled bar 84 Dolder bar 44	Prospective multicenter	Survival of prosthesis: Maxilla: full-arch prosthesis 96.4%; Milled bar 94.7%; Dolder bar 87.5% Mandible: full-arch prosthesis 100%; Ball anchor 99%; Dolder bar 98% Implant success: Maxilla: full-arch prosthesis 92.1%; Milled bar 92.2%; Dolder bar 86.9% Mandible: full-arch prosthesis 96.2%; Ball anchor 93.7%; Dolder bar 93.9%
Tinsley et al[22]	2001	48	(37–80)	4–6 y	181	Calcitec HA-coated	21 FDP vs 27 bar, mandible (23 bars on 3 implants, 4 on 2 implants)	Prospective	Catastrophic results: 50% of overdentures were remade, 30% required a reline Only 83% implant survival HA implants lost a lot of bone

NR = not recorded; FDP = fixed dental prosthesis.

bar (11 cases, 1.0 events per year).[11] Over 5 years, 48 complications/repairs were observed in the ball group and 53 in the bar group. Mainly during the first year of function, there were statistically significantly more complications/repairs in the bar group. However, some of the technical complications were related to the devices needed for radiographic standardization.

Meijer et al[12] followed overdentures with Dolder bars on three different implant systems (IMZ, Nobel Biocare, and Straumann). Over 5 years, there was no effect on the implants and no information was presented on prosthetic aspects. In an earlier report by the same group comparing overdentures on IMZ and Nobel Biocare implants, multiple prosthetic revisions were noted.[13]

When the same patients were followed over 10 years,[14] the 56 surviving overdentures with round bars and Ackermann clips required 256 prosthetic actions, including replacement of broken abutments and loose clip screws, placement of new bars or gold cylinders and new or fastening clips, relining of maxillary or mandibular dentures, repair of denture bases or teeth, readjustment of occlusion, and provision of new maxillary and mandibular dentures—with no obvious difference between the IMZ and Nobel Biocare groups. A clinical implant performance scale was used to score the events. With a mean score of 1.3 for the IMZ group and 1.2 for the Nobel Biocare group, the clinical outcomes appeared to be similar.

Three types of overdenture designs were compared comprehensively using a computerized random allocation procedure.[15] Thirty-six overdentures were attached to two ball anchors, 37 to a bar on two implants, and 37 to a bar on four implants. General satisfaction with phonetics, esthetics, and social functioning remained high. The score reflecting satisfaction with retention and stability of the overdenture decreased significantly in the group with two ball attachments.

Comparing 30 overdentures with bars on two implants to 30 overdentures with bars on four implants, Visser et al[16] found a tendency for more biological complications with four implants but a higher need for prosthetic aftercare on two implants (not statistically significant).

Six additional studies were found in which overdentures with different attachment systems were compared longitudinally. In these studies, allocation of the groups was not performed using randomization (Table 2).

Forty-nine patients with maxillary and mandibular overdentures were followed over 62 months (range 12 to 106 months).[17] When patients received overdentures either on ball anchors or on a round bar, the overdentures that were not reinforced with a metal framework were at high risk of fracturing. In the bar group, 30 of 36 patients required denture repairs. In the maxilla, 25% of the originally placed implants were lost compared to none in the mandible. The amount of bone anchorage in relation to the lever arm was higher in the lost implants (mean lever arm–bone anchorage ratio of 1.3) than in all implants placed (a mean lever arm–bone anchorage ratio of about 1).

Over an observation period of 5 to 15 years (mean 9.3 years), 119 patients with implant-supported overdentures were monitored at regular intervals.[18] The rate of prosthetic maintenance per patient over 5 years was similar for the resilient and rigid types of fixation applied. However, the characteristics of the complications differed. Whereas resilient attachments had more complications with retainers, more denture base resin fractures, mucosal hyperplasia, and denture relines, the rigid support attachments had more fractures of bar extensions and needed retightening of female parts. It was obvious that rigid fixation was an advantage, since less time was required for services. The time to the first change of a component was not significantly different for resilient versus rigid attachments.

The amount of aftercare in patients with overdentures was assessed cumulatively up to 8 years by Nedir et al.[19] The percentage of overdentures remaining free from complications was 57% for the bar devices but only 24% for overdentures with ball anchors ($P < .04$); 1.5 events per year were noted in the ball attachment group, whereas 0.9 events per year per patient occurred in the bar group.

Anatomical, morphologic, and prosthetic variables are considered to be of importance when selecting a particular implant position. Oetterli et al[20] evaluated the casts and clinical parameters of 90 edentulous patients, each one with two intraforaminal implants supporting an overdenture. The angle β between the virtual axis connecting both implants and the mandibular hinge axis was measured on mounted casts. The supporting surface was identified between bent clip bars and U-shaped extension bars. Seventy patients could be evaluated clinically after 5 years. The positions and retention mechanism of mandibular implants supporting an overdenture had little influence on the clinical parameters assessed. No data related to technical/mechanical complications were reported.

The long-term function (10-year life table) of overdentures was compared to the clinical outcome with full-arch fixed prostheses in a study including 233 patients receiving 163 overdentures and 95 fixed full-arch prostheses.[21] The survival rates for overdentures on Dolder bars were 87.5% for the maxilla and 97.7%

for the mandible. Survival of full-arch prosthses was 96.4% in the maxilla and 100% in the mandible. Overdentures on milled bars had a 94.7% survival rate in the maxilla, and overdentures on ball anchors in the mandible had a 98.8% survival rate.

One study reported a dramatic incidence of implant loss (27% over 4 to 6 years), remakes of overdentures (50%), and relinings (30%).[22] Handling such frequent catastrophic events would be highly impracticable in daily clinical practice.

Fixed Dental Prostheses (FDP) with Cantilever Extension(s) (Table 3)

In four papers, the presence of a cantilever extension as a potential risk for technical/mechanical complications was assessed. In the oldest report, dramatically higher failure rates with cantilever extensions > 15 mm were noted.[23] In 25 patients, 24 edentulous mandibles and four edentulous maxillae were restored with full-arch fixed bilateral cantilever prostheses on five to six implants. The prostheses were grouped into those with a cantilever length of > 15 mm and those with ≤ 15 mm (range 5 to 22 mm). The prostheses were followed from 20 to 80 months. Of the 28 prostheses, 12 had to be remade. Practically all of those were originally designed with cantilever extensions > 15 mm.

Comparing 24 FDPs with cantilever extensions to 26 FDPs without cantilever extensions over 5 years in 45 consecutive patients, Wennström et al[24] did not find any negative effect on the peri-implant conditions. The six technical complications noted were not related to the cantilever extensions.

Romeo et al[25] collected clinical and radiographic data from 42 FDPs with a cantilever extension and 137 FDPs without a cantilever extension. The cumulative survival rates of the implants reached 94.4% with the risk "cantilever extension" and 96.5% without the risk "cantilever extension," as assessed in a 7-year life table analysis. Radiographic success was defined as absence of bone loss > 1 mm during the first year of loading and 0.2 mm/year thereafter. Clinical success, defined as absence of probing pocket depths > 3 mm, was observed in 76.3% of cases with cantilever extensions and in 73.8% of cases without cantilever extensions.

Nedir et al[19] presented data on consecutive patients treated with implant-supported removable or fixed prostheses and single crowns on implants. Seventeen of the fixed reconstructions had a cantilever extension and 228 did not. Up to 8 years follow-up, the authors found technical complications in about 30% of the reconstructions with cantilever extensions but in only 8% of the reconstructions without cantilever extensions.

Romeo et al[26] collected radiographic and clinical information on fixed dental prostheses in 49 partially edentulous patients. Fifteen of the FDPs had a distal cantilever extension and 34 a mesial cantilever extension. After a mean follow-up of 4 years, no negative effects related to the presence of the mesial or the distal cantilever extension were found.

Cemented Versus Screw-Retained Dental Prostheses (Table 4)

In a prospective randomized study, 12 cemented and 12 screw-retained crowns were constructed on implants to replace missing lateral incisors.[27] Four years after loading, no differences in peri-implant conditions and no prosthetic complications were noted.

In two other reports, similar rates of complications were noted over 5 years with cemented and screw-retained crowns and FDPs.[19,28] It should be noted, however, that the group with cemented reconstructions was considerably larger in both studies. The screw-retained reconstructions in the study by De Boever et al[29] demonstrated twice as many complications as the cemented ones: 29/127 cemented (22.8%) and 26/45 screw-retained (57%) reconstructions demonstrated technical/mechanical complications ($P < .001$). In 21 of the 26 interventions, however, only retightening was required.

Angled/Angulated Abutments (Table 5)

Two studies focusing on the potentially negative influence of nonparallel implants requiring the placement of angled abutments were found. In a report by Sethi et al,[30] misangulations ranged from 0 to 45 degrees. Of 3,101 implants, 264 implants with an abutment angulation of > 15 degrees were compared to 352 implants with a more axial abutment (≤ 15 degrees). Over 10 years, the angulation had no effect on the probability of survival of the implants. However, no information on mechanical/technical complications was available.

A more sophisticated method of analyzing angles was presented by Koutouzis and Wennström in 2007.[31] Standardized photographs were taken of the maxillary and mandibular study casts in occlusion and then with guide pins in place. Thus, within the superimposed image, the inclination of the implants in relation to the occlusal plane was obtained. Finally, interimplant inclinations in both mesiodistal and buccolingual directions were obtained. Axial implants were defined as ranging from 0 to 4 degrees and nonaxial implants from 12 to 30 degrees. The 36 axial and 33 nonaxial implants yielded similar bone remodeling over 5 years, as assessed in radiographs. Moreover, there was no increased risk of mechanical/technical complications associated with tilted implants.[31]

Table 3 Extension

Study	Year	No. of patients	Mean age, y (range)	Mean observation time	No. of implants	Implant system	Designs of reconstruction	Study design	Findings
Wennström et al[24]	2004	45	57 ± 10.3 62 ± 8.5 mo	5 y	130	Astra Tech	24 FDPs with extension 26 FDPs without extension Short FDPs	Consecutive patients	6 complications in 5 y not related to presence of extension No influence on peri-implant condition
Shackleton et al[23]	1994	25	NR	20–80 mo	NR	Nobel Biocare	28 full-arch prostheses with extensions ≤ 1.5 cm and > 1.5 cm	5-y survival	Length > 1.5 cm dramatically more fractures 12/28 remakes No influence on implant loss
Romeo et al[25]	2004	NR	NR	4 y after loading	379	Straumann	42 FDP with extensions 137 FDP without extensions	3.8 y survival	Implant survival FP with extensions (94.4%) Implant survival FP without extensions (96.1%)
Nedir et al[19]	2006	NR	NR	8-y life table	NR	Straumann	17 with extensions 228 without extensions	Consecutive	29.4% complications versus 7.9% $P < .01$

NR = not recorded, FDP = fixed dental prosthesis.

Table 4 Cemented Versus Screw-Retained

Study	Year	No. of patients	Mean age, y (range)	Mean observation time	No. of implants	Implant system	Designs of reconstruction	Study design	Findings
Vigolo et al[27]	2004	12	NR	4 y after loading	24	Biomet 3i	12 cemented	12 screw-retained	Prospective randomly assigned No complications at all No influence on bone and soft tissue
Brägger et al[28]	2001	85	55.7 (23–83)	50.8 mo	130 implants 142 teeth	Straumann	40 I-I 58 T-T 18 I-T	Retrospective cohorts	13/79 cemented with complications 3/26 screw-retained with complications (ns) No influence on implant loss
Nedir et al[19]	2006	NR	NR	8-y life table	NR	Straumann	189 cemented 32 screw-retained	8-year life table	No significant difference in complication rate No influence on implant loss
De Boever et al[29]	2006	105	25–86	62.5 ± 25.3 mo	283	Straumann	FDP/Crown 45 screw-retained versus 127 cemented	Consecutive	29 complications out of 127 (22.8%) 26 complications out of 45 (57%) $P < .001$ No influence on implant loss

NR = not recorded; ns = not significant; FDP = fixed dental prosthesis; I-I = implant-to-implant FDP; I-T = implant-to-tooth FDP; T-T = tooth-to-tooth FDP.

Table 5 Angulation Versus No Angulation

Study	Year	No. of patients	Observation time	No. of implants	Implant system	Factors	Finding for reconstruction	Finding for implants
Sethi et al[30]	2002	NR	10 y	3,101	Ankylos	From 0–45 degrees; 264 implants > 15 degrees, 352 implants ≤15 degrees	No information on prosthetic complications	Survival probability for implants NS
Koutouzis and Wennström[31]	2007	38	5 y	69	Astra Tech	36 axial (0–4 degrees inclination) versus 33 nonaxial (12–30 degrees)	No increased risk of technical complications	No influence on bone loss around implants

NR = not recorded; NS = not significant.

Table 6 Bruxism

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Design of reconstructions	Type of study	Findings
Brägger et al[28]	2001	85	55.7 (23–83)	56.8 mo	103 (142 teeth)	Straumann	FDPs: 40 I-I; 58 T-T; 18 I-T	Retrospective cohorts	13/75 nonbruxers (17.3%) had technical complications and 6/10 bruxers (60%) had complications $P < .01$ No influence on implant loss
Ekfeldt et al[32]	2001	54	NR	NR	301	Nobel Biocare	Edentulous maxillary FPD or overdenture; 27 with clustered implants loss (50%) vs 27 with no such loss (control)	Clustered failures as test group versus matched control group	In the test group with clustered losses, there were 7 patients with bruxism Heavy influence on implant loss
De Boever et al[29]	2006	105	25–86	65.2 ± 25.3 mo	283	Straumann	23 bruxers, 80 nonbruxers 43 reconstructions at risk in bruxers 126 reconstructions at risk in non-bruxers	Consecutive	17/43 (39%) had complications in the bruxing group 29/126 (23%) had complications in the non-bruxing group; $P < .001$ No influence on implant loss
Tawil et al[33]	2006	109	53.6 (22–80)	53 (12–108) mo	NR	Nobel Biocare	123 FPDs: 22.6% bruxers, 5.9% occasional bruxers, 71.4% nonbruxers	Consecutive patients	22.6% of the patients were defined as bruxers; they had 50% of the veneer fractures; however, ns No significant influence on implant loss
Nedir et al[19]	2006	26 bruxers 189 nonbruxers	NR	8-y life table	72	Straumann	26 bruxers/ 189 nonbruxers	Consecutive	No statistically significant increase in complication rate for FDPs and overdentures NS

NR = not recorded; FDP = fixed dental prosthesis; NS = not significant; I-I = implant-to-implant FDP; I-T = implant-to-tooth FDP; T-T = tooth-to-tooth FDP.

Bruxism (Table 6)

Based on clinical experience, probably every dentist would group bruxers into a high-risk category for technical and mechanical complications and failures. Even implant fractures seem to occur more frequently in bruxers according to case reports. The present literature search indicated five studies in which bruxers were compared to nonbruxers. In two of the clinical reports, statistically significantly higher rates of mechanical/technical complications (ie, 17.3% and 23%) and failures (ie, 60% and 39%) were found in bruxers compared with nonbruxers.[28,29] In two additional publications, trends toward more frequent mechanical/technical complications and implant losses were observed in bruxers.[32,33] Nedir et al,[19] however, found no increased rate of complications in FDPs and overdentures in bruxers compared to nonbruxers.

Crown-to-Implant Ratio (Table 7)

Adopted from perioprosthetic concepts, the crown-to-implant (C:I) ratio might also be a negative biomechanical factor to be considered in implant-supported reconstructions. If the ratio of the supracrestal leverage increases, unfavorable forces and load may be transmitted to the implant. If the crown and the supracrestal implant components have the same length as the osseointegrated part of the implant, the crown-to-implant ratio is 1. It may be logical to expect less favorable load conditions with a crown that is twice as long as the implant, and vice versa.

Three clinical studies were found in which implants and their fixed reconstructions were grouped into ranges of C:I ratios. In 123 FDPs, no significant influence of the parameter C:I on the peri-implant conditions was found over a mean observation period of 53 months.[33] Similar results were obtained by Rokni et al[34] over 4 years and Blanes et al[35] over 5 years. However, all three studies were restricted to radiographic analyses and did not report mechanical/technical complications.

Length of the Suprastructure (Table 8)

In 105 partially edentulous patients, 283 implants were placed and restored with 80 single crowns, 39 double crowns, and 38 three- to four-unit FDPs.[29] Over 5 years, 25% of the single crowns, 35% of the double crowns, and 44% of the three- to four-unit FDPs demonstrated a complication. Of the necessary clinical repairs, 36% were solved by recementation and 30% by retightening the screws. Longer reconstruc tions seemed to be more prone to complications.

Prosthetic Materials (Table 9)

In addition to gold alloys, other metal alloys have been used to fabricate prosthetic frameworks. A longitudinal study was carried out to compare two cast framework alloys with different mechanical properties: gold alloy and silver-palladium.[36] Fixed implant-supported mandibular prostheses were constructed in 26 edentulous patients. The frameworks in group A were cast with Chicago IV gold alloy, and those in group B were cast with Palliag M silver-palladium alloy. Acrylic resin teeth were used and heat cured onto the frameworks. Frameworks had a distal cantilever extension of 10 mm, and the patients received maxillary complete dentures with acrylic teeth. The number of screw loosenings (11 in group A and 13 in group B) as well as other technical complications were similar in the groups over 5 years of observation.

In another study, after random assignment, conventional ceramometal cast frameworks were fabricated for FDPs on one side of the jaw in 21 patients, while 21 laser-welded titanium frameworks with low-fusing porcelain were constructed for FDPs on the other side of the jaw.[37] An additional cohort of 21 cases with laser-welded titanium frameworks with low-fusing porcelain was added. Fifteen events of fractured porcelain veneer were noted over 5 years with the combination titanium/low-fusing porcelain, compared to three events with the conventional ceramometal FDPs.

In a study by Hedkvist et al, 36 patients were provided with 46 FDPs on 207 implants.[38] While 37 prostheses used the conventional implant/abutment configuration, 19 prostheses were placed directly at the implant level (Cresco Ti Precision, Astra Tech). Thirty-three patients with 43 prostheses could be reexamined after 5 to 8 years of function. Technical complications included six resin fractures and one porcelain fracture. These were not related to the type of framework used.

Andersson et al conducted a multicenter study in 32 patients with 105 implants.[39] Nineteen short-span FDPs were seated on 53 ceramic abutments (Cer-adapt alumina ceramic, Nobel Biocare) and 17 were mounted on 50 titanium abutments. After 5 years, 30 patients with 29 FDPs could be re-examined. Only one of the ceramic abutments failed.

In all four of the above-mentioned studies, no effects on the peri-implant conditions of the different materials used for frameworks or abutments were detected.

Table 7 Crown-to-Implant Ratio

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Crown-to implant ratio	Type of study	Findings
Tawil et al[33]	2006	109	59.6 (22–80)	53 mo	262	Nobel Biocare	123 FDPs ranged from C:I < 1 to > 2 for 234 implants 30 were < 1, 8 > 2	Consecutive patients	No influence on bone loss No risk factor for implant loss
Rokni et al[34]	2005	74	53 (20–76)	46 mo	199	Endopore	22: ≤ 1.0 157: 1.1–2.0 20: > 2.0	Consecutive patients	No influence on bone loss No risk factor for implant loss
Blanes et al[35]	2007	83	NR	6 (5–10) y	192	Straumann	8: 0–0.99 133: 1–1.99 51: ≥ 2	Consecutive patients	No influence on bone loss No risk factor for implant loss

NR = not recorded; C:I = crown-to-implant ratio; FDP = fixed dental prosthesis.

Table 8 Length of Reconstruction

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Type of study	Design of reconstruction	Findings
De Boever et al[29]	2006	105	25–86	62.5 ± 25.3 mo	283	Straumann	Consecutive patients	80 SC 39 two connected crowns 38 3- to 4-unit FDP	25% of SC had complications 35% of two connected crowns had complications 44% of 3- to 4-unit FDP had complications, $P < .04$

SC = single crowns; FDP = fixed dental prosthesis.

Number of Implants Supporting an FDP (Table 10)

In the early days of osseointegration, the number of implants used per reconstruction to replace teeth was preferably kept high. Already by 1995, however, it was reported that the function of full-arch prostheses over 10 years was the same when 14 cases with FDPs on four implants were compared to 70 cases with FDPs on six implants in the maxilla and 13 prostheses on four implants were compared to 59 on six implants in the mandible.[40] The survival rates for individual implants and prostheses were similar in the groups at the end of a 10-year observation period.

As a concept for the restoration of free-end situations with FDPs on implants, it was advocated to preferably place three implants not aligned but rather offset. The distribution of load would thus prevent implant failures and complications with screw loosening.

In a report by Eliasson et al,[41] 63 FDPs were fixed on two implants and 83 FDPs on three implants. Over 9.5 years (range 5 to 18 years), the survival rates of the FDPs were similar: 96.8% and 97.6%, respectively. FDPs on two implants had more screw loosening ($P < .05$); in FDPs on three implants, more porcelain fractures ($P < .05$) were observed.

Farzad et al[42] applied measurements of implant stability and found somewhat higher ISQ (Implant Stability Quotient) values assessed by means of Osstell readings at implants supporting three-implant prostheses compared to two-implant prostheses. Apart from that, no differences were observed in the 30 FDPs on two implants and the 74 FDPs on three implants followed over 4 years.

History of Complications (Table 11)

In two studies, odds ratios for reconstructions with previous complications ending in failure were statistically significantly increased compared to reconstructions that had not had previous complications (Table 11).[43,44] Of 30 failed reconstructions, 15 had already had major so-called retrievable complications (odds ratio 3.55, $P < .001$). Altogether, 214 crowns or FDPs were observed over 4.2 years.[43] When 69 single crowns, 33 FDPs on implants, and 22 tooth-implant–supported FDPs were followed over 10 years (range 8 to 12 years), the odds ratio for technical failure of those reconstructions with a previous loss of retention reached 17.6 (95% CI: 3.6 to 86.4). The odds ratio for a suprastructure failure was 11.0 (95% CI: 2.1 to 57.9) for reconstructions with a history of porcelain fractures ($P < .01$).[44]

DISCUSSION

Data Extraction

The main objective of this report was to extract published evidence related to mechanical/technical risk factors for any kind of damage to an implant-supported reconstruction. We searched for technical and/or biological complications or failure rates experienced with or without exposure to a certain mechanical/technical characteristic. Studies related to implant surfaces, loading protocols, tooth-implant–supported reconstructions, implant length, and width of the platform were excluded.

Assessment of Complications and Failures

To compare the outcomes with implant-supported reconstructions achieved in different patient populations, useful parameters for statistical analyses should be provided. Standardization of the criteria used in the assessment of the frequency, the kind of events observed, and the severity of the damage is required. Of particular interest were, therefore, the various attempts of authors to score and describe the outcomes related to experiences with implant-supported reconstructions.

According to Dudic and Mericske-Stern,[18] categories of prosthetic problems with overdentures included:

- Complications and failures of implant-related parts (abutments, bars and anchors, retainers, occlusal screws)
- Mechanical and structural failures of prostheses (denture base, teeth, prosthetic design, fabrication of new dentures)
- Prosthesis-related adjustments (relining, occlusion, esthetics, hyperplasia)

The rates of prosthetic maintenance services (events per patient) were calculated for comparable periods of time (per year, per 2 years, per 5 years) and according to the three categories.[18] The rates of prosthetic maintenance per patient over 5 years were similar for resilient and rigid types of fixation; however, the characteristics of the complications were different. An additional useful parameter for statistical analyses was also assessed by calculating the time to the first event for resilient and rigid attachment systems.

In other reports, a clinical implant performance scale (CIP) was used.[14] This included scores from 0 to 4, as follows:

Table 9 Material Aspects

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Design of reconstruction/ materials used	Type of study	Findings
Murphy et al[36]	2002	26	60	5 y	NR	Astra Tech	13 FDP mandible Chicago IV gold alloy A 13 FDP Palliag M silver palladium B	Not randomized	Similar number of events for technical complications No influence on bone loss; no risk factor for implant loss
Jemt et al[37]	2003	42	56 ± 11 50 ± 12	5 y	170	Nobel Biocare	21 FDP ceramometal cast framework left 21 FDP ceramometal cast framework right with low-fusing porcelain 21 with titanium framework prosthesis with low-fusing porcelain	Groups arranged at random, split mouth	No difference in prosthesis survival, more porcelain chips with titanium 19% versus 10% ($P > 0.3$) No risk factor for implant loss No more bone loss
Hedkvist et al[38]	2004	36	NR	5–8 y	207	Nobel Biocare	27 prostheses with abutment 19 at implant level, Cresco Ti Precision	Consecutive	No difference in complication rates No difference in bone loss around implants
Andersson et al[39]	2003	32/30	NR	5 y	105/103	Nobel Biocare	53 ceramic abutments (Ceradapt alumina ceramic) 50 titanium abutments 19 FDP on ceramic abutments 17 FDP on titanium abutments/29 left Short FDP	Consecutive	Patients satisfied with esthetics Only one ceramic abutment failed No influence on implant bone loss

NR = not recorded, FDP = fixed dental prosthesis

Table 10 Number of Implants

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Design of reconstruction/ materials used	Type of study	Findings
Eliasson et al[41]	2006	178	65 (32–91)	9.5 (5–18) y	375	Nobel Biocare	63 FDP on 2 implants 83 FDP on 3 implants Free-end situations	Not randomized	Survival rate 96.8%/97.6% More screw loosening with 2 implants; $P < .05$ More porcelain fractures with 3 implants; $P = .05$ No influence on implant loss and bone loss
Farzard et al[42]	2004	34	62 (43-80)	3.9 y	210	Nobel Biocare	30 FDP on 2 implants 74 FDP on 3 implants	Not randomized	Small difference in ISQ value No influence on reconstruction No influence on implant loss
Brånemark et al[40]	1995	156	NR	10 y	882	Nobel Biocare	Maxilla: 14 FDP on 4 implants 70 FDP on 6 implants Mandible: 13 FDP on 4 implants 59 FDP on 6 implants	Age- and gender-matched groups	Function of prostheses over 10 y was same All mandibular prostheses stable 1/14 on 4 implants lost 6/70 on 6 implants lost in the maxilla Survival of implants 88.4%/ 93.4% Higher risk to lose an implant if only 4 were placed

NR = not recorded; ISQ = implant stability quotient; FDP = fixed dental prosthesis.

Table 11 Complications Leading to Failures

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Design of reconstruction/ materials used	Type of study	Findings
Parein et al[43]	1997	152	55.7 (14–90)	4.2 y	392	Brånemark	56 SC on implants 168 FDP on implants	Consecutive	Of 30 failures with reconstructions, 15 had major so-called retrievable complications before Odds ratio 3.55; $P < .001$
Brägger et al[44]	2005	89	58.9 (28–88)	10 (8–12) y	160 (24 teeth)	Straumann	69 SC on implants 33 FPDs I-I 22 FPDs I-T	Prospective	Loss of retention leading to technical failure; Odds ratio 17.6 (3.6–86.4); $P < .001$ Fracture of porcelain leading to technical failure; Odds ratio 11.0 (2.1–57.9); $P < .004$

SC = single crowns; FDP = fixed dental prosthesis; I-I = implant-to-implant FDP; I-T = implant-to-tooth FDP.

0: Success, no complications
1: Minor complications, such as: gingival hyperplasia, relining of maxillary or mandibular dentures, readjustment of occlusion, clip loosening, coping/screw loosening, broken abutment, a slight disturbance of the mental nerve, probing depth = 6 mm, or x-ray score 1 with PPD 5 mm
2: Complications with a chance of recovery or stabilization of the present situation, such as: correction of a non-fitting superstructure, fracture of the superstructure, a severe disturbance of the mental nerve, x-ray score 1 with PPD 6 mm, or x-ray score 2 with PPD 5 mm
3: Serious complications that may lead to failure of the implant system: X-ray score 2 with PPD 6 mm or x-ray score 3
4: Failure of the implant system: removal of one or two implants after placement of the suprastructure

The x-ray score 0 related to no apparent bone loss; 1, to a reduction < $^1/_3$ of the length of the implant; 2, to a reduction between > $^1/_3$ and < $^1/_2$ of the implant length; and 3, to a reduction > $^1/_2$ of the implant length.

Pooling wide ranges of biological and technical complications in the same category may mask clinically important differences between groups.[43]

In 2006, Nedir et al grouped prosthetic complications of overdentures into foreseeable and nonforeseeable events.[19] Change of female parts of the spherical attachment, change of the clip, and relining were categorized as foreseeable. Mechanical retention problems, repair and replacement of the overdenture, and complications of the opposing complete denture were unforeseeable complications in the overdenture group. For the fixed restoration group, complications were graded as minor or major. A fracture was considered major if it affected esthetics, caused the metal framework to be visible, resulted in a missing interproximal contact point, or caused the patient to complain of tongue- or masticatory-related discomfort. Major fractures resulted in a prosthesis remake; minor fractures did not lead to remakes.

In a series of systematic reviews on complication and failure rates reported with various types of reconstructions on teeth and implants, the extracted data were listed as the estimated event rates per 100 reconstructions per year, considering the actual exposure time and assuming no change in the long-term risk intensity.[6] Statistically significantly increased failures rates were calculated for cantilever FDPs on teeth and tooth-implant–supported FDPs compared to FDPs on teeth without extension, implant-supported FDPs, and single crowns on implants over 10 years. In addition, statistically signifi-

cantly increased complication rates were calculated for loss of vitality and loss of retention when comparing cantilever FDPs with conventional FDPs. The 5-year complication rates were similar for the implant-supported FDPs and single crowns.

Risk Factors Affecting the Implants

The most obvious and clinically relevant finding in this review is that almost none of the technical/mechanical risk factors extracted seemed to affect the implant per se or the surrounding bone. This is very surprising, since for many years overload, nonaxial loading, and biomechanical stress were considered the main reasons for implant losses.

Risk Factors Affecting the Suprastructures

Eight studies presented comparisons of prosthetic outcomes with overdentures using different attachment systems and implant components in the edentulous mandible—the best model in prosthodontics to perform RCTs. The groups compared, however, were so diverse that an analysis of the combined data was not feasible.

Some of the overdenture designs, however, indicated clinically relevant increased risks.

Satisfaction of the patients with the retention of an overdenture was affected by the attachment mechanism and seemed to be best with bar devices. The amount of aftercare was higher with spherical attached systems in most of the reports. Fractures of dentures occurred frequently if no metal frameworks were constructed, especially with bar devices.

In two of four included reports, the presence of a cantilever extension in an FDP on implants did not lead to increased failure or complication rates.[24,25] The reported higher rate of failures with FDPs on implants was restricted to very long cantilever extensions (> 15 mm).[23] The small number of FDPs with cantilever extensions in the report by Nedir et al may not be representative.[19]

Findings from a meta-analysis of a systematic review on implant-supported short-span FDPs with cantilever extensions yielded estimated survival rates of 94.4% (95% CI: 87.0 to 97.6) after 5 years and 89.1% (95% CI: 75.7 to 95.3) after 10 years.[45]

The lack of a negative effect of cantilever extensions in FDPs on implants is in contrast to the increased complication and failure rates reported with cantilever extensions in FDPs on teeth.[4] For treatment-planning aspects, this mechanical/technical advantage of implant-supported reconstructions is of considerable importance.

In three of four publications comparing complications/failures with screw-retained versus cemented FDP crowns, the retention mechanism could not be identified as a risk factor. Both of two extracted papers on angled abutments did not indicate that angulations > 15 degrees for the abutments and the prosthesis had any effect on the outcome. The patient risk factor bruxism resulted in significantly increased event rates in two studies, in trends for higher rates in two studies, and in no difference in one report.

From a retrospectively assessed cohort of 368 patients with 838 endosseous implants, 19 cases were selected in which there were technical/mechanical complications such as implant fractures, abutment fractures, screw loosening, occlusal wear, or damage to the prosthesis.[46] The 19 patients were evaluated for sleep bruxism using polysomnographic analysis. Most of the bruxism episodes occurred during light sleep and did not cause arousal, and the patients were unaware of the nocturnal parafunctional habits. Bruxism was reported to have continued despite the fact that all these patients were provided with a nightguard.

Crown-to-root ratio, material aspects, and the number of implants placed were not identified as risk factors for increased failure/complication rates. The complexity of a reconstruction, expressed as the number of units, was identified as a risk in only one study, and having had a previous complication was identified as a risk in two.

The implant length in relation to the height of the suprastructure as well as the number of implants needed to physically support an FDP and assure its function are risk factors related to the quality and quantity of the osseointegration and the torque needed to disrupt the "chemical" and histologic bonding between the supporting bone and the implant surface.

Efforts to improve osseointegration in implant dentistry by modifying the surface characteristics, such as the topography and chemistry, have led to much more reliable clinical results compared to the original machined implants when using shorter and fewer implants.[47,48]

Limitations/Critical Remark

The fact that some of the mechanical/technical characteristics evaluated were not identified as true risk factors in this review does not mean that they are not, in fact, risks. Limitations of the study designs, too many uncontrollable variables, small number of subjects, etc, may have hidden the actual facts in some of the studies.

CONCLUSIONS

- Mandibular overdentures: Independent of the retentive element system used, patients required multiple prosthetic services during the observation period (six RCTs). Technical/mechanical complications occurred more frequently with a ball attachment than with a bar retentive system (one RCT). With respect to retention, patients were most satisfied with a bar retentive system, followed by ball anchors, and least satisfied with magnets (one RCT). Metal frameworks protected overdentures from fractures (one consecutive case study).
- The presence of cantilever extensions was not associated with increased mechanical/technical risks for implants supporting short-span FDPs (three consecutive case studies).
- The presence of cantilever extensions > 15 mm was associated with an increased risk of full-arch FDP fracture compared with the presence of cantilever extensions ≤ 15 mm (one consecutive case study).
- No increased mechanical/technical risks for FDPs were observed in three of four studies (one prospective, one retrospective, and one consecutive case study) comparing screw-retained versus cemented reconstructions.
- The presence of angled/angulated abutments was not associated with increased mechanical/technical risks for implant-supported FDPs (one consecutive case study).
- Increased mechanical/technical risks for FDPs were observed in bruxers in four of five studies (two retrospective and two consecutive case studies) comparing bruxers and nonbruxers.
- The crown-to-implant ratio was not associated with implant loss and marginal bone loss of implants supporting FDPs (2 consecutive case studies).
- Increased mechanical/technical risks for FDPs were observed in 1 study (consecutive cases) comparing 3- to 4-unit FDPs with single crowns and double crowns.
- Increased mechanical/technical risks for FDPs were observed in two studies (consecutive case studies) comparing FDPs with and without a history of complications.
- Regarding the survival/success rate of the implant, none of the 10 listed mechanical/technical risks had an influence.

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Consensus Statements and Recommended Clinical Procedures Regarding Risk Factors in Implant Therapy

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INTRODUCTORY REMARKS

This group was asked to address the available evidence for potential risk factors in implant therapy. The authors were requested to prepare narrative reviews using a systematic approach, and were provided with general topics rather than specific research questions. The four reviews presented for discussion within the group addressed: *(1)* systemic conditions and treatments as risks for implant therapy, *(2)* history of treated periodontitis and smoking as risks for implant therapy, *(3)* mechanical and technical risks in implant therapy, and *(4)* local risk factors for implant therapy.

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The group's participants critically reviewed each of the review papers produced by its members, and amendments were made following thorough discussion. The included papers, general conclusions, clinical recommendations, and recommendations for future research were determined by group consensus and following acceptance at plenary sessions.

Risk

To identify a *true risk factor,* causality must be established, requiring prospective longitudinal studies. In the four reviews included, the term *risk* refers to a factor which is associated with the outcomes of implant therapy.

It was noted that few risk factors were evaluated as independent variables. In addition, there was inconsistency in reporting of and adjustment for confounding factors. Within each review, considerable heterogeneity among included studies in terms of definitions of patient population and outcome variables was found. There was a wide range in the level of evidence available among the different review papers, ranging from case series to systematic reviews. The group felt that the possibility of publication bias leading to an overestimation of success could be a specific problem where evidence was in the form of case series and reports.

In the selected studies, a distinction between different implant designs, implant surfaces, operator experience, and precision of the prosthetic restoration was rarely reported. In general, the evolution of implant dentistry is such that implants currently used are not necessarily those evaluated in the included studies. Many potential risk factors may never be evaluated due to the difficulty in conducting appropriate studies and for ethical reasons.

Disclosure

None of the participants in this group reported a conflict of interest.

SYSTEMIC CONDITIONS AND TREATMENTS

General Comments

The aim of this review was to assess various systemic conditions and their treatments as risk factors for implant therapy.

Many patients who may benefit from implant placement present with concomitant systemic diseases. For many systemic diseases, there are no reports on the use of oral implants. The largest amount of information exists for diabetes mellitus, osteoporosis, and radiotherapy. Most of the information is in the form of case reports and case series. The possibility of publication bias, leading to an overestimation of success, needs to be considered, and this is a major problem of case reports and case series.

The published literature does not allow distinguishing between subtypes of systemic diseases, such as diabetes mellitus type 1 and 2, or primary and secondary osteoporosis. Patients may present with multiple risks that may be interrelated, making the estimation of the impact of a single factor difficult.

Clinical Recommendations

With respect to systemic conditions and treatments as risk factors for implant therapy, the following recommendations can be made:

- A thorough medical history is essential to identify potential systemic risks.
- Risks for implant failure and risks for medical complications should be differentiated and evaluated. In some instances, conditions and their treatments may pose increased risks for implant failure, whereas the risk for the patient may be minimal. As an example, there are no data to support withholding implant treatment for patients with diabetes or osteoporosis. However, these patients need to be informed of the possibility of implant complications.
- Where there is a potential risk of a medical complication—for example, osteonecrosis of the jaw in patients taking oral bisphosphonates and patients undergoing radiotherapy—the option of implant therapy should be chosen restrictively, and the patient should be informed specifically, taking into account the current level of uncertainty with regard to the consequences. For patients with a life-threatening systemic disease, implant placement should be postponed until the patient's medical condition is stabilized and has improved.

Recommendations for Future Research

- Well-designed prospective, controlled clinical trials are needed in subjects with systemic diseases, especially common chronic diseases. The medical diagnosis, status, comorbidities, and treatments should be reported in detail.
- With regards to diabetes, assessment of glycemic control should be included. Studies addressing implants placed in patients taking oral bisphosphonates should record the type of the drug, its dosage, and the duration of therapy.
- Regarding rare and uncommon systemic conditions, clinicians are encouraged to report complications with implant therapy.

HISTORY OF TREATED PERIODONTITIS AND SMOKING

General Comments

The aim of this paper was to evaluate cigarette smoking and a history of treated periodontitis, both alone and combined, as risk factors for adverse implant outcomes.

Considerable heterogeneity among studies was found, making comparisons of outcomes difficult. The definitions of periodontitis and nonperiodontitis patients differed among studies. Where a description of the type of periodontitis was given, the type of periodontal disease was usually described as chronic periodontitis.

While all studies reported that periodontal patients were treated, and the majority of studies reported regular supportive periodontal therapy, the periodontal status was infrequently reported.

A range of definitions for smokers, nonsmokers, and former smokers were used in the studies. Few studies reported and adjusted for confounding factors.

The outcomes addressed in this review were implant survival, implant success (as defined by the authors), longitudinal radiographic bone levels, and occurrence of peri-implantitis.

History of Treated Periodontitis. Three controlled studies reported statistically significantly lower implant survival rates in patients with a history of periodontitis compared to nonperiodontal patients. However, the majority of studies report high implant survival rates (> 90%). There is evidence that patients with a history of periodontitis are at greater risk for peri-implantitis than patients without a history of periodontitis (reported odds ratios ranged from 3.1 to 4.7).

Smoking. There is strong evidence that smoking is a risk factor for adverse implant outcomes. The evidence shows that smokers have an increased risk of peri-implantitis (reported odds ratios ranged from 3.6 to 4.6) and radiographic marginal bone loss (reported odds ratios ranged from 2.2 to 10) compared to nonsmokers. There is some evidence for a dose effect of cigarette smoking.

History of Treated Periodontitis and Smoking Combined. There are few studies evaluating the combined effect of smoking and a history of periodontitis. There is some evidence of an increased risk for implant failure and bone loss in smokers with a history of treated periodontitis compared to nonsmokers with a history of treated periodontitis.

Clinical Recommendations

With respect to a history of treated periodontitis and smoking, the following recommendations can be made:

- ***History of Treated Periodontitis.*** A history of treated periodontitis is not a contraindication for implant placement. However, patients with a history of treated periodontitis should be informed of an increased risk of implant failure and peri-implantitis. Patients with a history of periodontitis should receive individualized periodontal maintenance and regular monitoring of peri-implant tissue conditions.
- ***Smoking.*** Smoking is not a contraindication for implant placement. However, patients should be informed that the survival and success rates are lower in smokers. Heavy smokers should be informed that they are at greater risk of implant failure and loss of marginal bone. Patients who smoke should be informed that there is an increased risk of implant failure when sinus augmentation procedures are used.
- ***History of Treated Periodontitis and Smoking Combined.*** Patients who smoke and have a history of treated periodontitis should be informed that they have an increased risk of implant failure and peri-implant bone loss.

Recommendations for Future Research

- The impact of the patient's periodontal status at the time of implant placement on implant outcomes needs to be evaluated.
- A uniform definition of treated periodontitis should be established.
- The effect of maintaining a periodontally involved tooth on the potential for future implant placement should be assessed.
- Smoking habits including information on the exposure, dose, and duration should be recorded in future studies of implant survival and success.
- A uniform definition of a smoker, former smoker, and nonsmoker in relation to implant therapy should be established for future studies.
- Implant failures need to be differentiated according to the time of occurrence, since the pathogenic mechanisms are different.
- Studies evaluating the effect of smoking cessation protocols are needed.
- The combined effect of a history of periodontitis and smoking on implant outcomes needs to be further investigated.

MECHANICAL AND TECHNICAL RISKS

General Comments

The review addressing mechanical/technical risks in implant therapy was based solely on controlled studies (ie, with or without exposure to the mechanical/technical risks).

In terms of the quantity of the evidence, for each of the 10 identified mechanical/technical risks, a wide range in the number of included publications was found (eg, between 1 and 14).

In terms of the quality of the evidence, the level of evidence ranged from randomized clinical trials to prospective and retrospective cohort studies.

A standardized classification of prosthetic complications is lacking.

Clinical Recommendations

With respect to mechanical/technical risks, the following recommendations can be made:

- In general, implant reconstructions should be planned to minimize mechanical/technical risks.
- Patients receiving implant therapy should receive regular maintenance care in order to detect mechanical/technical complications early, particularly in patients with overdentures.
- Both cemented and screw-retained implant-supported reconstructions can be recommended.
- Patients should be evaluated for bruxism.

Recommendations for Future Research

- Future clinical studies should include detailed listings of the incidence and the frequency of mechanical complications/failures of components, as well as the incidence and the frequency of technical complications/failures of laboratory-fabricated suprastructures or their materials.

- Patient-based and reconstruction-based rates of mechanical and technical complications/failures over a specified time period should be assessed in future studies.
- Laboratory procedures should be better delineated.
- The development of devices to measure clinical functional/parafunctional loading of components and laboratory-fabricated suprastructures should be encouraged.
- The development of materials for components and laboratory-fabricated suprastructures with improved mechanical properties should be encouraged.
- Studies should be designed to critically evaluate the role of the mechanical/technical risks listed in the present review.

LOCAL RISK FACTORS

General Comments

The aim of the review was to assess the influence of various local risk factors on the outcome of implant therapy.

- Limited data (two prospective clinical trials) exist evaluating the available interdental space as a risk factor for implant survival.
- Two clinical studies (both prospective clinical trials) show that as the proximity of the implant to the neighboring tooth decreases (< 3 mm), the proximal bone loss on adjacent teeth could increase following implant placement.
- There is evidence examining the placement of dental implants into infected sites exhibiting apical pathology. Two clinical trials (one randomized clinical trial, one prospective randomized trial) have shown survival rates greater than 92% after 1 year when the implants were placed in debrided sockets and with primary stability.
- There is no evidence supporting soft tissue thickness as a risk factor in implant survival. While the secondary outcome of gingival recession is important, there was no significant correlation with tissue thickness and recession around dental implants (one retrospective clinical study).
- In a recent systematic review, methods of bone density and implant stability assessment were not validated and therefore cannot be linked with implant survival.

Clinical Recommendations

With respect to local risk factors, the following recommendation can be made:

- Special care should be taken in selection of implant diameter and design in areas with limited interdental space.

Recommended Topics for Future Research

- The effect of implant malposition
- The effect of soft tissue thickness on mucosal recession

GROUP 2

Emerging Techniques and Technologies in Implant Dentistry

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Review Papers Submitted for Discussion:

Computer Technology Applications in Surgical Implant Dentistry: A Systematic Review
Ronald E. Jung/David Schneider/Jeffrey Ganeles/Daniel Wismeijer/Marcel Zwahlen/Christoph H. F. Hämmerle/Ali Tahmaseb

Computer-Aided Design and Computer-Assisted Manufacturing in Prosthetic Implant Dentistry
Theodoros Kapos/Linah M. Ashy/German O. Gallucci/Hans-Peter Weber/Daniel Wismeijer

Flapless Surgery and Its Effect on Dental Implant Outcomes
Nadine Brodala

Computer Technology Applications in Surgical Implant Dentistry: A Systematic Review

Ronald E. Jung, PD, Dr Med Dent[1]/David Schneider, Dr Med, Dr Med Dent[1]/
Jeffrey Ganeles, DMD[2]/Daniel Wismeijer, DMD, PhD[3]/Marcel Zwahlen, PhD[4]/
Christoph H. F. Hämmerle, DMD, Dr Med Dent[5]/Ali Tahmaseb, DDS[6]

Purpose: *To assess the literature on accuracy and clinical performance of computer technology applications in surgical implant dentistry.* ***Materials and Methods:*** *Electronic and manual literature searches were conducted to collect information about (1) the accuracy and (2) clinical performance of computer-assisted implant systems. Meta-regression analysis was performed for summarizing the accuracy studies. Failure/complication rates were analyzed using random-effects Poisson regression models to obtain summary estimates of 12-month proportions.* ***Results:*** *Twenty-nine different image guidance systems were included. From 2,827 articles, 13 clinical and 19 accuracy studies were included in this systematic review. The meta-analysis of the accuracy (19 clinical and preclinical studies) revealed a total mean error of 0.74 mm (maximum of 4.5 mm) at the entry point in the bone and 0.85 mm at the apex (maximum of 7.1 mm). For the 5 included clinical studies (total of 506 implants) using computer-assisted implant dentistry, the mean failure rate was 3.36% (0% to 8.45%) after an observation period of at least 12 months. In 4.6% of the treated cases, intraoperative complications were reported; these included limited interocclusal distances to perform guided implant placement, limited primary implant stability, or need for additional grafting procedures.* ***Conclusion:*** *Differing levels and quantity of evidence were available for computer-assisted implant placement, revealing high implant survival rates after only 12 months of observation in different indications and a reasonable level of accuracy. However, future long-term clinical data are necessary to identify clinical indications and to justify additional radiation doses, effort, and costs associated with computer-assisted implant surgery.* Int J Oral Maxillofac Implants 2009;24(suppl):92–109

Key words: *computer-assisted implant dentistry, dental implants, navigation*

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None of the authors reported a conflict of interest.

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Osseointegration of dental implants is today considered to be highly predictable.[1,2] Even in patients with bone atrophy and in locations previously considered unsuitable for implants, implant placement has been made possible through bone regeneration techniques.[3,4] The predictability of these techniques has allowed placement of implants according to the prosthetic requirements.

Conventional dental panoramic tomography and periapical radiography are often performed with the patient wearing a radiographic template simulating the preoperative prosthetic design. However, these imaging techniques do not provide complete three-dimensional (3D) information of the patient's anatomy. In addition, conventional surgical templates have been fabricated on the diagnostic cast that will direct the bone entry point and angulations of the drill, but they neither reference the underlying anatomical structures nor provide exact 3D guidance.[5,6]

To overcome these limitations in dental implantology, current research has been dedicated to developing techniques that can provide optimal 3D implant positioning with respect to both prosthetic and anatomical parameters. The introduction of computed tomography (CT), 3D implant planning software, and

CAD/CAM (computer-aided design/computer-assisted manufacturing) technology have undoubtedly been important achievements in this field. The digital CT (also including cone beam CT, or CBCT) images derived in this way can be converted into a virtual 3D model of the treatment area. This provides the practitioner with a realistic view of the patient's bony anatomy, thus permitting a virtual execution of the surgery in an ideal and precise prosthetically driven manner.

Different approaches have been introduced to transfer this planned digital information to the clinical situation. Mechanical positioning devices or drilling machines convert the radiographic template to a surgical template by executing a computer transformation algorithm.[5,6] Other approaches include CAD-CAM technology to generate stereolithographic templates or bur tracking to allow for intraoperative real-time tracking of the drills according to the planned trajectory. The so-called navigation systems visualize the actual position of the surgical instrument in the surgical area on the reconstructed 3D image data of the patient on a screen "chairside" (see Appendix for definitions).

The use of these computer-assisted technologies is often restricted to the surgical aspects of implant treatment. Prosthetic treatment still has to be carried out following conventional protocols. However, the link to transfer prosthetic information to the patient is of great importance, and exact reference points are required to position the implants in such a way that prefabricated prosthetics have a precise fit.[7]

Today, a growing body of literature on the topic of computer-assisted implant dentistry is available. Authors report about different guided techniques, about the accuracy of the position of the implants compared to the virtual digital planning, and about clinical and patient-centered outcomes. As many of these techniques are already available in clinical practice or are on the way to becoming established as routine clinical treatment options, it is of great importance to analyze the currently available systems. This will allow discussion of the possibilities and limitations of computer-assisted implant dentistry in clinical applications. Hence, the aim of this systematic review was to systematically assess the literature regarding the accuracy and the clinical performance of computer technology applications in surgical implant dentistry.

MATERIALS AND METHODS

An electronic literature search of the PubMed database was performed with the intention of collecting relevant information about *(1)* the accuracy and *(2)* the clinical performance of computer-assisted implant systems. The search included articles published from 1966 up to December 2007 in the dental literature. The search was limited to studies in English, German, Italian, or French, using the terms *dental*, *implant*, *implants*, *implantation*, *implantology*, *compute**, *guid**, and *navigat**, and was performed by two independent reviewers. Every search was complemented by manual searches of the reference lists of all selected full-text articles. Additionally, full-text copies of review articles published between January 2004 and December 2007 were obtained.

Inclusion Criteria

The applied inclusion criteria were different for the studies focusing on accuracy and for the studies focusing on clinical outcomes. For the accuracy studies, clinical, preclinical, and ex vivo studies were included. The primary outcome of the experiments had to be accuracy of computer-assisted implant dentistry. Only studies providing exact information about the amount and direction of implant or instrument deviation were included.

For the clinical studies at least five patients had to be included. A follow-up period was not defined for evaluation of intraoperative complications or unexpected events during operation. However, for the evaluation of implant and prosthetic survival and complication rates, the minimum follow-up time was set at 12 months. The reported treatment outcomes had to include at least one of the following parameters: clinical, radiographic, or patient-centered outcomes of computer-assisted implant dentistry in humans.

Exclusion Criteria

Studies not meeting all inclusion criteria were excluded from the review. Case reports with fewer than five patients were not included for the analysis of accuracy or for clinical studies. Studies with zygoma implants, pterygoid implants, or mini-implants for orthodontic purposes were excluded. Publications were also excluded if the study exclusively reported on the radiographic planning.

Data Extraction

Two reviewers independently extracted the data using data extraction tables. Any disagreements were resolved by discussion. Data were only included in the analysis if there was agreement between the two reviewers.

Statistical Analysis

The statistical analysis comprised two parts*: (1)* a summary of the evidence from the accuracy studies and *(2)* a summary of the outcomes reported from the clinical studies. For summarizing the accuracy

studies, methods appropriate for meta-analysis of the mean values observed in groups of a given size were used. The ideal information for this would be to have the mean and its standard error and then to perform inverse variance weighted fixed or random effects meta-analysis. The standard error (SE) can be derived from the observed standard deviation (SD) of the accuracy values using the formula: $SE = SD/\div\overline{n}$, where n is the number of observations in the study. Therefore, when the mean or the standard deviation was not reported in the original article, it was imputed using the available information according to the formulae given in Table 3 of the research methods article by Hozo and colleagues.[8] Heterogeneity between studies was assessed with the I^2 statistic as a measure of the proportion of total variation in estimates that is due to heterogeneity,[9] where I^2 values of 25%, 50%, and 75% are considered as cutoff points for low, moderate, and high degrees of heterogeneity. Meta-regression analyses were done to perform formal statistical tests of the differences in mean accuracy according to the groupings of the studies.[10]

For summarizing the outcomes reported from the clinical studies, methods described in detail in a systematic review of fixed partial dentures were used.[1] Briefly, for each report the event rate was calculated by dividing the number of events (failures or intraoperative complications) in the numerator by the total exposure time in the denominator. Total exposure time was approximated by multiplying the number of implants by the mean follow-up time reported in the studies. For further analysis, the total number of events was considered to conform to a Poisson distribution for a given sum of exposure time, and Poisson regression with a logarithmic link function and total exposure time per study as an offset variable were used. To assess heterogeneity of the study-specific event rates, the Spearman goodness-of-fit statistics and associated *P* value were calculated. If the goodness-of-fit *P* value was below .05, indicating heterogeneity, random-effects Poisson regression (with g-distributed random effects) was used to obtain a summary estimate of the event rates.

Summary estimates and 95% confidence intervals (95% CI) and *P* values from meta-regression or Poisson regression for assessing differences in outcomes between groups of studies are reported. All analyses were done using Stata (StataCorp) version 10.

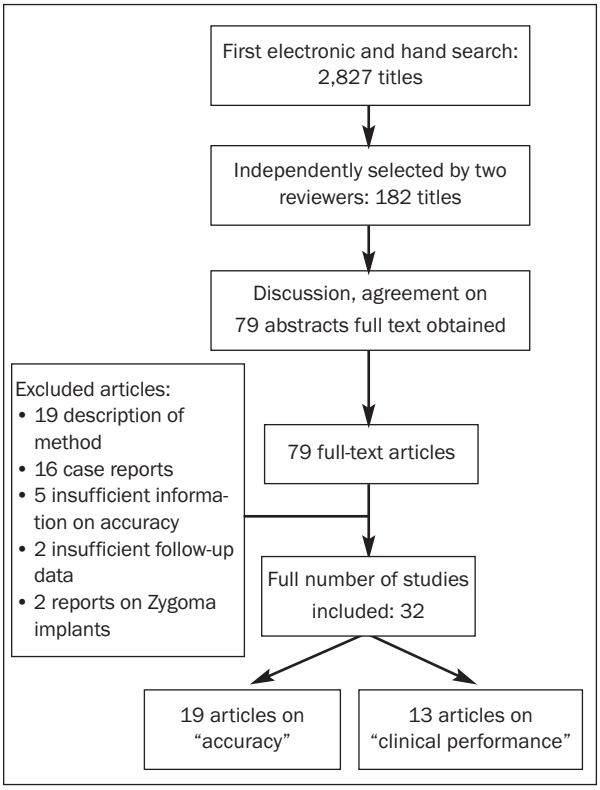

Fig 1 Literature search and selection of articles.

RESULTS

After initial identification of a total of 2,827 titles, the exclusion of irrelevant studies was performed by two independent reviewers, who reduced the number of titles to 182. After review of these manuscripts' abstracts, 85 publications were selected for full-text evaluation. Thirteen clinical and 19 accuracy studies were ultimately used for this review (Fig 1).

Table 1 Distribution and Number of Specimens (Humans, Cadavers, or Models) According to Location and Dentition

		Maxilla				Mandible							
										Edentulous			
	Specimens	Total	Edent	Part edent	Dentition unknown	Total	Edent	Part edent	Unknown	Total	Unknown	Part edent	Unknown
Model	112	46		20	26	56	29	11	16	30	1	31	10
Cadaver	6	1			1	3			3				2
Human	33					29	21		8	41	20		4
Total	151	47		20	27	88	50	11	27	71	21	31	16

Edent = edentulous; Part edent = partially edentulous.

Table 2 Extracted Data on Accuracy

	Study	Year	System	Principle	Study design	Positioning method	Sites (n)	Direction	Error entry (mm)			Error apex SD (mm)			Error angle (degrees)			Error height (mm)		
									Mean	SD	Max	Mean	SD	Max	Mean	SD	Max	Mean	SD	Max
1	Di Giacomo et al[24]	2005	SimPlant	Guide	Human	Implant	21		1.45	1.42	4.50	2.99	1.77	7.10	7.25	2.67	12.20	-	-	-
2	Sarment et al[26]	2003	SimPlant	Guide	Model	Bore	50		1.50	0.70	1.80	2.10	0.97	3.70	8.00	4.50	8.70	-	-	-
				Guide	Model	Bore	50		0.90	0.50	1.20	1.00	0.60	1.60	4.50	2.00	5.40	-	-	-
3	Van Assche et al[27]	2007	Nobel	Guide	Cadaver	Implant	12		1.10	0.70	2.30	1.20	0.70	2.40	1.80	0.80	4.00	-	-	-
4	van Steenberghe et al[28]	2002	Nobel	Guide	Cadaver	Implant	16		0.80	0.30	-	0.90	0.30	-	1.80	1.00	-	-	-	1.10
5	Kusumoto et al[11]	2006	PHANToM	Navigation	Model	Bore	6	x-axis	0.12	0.06	-	-	-	-	-	-	-	-	-	-
								y-axis	0.20	0.18	-	-	-	-	-	-	-	-	-	-
6	Chiu et al[12]	2006	IGI, DenX	Navigation	Model	Bore	80		0.43	0.56	2.23	-	-	-	4.00	3.50	13.60	0.37	0.28	1.04
7	Kramer et al[25]	2005	IGI, DenX	Navigation	Model	Implant	40		-	-	0.30	-	-	-	-	-	4.00	-	-	0.30
8	Brief et al[29]	2001	IGI, DenX	Navigation	Model	Bore	38	x-axis	0.50	-	1.10	0.60	-	1.10	-	-	-	0.20	-	0.70
								y-axis	0.30	-	0.90	0.30	-	1.00	-	-	-	0.20	-	0.70
				Navigation	Model	Bore	8	x-axis	0.30	-	0.60	0.20	-	0.30	-	-	-	0.20	-	0.50
								y-axis	0.20	-	0.50	0.60	-	1.20	-	-	-	0.20	-	0.50
9	Widmann et al[5]	2005	Treon	Navigation	Model	Bore	112		0.42	0.26	1.00	-	-	-	-	-	-	0.25	0.12	0.60
10	Widmann et al[30]	2007	Treon	Guide	Model	Bore	56		-	-	-	0.50	0.30	1.20	-	-	-	-	-	-
				Guide	Model	Bore	56		-	-	-	0.60	0.30	1.40	-	-	-	-	-	-
				Navigation	Model	Bore	56		-	-	-	0.40	0.30	1.00	-	-	-	-	-	-
11	Wittwer et al[31]	2006	Treon	Navigation	Human	Implant	80		1.20	0.80	3.40	0.80	0.60	2.00	-	-	-	-	-	-
12	Gaggl et al[14]	2002	SNM	Navigation	Model	Bore	60		0.20	-	-	-	-	-	-	-	-	0.11	0.22	0.60
				Navigation	Model	Implant	60		0.20	-	-	-	-	-	-	-	-	0.25	0.26	0.90
13	Gaggl et al[13]	2001	SNM	Navigation	Model	Bore	100		-	-	-	-	-	-	-	-	-	0.14	0.05	0.23
14	Wanschitz et al[32]	2002	VISIT	Navigation	Cadaver	Implant	20	Buccal	0.55	0.31	1.50	1.44	0.79	3.50	-	-	-	-	-	-
								Lingual	0.49	0.38	1.40	1.36	0.70	3.20	-	-	-	-	-	-
15	Wanschitz et al[33]	2002	VISIT	Navigation	Cadaver	Implant	15	Buccal	0.58	0.40	1.40	0.79	0.71	3.10	3.55	2.07	10.40	-	-	-
								Lingual	0.57	0.49	1.80	0.77	0.63	2.90	-	-	-	-	-	-
16	Wagner et al[34]	2003	VISIT	Navigation	Human	Implant	32	Lingual	1.00	0.50	2.60	1.30	0.90	3.50	6.40	-	17.40	-	-	-
								Buccal	0.80	0.30	2.10	1.10	0.90	3.40	-	-	-	-	-	-
17	Hoffmann et al[15]	2005	Vector Vision	Navigation	Model	Bore	240		0.95	0.25	-	-	-	-	1.35	0.42	-	0.97	0.34	-
18	Brief et al[16]	2005	Robodent	Navigation	Model	Bore	15		0.35	0.17	0.75	0.47	0.18	0.72	2.12	0.78	3.64	0.32	0.21	0.71
			IGI, DenX	Navigation	Model	Bore	15		0.65	0.58	2.37	0.68	0.31	1.22	4.21	4.76	20.43	0.61	0.36	1.43
19	Wittwer et al[17]	2007	VISIT	Navigation	Human	Implant	32	Buccal	1.00	0.50	2.00	0.60	0.20	0.90	-	-	-	-	-	-
								Lingual	0.70	0.30	1.20	0.70	0.30	1.00	-	-	-	-	-	-
			Treon	Navigation	Human	Implant	32	Buccal	1.00	0.50	2.40	0.80	0.60	2.00	-	-	-	-	-	-
								Lingual	1.20	0.80	3.40	0.70	0.50	1.60	-	-	-	-	-	-

Table 3 Systems Used in Studies Reporting on Accuracy

System	No. of studies
Dynamic	
IGI, DenX	5
VISIT	4
Treon	4
SMN, Zeiss	2
Vector Vision	1
Robodent	1
PHANToM	1
Static	
SimPlant	2
Nobel Biocare	2

Table 4 Distribution and Number of Evaluated Sites in Terms of Accuracy

	No. of sites	No. of studies
Navigation	1,041	14
Guide	261	5
Model	1,042	10
Cadaver	63	4
Human	197	5
Drill	942	10
Implant	360	9

Accuracy Studies

Literature. Nineteen articles from the systematic review, published from 2001 to 2007, provided useful information about accuracy in computer-assisted implant dentistry. Twelve research groups from seven countries were involved.

Material. Eleven in vitro studies were performed on models, mostly made of acrylate. Of the remaining eight studies, four reported the use of human cadavers and four were available as clinical studies with a total of 45 patients. In 16 of these patients, implants were placed in an edentulous mandible, in 20 cases in edentulous jaws without further specification, and in the remaining cases the location was not reported (Tables 1 and 2).

Systems. Nine different computer-assisted implantation systems were tested (Table 3). The majority of the systems were "dynamic" systems, based on intraoperative feedback produced by recording the position of the handpiece with infrared cameras (six systems) or by haptic feedback (one system, PHANToM[11]). These navigational systems were used in 19 studies at 1,041 implant sites (Tables 2 and 4). Two of the nine systems used drill guides, based on the computer-assisted implant planning; 261 implant sites were drilled or implanted with the assistance of a drill guide.

Drillings/Implants/Positions and Their Evaluation. A total of 1,302 positions were evaluated (Tables 2 and 4); 360 of the positions were measured on implants, with 100 of these placed in models, 63 in human cadavers, and 197 in humans. The remaining 942 positions were assessed on drill holes made in models. In the majority of the studies (14 studies) a CT scan was performed to assess the accuracy, whereas only in three studies was the position of the drill holes or implants directly measured in models.[12–14] Calculation of the error by registration of the handpiece or 3D probe position after drilling and by coordinate measurements was used in two studies.[15,16]

To assess the accuracy of the implant systems, the following parameters were selected:

a. Deviation error in a horizontal direction at the entry point of the drill or implant
b. Beviation error in a horizontal direction at the apex of the drill or implant
c. Deviation in height (vertical direction)
d. Deviation of the axis of the drill or implant

For the first two parameters, the extracted data allowed a statistical analysis (Table 2). Regarding the latter two parameters, data were insufficient for a meta-analysis.

(a and b) Error at Entry Point and Apex (Figs 2 to 9). The overall mean error at the entry point was 0.74 (95% CI: 0.58 to 0.90) mm with a maximum of 4.5 mm, while the mean error at the apex was 0.85 (95% CI: 0.72 to 0.99) mm with a maximum of 7.1 mm.

With systems using surgical guides, the mean error was 1.12 (95% CI: 0.82 to 1.42) mm (max 4.5 mm) at the entry point and 1.2 (95% CI: 0.87 to 1.52) mm (max 7.1 mm) at the apex. For dynamic intraoperative navigation (14 studies) the mean error was 0.62 (95% CI: 0.43 to 0.81) mm (max 3.4 mm) at the entry point and 0.68 (95% CI: 0.55 to 0.80) mm (max 3.5 mm) at the apex. The dynamic systems showed a statistically significantly higher mean precision by 0.5 mm ($P = .0058$) at the entry point and by 0.52 mm ($P = .0354$) at the apex.

Implants positioned in humans showed a higher mean deviation at entry point and apex compared to implants or drills in cadaver studies (Δ entry = 0.32 mm, $P = .0497$; Δ apex = 0.02 mm, $P = .8546$) and studies on models (Δ entry = 0.43 mm, $P = .0015$; Δ apex = 0.33 mm, $P = .1245$).

The mean error was significantly higher in studies in which the position of implants was measured, compared to studies in which the position of drill holes was assessed (Δ entry = 0.3 mm, $P = .0103$; Δ apex = 0.33 mm, $P = .0578$).

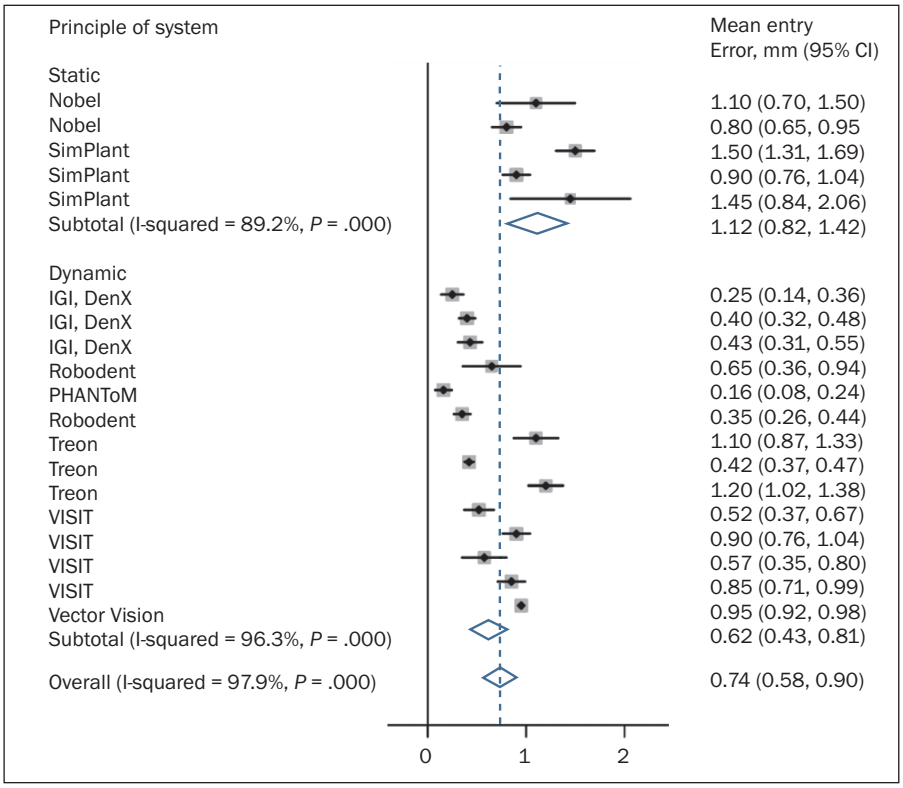

Fig 2 Mean deviation at entry point, stratified by principle of system (static vs dynamic).

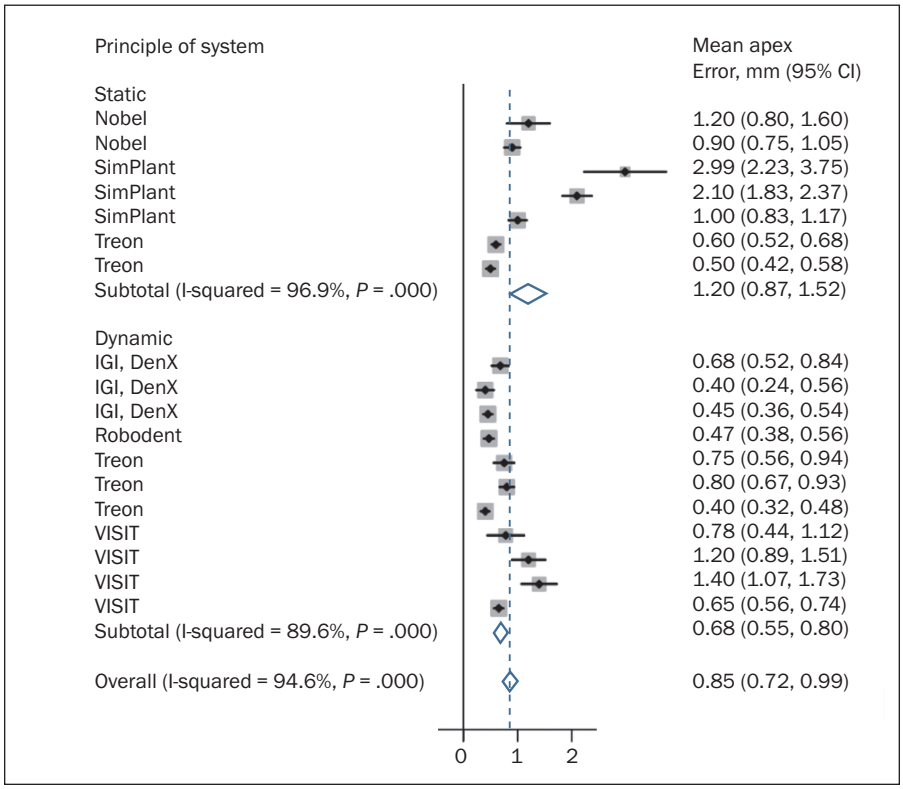

Fig 3 Mean deviation at apex, stratified by principle of system (static vs dynamic).

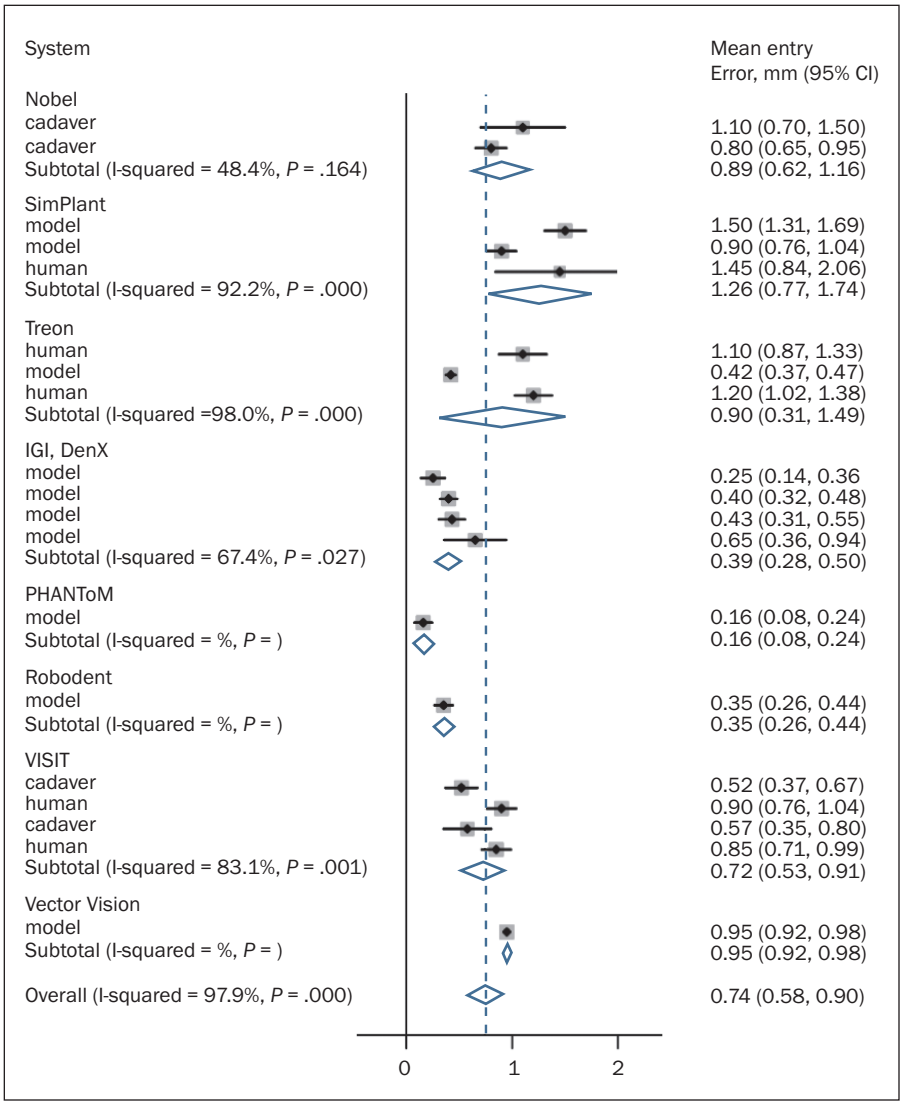

Fig 4 Mean deviation at entry point, stratified by system.

(c) Error in Height (Table 2). The mean error in height was reported in seven studies, all of which were performed on models using a dynamic implant system. Only one of these seven studies used implants[14]; all others used drill holes for the evaluation of the system accuracy. The median error in height was 0.23 mm, with a maximum of 1.43 mm.

(d) Error in Angulation (Table 2). Information about the deviation in angulations was found in nine studies. The median error in angulation was 4.0 degrees, with a maximum of 20.43 degrees.

Clinical Studies

Literature. Thirteen human studies identified by systematic review and published from 2001 to 2007 provided information about clinical, radiographic, or patient-centered outcomes in computer-assisted implant dentistry. Only two studies were randomized controlled clinical studies,[17,18] whereas the remaining 11 studies were prospective studies.

Material. A total of 580 patients with 1,243 implants were treated with computer-assisted implant dentistry and have been included in this review. The mean age was 56.1 years, with a range from 18 to 89 years. The mean follow-up period was 7.7 (0 to 26.4) months. The majority of the studies reported on edentulous patients in the maxilla and mandible. However, there were also studies treating single-tooth gaps and partially edentulous patients.

In 6 of the 13 included studies an immediate restoration of the implants was performed. In addition, all of these implants were inserted using a flapless procedure (Table 5).

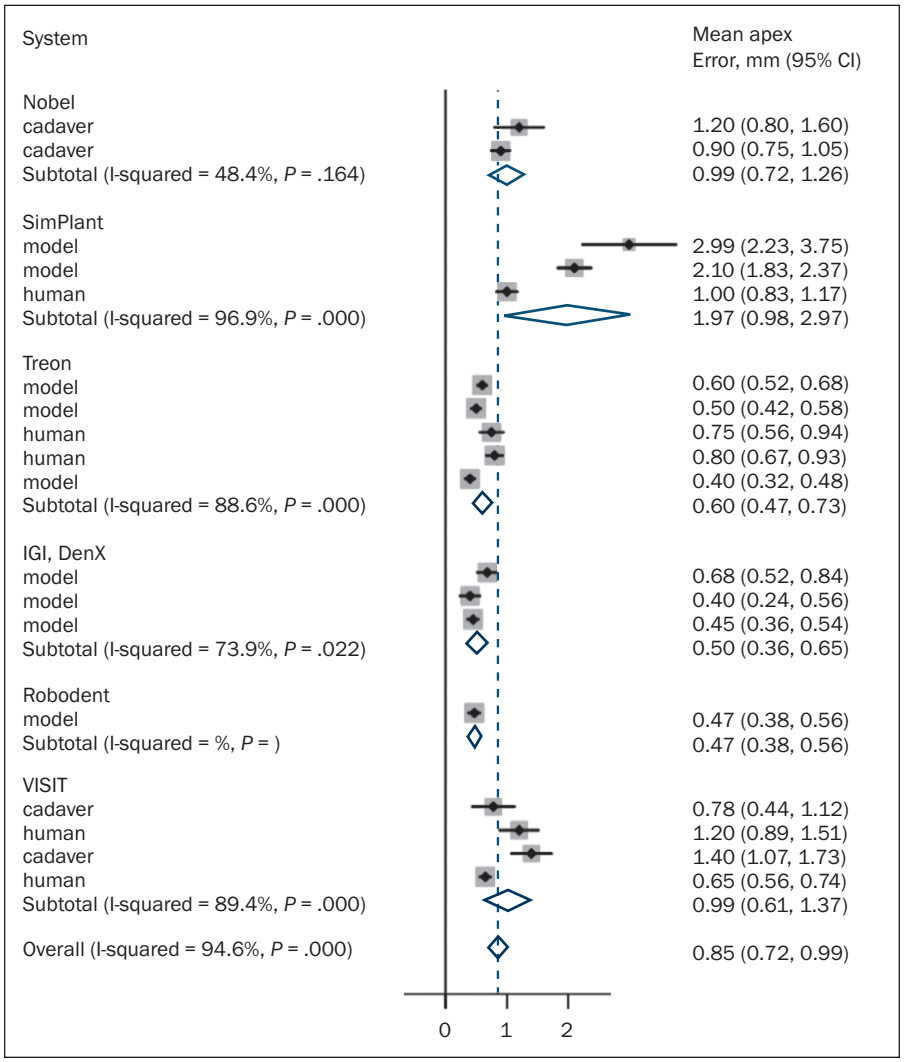

Fig 5 Mean deviation at apex, stratified by system.

Systems. The included studies reported about 10 different dynamic and static systems (Table 6). In all except one study,[19] in which a cone beam technique was used for preoperative planning, a CT scan was performed for that purpose.

Treatment Outcomes. The majority of the studies described intraoperative complications and reliability of the implant placement after computer-assisted implant planning. Other studies have looked at the assessment of pain, the operating room time, and marginal bone remodeling. Due to the short mean observation time, it was difficult to assess implant survival or success rates. However, 5 of the 13 studies reported an observation period of at least 12 months (Table 7). These studies have been included in the statistical analysis.

The mean annual implant failure rate for all 5 studies was 3.36%, ranging from 0% to 8.45%. In immediately restored cases the failure rate was significantly lower ($P = .0018$) by a factor of 5. A delayed restoration protocol was used in only one study with 29 patients and 71 implants.[20]

Ten of 13 studies reported on intraoperative complications, including interocclusal distances that were too limited to perform guided implant placement, limited primary stability of the inserted implants, or the need for additional grafting procedures (see Table 5). Intraoperative complications or unexpected events were observed in 4.6% (95% CI: 1.2% to 16.5%) of the implant placements. Dynamic systems showed a 2.2 times higher incidence of complications, although this ratio was not significant ($P = .5282$). In flapless procedures, the rate ratio for complications was 0.15 (95% CI: 0.03 to 0.88, $P = .035$), 7 times lower compared to procedures with an open flap. In edentulous patients, the rate ratio for complications was 0.23 (95% CI: 0.02 to 2.6, $P = .237$), 4 to 5 times lower than in partially edentulous patients.

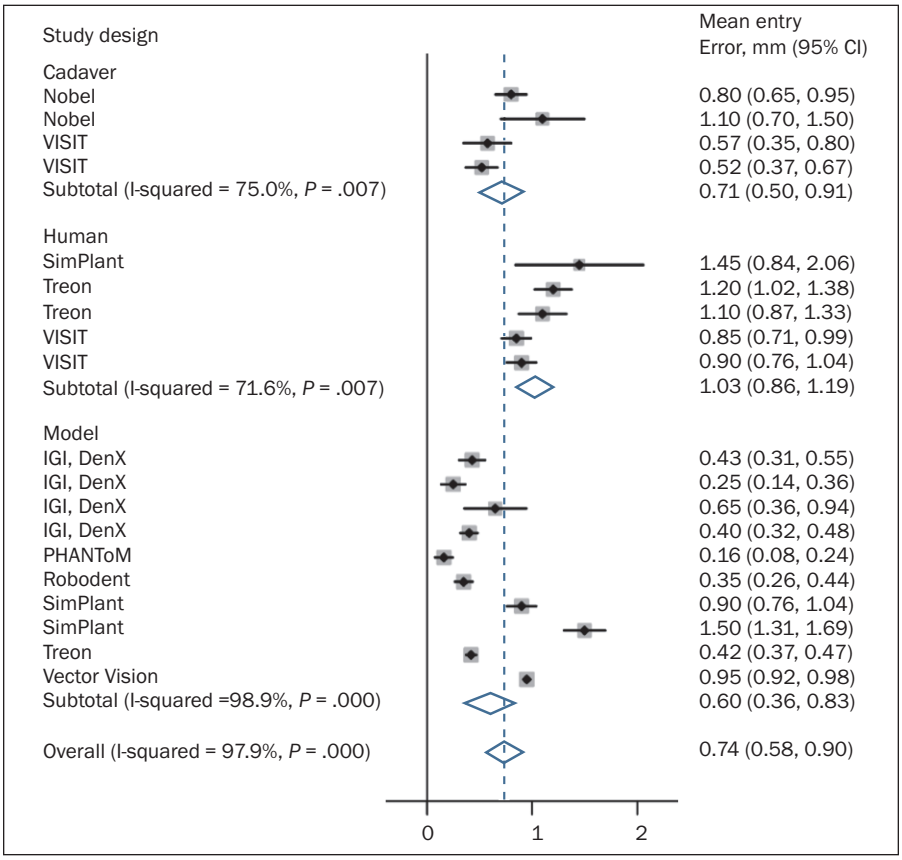

Fig 6 Mean deviation at entry point, stratified by study design (cadaver, human, model).

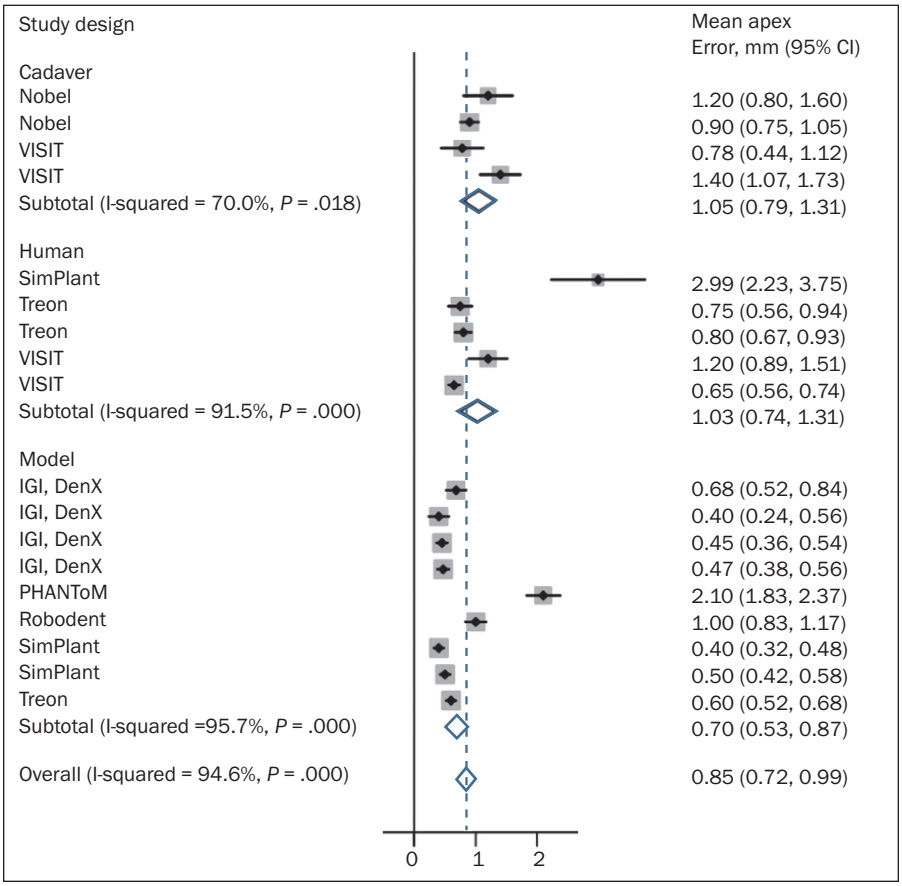

Fig 7 Mean deviation at apex, stratified by study design (human, cadaver, model).

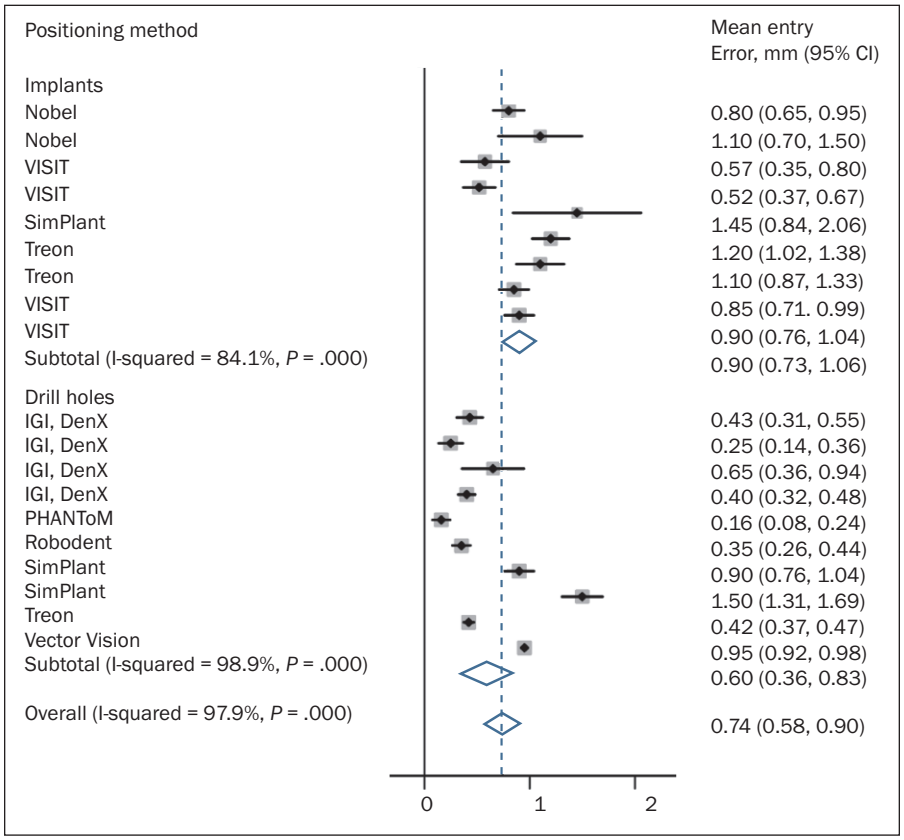

Fig 8 Mean deviation at entry point, stratified by positioning method (implants vs drill holes).

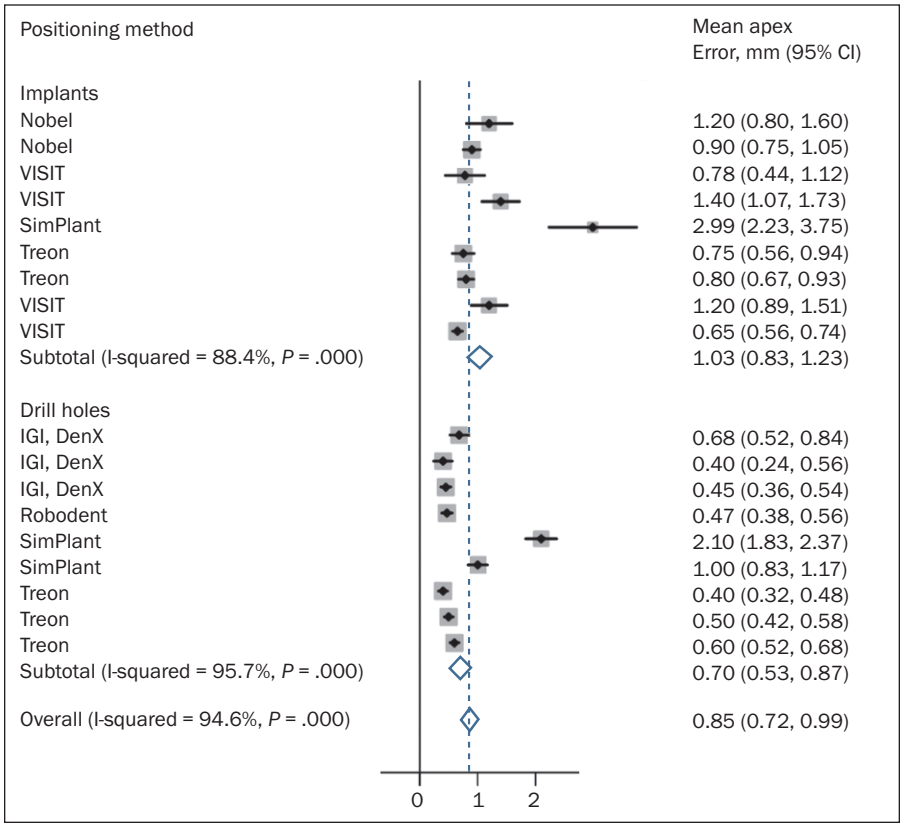

Fig 9 Mean deviation at apex, stratified by positioning method (implants vs drill holes).

Table 5 Clinical Studies

Study		Year	Study design	No. of patients	No. of implants after dropout	Age range (y)	Mean age (y)	Follow-up period (mo)	System	Dynamic intraop nav	Single tooth	Part edent	Comp edent	Max	Mand	Implant type	Flapless	Imm rest	No. of implant complications intraop	No. of implant failures	No. of prosthetic failures
1	Siessegger et al[35]	2001	Prospective	5	18	NR	NR	0	Vector Vision 2	1	0	1	1	1	0	Frialit 2	0	0	7	NR	NR
2	Mischkowski et al[22]	2006	Prospective	142	501	NR	NR	6	Med3D	0	1	1	1			NR	NR	0	0	8 (1.31%)	NR
			Prospective	21	78	NR	NR	6	coDiagnostiX	0	1	1	1			NR	NR	0	0		NR
			Prospective	5	32	NR	NR	6	SimPlant	0	1	1	1			NR	NR	0	0		NR
			Prospective	20	71	NR	NR	6	Robodent	1	1	1	1			NR	NR	0	0	4 (2.96%)	NR
			Prospective	18	64	NR	NR	6	Vector Vision 2	1	1	1	1			NR	NR	0	0		NR
3	Wittwer et al[31]	2006	Prospective	20	78	53–75	61.4	4	Stealth Station Treon	1	0	0	1	0	1	Ankylos	1	0	2	2	NR
4	Wittwer et al [36]	2007	Prospective	25	88	55–77	62.1	24	Stealth Station Treon	1	0	0	1	0	1	Ankylos	1	1	4	2	0
5	Wittwer et al [17]	2007	RCT	16	64	56–77	63.4	0	Stealth Station Treon/VISIT	1	0	0	1	0	1	Ankylos	1	1	0		
6	Wittwer et al [37]	2007	Prospective	20	80	56–77	64.3	0	VISIT	1	0	0	1	0	1	Ankylos	1	1	2	0	NR
7	Fortin et al[18]	2006	RCT	60	152	19–82	50	0.25	CADImplant	0	0	1	1			NR	1	NR	NR	NR	NR
8	van Steenberghe et al[38]	2005	Prospective	27	164	34–89	63	12	NobelGuide	0	0	0	1	1	0	Nobel Biocare	1	1	0	0	0
9	Fortin et al[39]	2004	Prospective	10	NR	NR	NR	12	CADImplant	0	0	0	1			NR	1	1	NR	0	0
10	Fortin et al[40]	2003	Prospective	30	95	18–70	44	0	CADImplant	0	0	1	1			NR	0	0	14	NR	NR
11	Nickenig and Eitner[19]	2007	Prospective	102	250	22–58	40.4	0	coDiagnostiX	0	1	1	1			NR	1	0	13	0	NR
12	Sanna et al [21]	2007	Prospective	30	183	38–74	56	26.4	NobelGuide	0	0	0	1			Nobel Biocare	1	1	NR	9 (4.9%)	NR
13	Vrielinck et al[20]	2003	Prospective	29	71	37–71	56.4	14	SurgiGuide, Materialise	0	0	0	1	1	0	Nobel Biocare	0	0	0	6	0
	Total			580	1,243		56.1	7.7		5	6	9	17	3			4	0	9	6	42

nav = navigation; Part edent = partially edentulous; Comp edent = completely edentulous; Max = maxilla; Mand = mandible; Imm rest = immediate restoration; NR = not reported.

Table 6 Systems Used in Studies Reporting on Clinical Outcome

System	No. of studies	No. of patients	No. of implants
Dynamic			
VISIT	2	28	122
Treon	3	53	198
Vector Vision	2	23	82
Robodent	1	20	71
Static			
SimPlant	1	5	32
SurgiGuide	1	29	71
Nobel Guide	2	57	347
coDiagnostiX	2	123	325
CADImplant	3	100	247
Med3D	1	142	501

Table 7 Implant Failures, Follow-up Period and Annual Failure Rates

Study	Year	Principle	No. of patients	No. of implants after dropout	No. of failures	% failures	Follow-up period (mo)	Failure rate (events per 100 y)
Wittwer et al[36]	2007	Navigation	25	88	2	2.27%	24	1.1
van Steenberghe et al[38]	2005	Guide	27	164	0	0.00%	12	0
Fortin et al[39]	2004	Guide	10	NR	0	0.00%	12	0
Sanna et al[21]	2007	Guide	30	183	9	4.92%	26.4	2.2
Vrielinck et al[20]	2003	Guide	29	71	6	8.45%	14	7.2
Total			121	506	17	3.36%		
Summary rate (95% CI)								2.4 (0.8–7.6)

NR = not reported.

One randomized clinical trial compared pain experience after implant placement with either an open-flap or a flapless surgical procedure.[18] The results showed a significant difference in pain measurements, with higher scores on the visual analog scale with the open-flap surgery.

Very limited data are available regarding prosthetic complication rates.

DISCUSSION

This review systematically assessed the literature regarding accuracy and clinical performance of computer-assisted implant dentistry. In the dental literature, 28 different image guidance systems are described (Appendix, Table 8). Based on five included clinical studies with a total of 506 implants using computer-assisted implant dentistry, it was demonstrated that the mean annual failure rate was 3.36% (0% to 8.45%) after an observation period of at least 12 months. As assessed by 19 clinical and preclinical studies, the accuracy at the entry point revealed a mean error of 0.74 mm, with a maximum of 4.5 mm, while at the apex the mean error was 0.85 mm, with a maximum of 7.1 mm.

Clinical Outcomes

It is important to distinguish between clinical studies reporting about dynamic navigation systems and about static template-based guidance systems. The majority of clinical studies have investigated the template-based guidance systems. The overall mean survival rate of 96.6% after 1 year is considered to be rather high. However, it is difficult to compare with other systematic reviews reporting implant survival rates ranging from 95.4% (implant-supported fixed partial dentures) to 96.8% (single-tooth implants) after 5 years, due to the lack of long-term data for the guided implant placements.[1,2] Only one study is available with an observation period of more than 2 years, and this reveals an implant survival rate of 95.1% using a template-based guidance system and a prefabricated fixed prosthesis that was immediately loaded.[21] To evaluate a new operation technique, it is important to know not just the implant survival rate but also the practicality of the method in clinical practice. In 4.6% of the cases, intraoperative complications or unexpected events were reported, including *(1)* interocclusal distances that were too limited to perform guided implant placement, *(2)* limited primary stability of the inserted implants, or *(3)* the need for additional grafting procedures. Since they are not

always reported and there is no consistent definition of a complication or an unexpected event, the data must be interpreted with caution. In addition, the rate for intraoperative complications and unexpected events was six times lower in flapless procedures. It might be possible that due to the lack of visual access, the complication rate in terms of implant malpositioning and the need for additional grafting procedures might be underestimated. However, this finding is only based on very limited data and should be further evaluated in future study designs.

It is clearly beyond the intent or scope of this review to judge the benefits or merits of navigation versus template-based guidance systems. Only one included study performed a comparison of the two.[22] It was reported that the static approach has a clear advantage due to the uncomplicated intraoperative handling of the surgical templates and the less expensive equipment. Additionally, the process can be planned by the surgeon and/or coworkers, or in cooperation with the company which is responsible for the fabrication of the templates. In contrast, with the dynamic system the time spent on presurgical set-up and intraoperative application can be considered significantly longer, partly due to the navigation device. High purchase and maintenance costs of the systems have to be taken into consideration.[22] In general, today there seems to be a trend toward the static template-based guidance systems in dental implantology.

A consensus workshop organized by the European Association of Osseointegration raised several questions, including which clinical indication would potentially benefit from computer-assisted implant dentistry.[23] The present systematic review included studies reporting about edentulous, partially edentulous, and single-tooth replacement cases. The majority of the included studies reported about edentulous cases. The reason may be the better cost-benefit ratio and the better acceptance of additional radiographic examinations (CT scans) in patients with completely edentulous ridges compared to single-tooth replacements. However, in the future, reductions in radiation doses through improved radiographic techniques (ie, cone beam technique) and greater accuracy might increase the number of indications for computer-assisted implant placement.

Accuracy

Computer-assisted implant dentistry has often been recommended for flapless procedures and for implant placements in situations with a limited amount of bone or proximity to critical anatomical structures. Hence, it is of utmost importance to know the accuracy of the dynamic and static systems available for implant dentistry. In this systematic review, the accuracy in computer-assisted implant dentistry was assessed by including various methods of evaluation (mostly CT, but also direct measurements of sectioned models or registration of the handpiece position), and by including preclinical and clinical models. In general, the accuracy was better in studies with models and cadavers than in studies with humans. This can be explained by better access, better visual control of the axis of the osteotomy, no movement of the patient, and no saliva or blood in the preclinical models. There was no significant difference between cadavers and models; therefore, the influence of the material (bone versus acrylic) might be negligible for testing the accuracy in a preclinical model. However, it is recommended that the accuracy be assessed in clinical situations. This recommendation is supported by the results of this review, in which the highest number of deviations were revealed in human studies compared to preclinical models (see Table 7). In addition, it is more important to report the maximum deviation, which is crucial to prevent damage of anatomical structures, than to report the mean deviation.

One included study using a static template-based system reported a maximum deviation of 4.5 mm at the entry point.[24] This is by far the highest value for deviation reported in all studies in the present review. The authors proposed that this difference might result from movements of the surgical guide during implant preparation. They suggested further improvements to provide better stability of the template during surgery when unilateral bone-supported and non–tooth-supported templates are used.[24]

In the present systematic review, the overall mean error at the entry point was 0.74 mm. To interpret this value it is important to know the accuracy of manual implant preparation. Two preclinical studies performed on acrylic models compared the accuracy of two dynamic navigated systems with conventional implant preparation.[16,25] In one study, the reported maximum error at the entry point ranged from 0.8 to 1 mm for the conventional insertion and was 0.6 mm for the navigated insertion.[25] The other study reported a mean error at the entry point of 1.35 mm for manual implantation and 0.35 to 0.65 mm (RoboDent and IGI DenX Systems) for dynamic navigated implant placement. These values are in accordance with the mean error at the entry point in preclinical models revealing a difference of 0.6 mm in the present review. Both studies demonstrated a statistically significantly higher accuracy for the navigated systems compared to the manual implant placement.[16,25] However, this comparison was only performed on dynamic navigated systems, and no data for static template-based systems are available. This is even more important because the

dynamic systems in the present systematic review provided greater accuracy than the static systems. This difference might be explained by the fact that static template-based systems were more often used clinically rather than in preclinical models, which have provided better accuracy.

Because of different study designs (human versus cadaver or model, drill holes versus implants, different evaluation methods), it is not possible to identify one system as superior or inferior to others.

A series of errors during the entire diagnostic and operative procedure might contribute to an accumulation of minor errors, leading to larger deviations of the implant position. The reproducibility of the template position during radiographic data acquisition and during implantation is a delicate issue, especially in edentulous patients.

In addition, it is important to realize that computer-assisted implant surgery is a new field of research that is undergoing rapid development and improvements in clinical handling properties and accuracy. Hence, the systems used today in clinical practice might demonstrate greater accuracy and might have solved some of the above-mentioned problems encountered with earlier versions, but these data are not yet available in the dental literature. This rapid advancement in computer technology should be considered when evaluating older reports of various systems, since those that were tested may not bear much similarity to current offerings.

CONCLUSION

It is concluded from this systematic literature search that a large number of different computer-assisted guided implant systems are available today in clinical practice. Differing levels and quantity of evidence were noted to be available, revealing a high mean implant survival rate of 96.6% after only 12 months of observation in different clinical indications. In addition, the mean percentage of intraoperative complications and unexpected events was 4.6%. The accuracy of these systems depends on all cumulative and interactive errors involved, from data-set acquisition to the surgical procedure. The meta-analysis of all preclinical and clinical studies revealed a total mean error of 0.74 mm at the entry point and 0.85 mm at the apex. Future long-term clinical data are necessary to identify clinical indications and to justify additional radiation doses, efforts, and costs associated with computer-assisted implant surgery. There is not yet evidence to suggest that computer-assisted surgery is superior to conventional procedures in terms of safety, outcomes, morbidity, or efficiency.

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APPENDIX

Review of Systems for Computer-Assisted Implant Dentistry

From information derived from review of the literature, combined with Internet searches and additional commercial sources, a compilation of computer-based products for implant surgery was created. It is important to clarify and distinguish the types of systems based on very specific definitions published in the *Glossary of Oral and Maxillofacial Implants* (GOMI; Chicago: Quintessence, 2007).

- ***Computer-aided design/Computer-assisted manufacture (CAD/CAM):*** Computer technology used to design and manufacture various components.
- ***Image guidance:*** General technique of using preoperative diagnostic imaging with computer-based planning tools to facilitate surgical and restorative plans and procedures.
- ***Imaging guide:*** Scan to determine bone volume, inclination and shape of the alveolar process, and bone height and width, which is used at a surgical l site.
- ***Surgical navigation:*** Computer-aided intraoperative navigation of surgical instruments and operation site, using real-time matching to the patients' anatomy. During surgical navigation, deviations from a preoperative plan can be immediately observed on the monitor.
- ***Computer-aided navigation****:* Computer systems for intraoperative navigation, which provide the surgeon with current positions of the instruments and operation site on a three-dimensional reconstructed image of the patient that is displayed on a monitor in the operating room. The system aims to transfer preoperative planning on radiographs or computed tomography scans of the patient, in real-time, and independent of the position of the patient's head.
- ***Surgical template:*** Laboratory-fabricated guide based on ideal prosthetic positioning of implants used during surgery. Also called *surgical guide*.
- ***Three-dimensional guidance system for implant placement:*** A computed tomography (CT) scan is performed to provide image data for a three-dimensional guidance construct for implant placement. A guide is a structure or marking that directs the motion or positioning of something, thus in implant dentistry this term should not be used as a synonym for *surgical implant guide*. A radiographic guide is rather used as a positioning device in intraoral radiography.

For the purpose of this consensus review, some GOMI definitions were clarified:

- ***Computer-guided (static) surgery****:* Use of a static surgical template that reproduces virtual implant position directly from computerized tomographic data and does not allow intraoperative modification of implant position.
- ***Computer-navigated (dynamic) surgery:*** Use of a surgical navigation system that reproduces virtual implant position directly from computerized tomographic data and allows intraoperative changes in implant position.

All systems incorporate planning of implant positions on a computer, using various software tools. These plans are then converted into surgical guides or used in other positioning systems in a variety of methods. In general, these implant positioning devices can be categorized into "static" and "dynamic" systems. "Static" systems are those that communicate predetermined sites using "surgical templates" or implant guides in the operating field. Therefore, "static systems" and "template-based systems" are synonymous. Alterations to implant position or deviations from the prefabricated template can be accomplished "free-hand".

Dynamic systems communicate the selected implant positions to the operative field with visual imaging tools on a computer monitor, rather than intraoral guides. The dynamic systems include "surgical navigation" and "computer-aided navigation" technologies. With these, the surgeon may alter the surgical procedure and implant position in real time using the anatomical information available from the preoperative plan and CT scan. Since the surgeon can see an avatar of the drill in a three-dimensional relationship to the patient's previously scanned anatomy during surgery, modifications can be accomplished with significantly more information. In essence, the navigation system provides a virtual surgical guide or template that may be altered when conditions indicate.

Table 8 is a compilation of currently available image guidance systems and those that appear to be in development or have some scientific publications available for review. The commercially available systems have been divided into two categories. The first section represents 22 software systems that are available for radiographic diagnosis and also generally provide for fabrication of surgical guides. The systems fall into the category of "three-dimensional guidance systems for implant placement," permitting implant planning from patient CT or CBCT scans. These products offer computer-based diagnostic and planning tools that permit enhancement, manipulation, and analysis of a patient's digital scan.

Table 8 Currently Available Systems in Computer-Assisted Implant Dentistry

Application	Website	Company	Virtual implant planning	Guide	Drill guide production	Notes
Surgical guides (static)						
3D-Doctor	www.ablesw.com	Able Software, USA	yes	Models	CDD	
Biodental Models	www.biomodel.com	BioMedical Modeling, USA	yes	Models	RP	
Implant3D	www.implant3d.com	Media Lab, Italy	yes	Models	RP	Create stereolithographic model
CyrtinaGuide	www.cyrtina.nl	Oratio, Netherlands	yes	Surgical guide	RP	
DentalSlice	www.bioparts.com.br	BioParts, Brazil	yes	Surgical guide	RP	
EasyGuide	www.keystonedental.com	Keystone Dental, USA	yes	Surgical guide	CDD	
GPIS		GPI Technology, Germany	Simplant/ IVS	Surgical guide	CDD	
ILS	www.tactile-tech.com	Tactile Technologies , Israel	yes	Surgical guide	Custom drilling tubes	Under development
ILUMA DigiGuide	www.imtec.com	IMTEC, USA	yes	Surgical guide	RP	Specific for MDI implants
Impla 3D	www.sdginnovations.com	Schutz Dental Group	yes	Surgical guide	CDD	
InVivoDental	www.anatomage.com	Anatomage , USA	yes	Surgical guide	CDD	Under development
AnatoModel	www.anatomage.com	Anatomage, USA	yes	Surgical guide	CDD	See EasyGuide
Implant 3D	www.med3d.de	Med3D, Switzerland	yes	Surgical guide	CDD	
Implant Master	www.ident-surgical.com	I-Dent Imaging, USA	yes	Surgical guide	RP	
Scan2Guide	www.ident-surgical.com	I-Dent Imaging, USA	yes	Surgical guide	RP	"Light" version of Implant Master
Ondemand3D Implant	www.cybermed.co.kr	Cybermed, Korea	yes	Surgical guide		
Oralim Oral Implant Planning System	www.medicim.com	Medicim, Belgium	yes	Surgical guide	RP	Marketed by Nobel Biocare
NobelGuide (Medicim Oralim)	www.nobelguide.com	Nobel Biocare, USA	yes	Surgical guide	CDD	Specific for Nobel Biocare implants
Simplant Master	www.materialise.com	Materialise Dental, Belgium	yes	Surgical guide	RP	
Simplant Planner	www.materialise.com	Materialise Dental, Belgium	yes	Surgical guide	RP	
Simplant Pro	www.materialise.com	Materialise Dental, Belgium	yes	Surgical guide	RP	
VIP	www.implantlogic.com	Implant Logic Systems, USA	yes	Surgical guide	CDD	Marketed by BioHorizons
Navigation systems (dynamic)						
VoNavix	www.codiagnostix.de	IVS Solutions, Germany	yes	Navigation	None	
Mona-Dent	www.imt-web.de	IMT, Germany	yes	Navigation	None	
NaviBase,NaviDoc & NaviPad	www.robodent.com	Robodent, Germany	yes	Navigation	None	
Treon (medical)	www.medtronicnavigation.com	Medtronic Navigation, USA	yes	Navigation	None	Not commercially available
IGI	www.image-navigation.com	Image Navigation, Israel	yes	Navigation	None	Formerly DenX, Inc
VISIT		University of Vienna, Austria		Navigation	None	not commercially available

RP = rapid prototyping; CDD = computer-driven drilling.

Planning information can remain stored on a computer in digital files for visual review or can be sent to a manufacturing facility to create three-dimensional models of the stored images. Most systems generate information to fabricate a surgical guide once appropriate surgical planning has been completed. This manufacturing process, generically called CAD/CAM, uses either rapid prototyping technologies such as 3D printing and stereolithography or "computer-driven drilling (CDD)" to create anatomical models.[41]

For surgical planning, implant avatars are positioned into the scanned images using software to simulate surgical placement. Once a satisfactory plan is approved and saved, CAD/CAM technology is used to produce a customized surgical template or guide. Depending on the manufacturer, guides can be indexed to available surrounding teeth, mucosal contours, or bony contours. Some manufacturers additionally offer prosthesis fabrication, combining the digital information with dental prosthetics.

Advantages of these systems may include general familiarity with the use of surgical guides based on long-established procedures. A high degree of precision may be obtained, particularly when guides incorporate graduated dimensions of drilling sleeves to guide increasing diameters of drills. Some systems provide two-dimensional (mesiodistal and buccolingual) guidance, while others also incorporate depth control. The precision of the surgical templates depends on the accuracy of the scan and the fit of the device during use. Some manufacturers require casts of the patients' arches or teeth to insure accurate fit, while others create the guides from the scanned images and contours. Difficulties can arise when patients have poor edentulous ridge form or loose teeth, or extractions are anticipated, since anatomical landmarks required for surgical guide stabilization could move or change. Several strategies to overcome these problems have been devised. As previously noted, some manufacturers fabricate provisional or final restorations from the digital plans, but there are too few long-term data to permit considering this a routine or accepted procedure.

The final group of devices includes six surgical navigation systems, four of which are commercially available. Surgical navigation systems require that sensors be attached to both the patient and the surgical handpiece. These sensors transmit three-dimensional positional information to a camera or detector that allows the computer to instantaneously calculate and display the virtual position of the instruments relative to the stored image of the patient's anatomy. An analogous technology is the global positioning system used for personal transportation, which similarly uses a satellite to track an individual's movements against a previously stored map. During surgery, the surgeon typically watches the computer monitor in addition to, or instead of, the surgical site to monitor positional accuracy. In medicine, this is similar to endoscopic or laparoscopic procedures, where the surgical sites are obscured, requiring viewing on a monitor.

An advantage of navigation systems is that the surgical plan can be altered or modified while retaining the "virtual vision" of the technology. The surgeon can either move the virtual implant on the plan or ignore the plan completely and use the navigation system to contemporaneously visualize the patient's anatomy. This permits the surgeon to steer around obstacles, defects, or conditions that were not apparent on the presurgical scan. Similar technology has been safely and effectively used in other branches of medicine, including neurosurgery, spinal surgery, and cardiac surgery. In addition to the stability problems noted for surgical guides, complications and difficulties can arise with navigation if the sensors are not precisely and firmly attached to the patient or handpiece. To date, restorations have not been CAD/CAM produced from planning files of the navigation systems. It is possible to do a sham procedure on dental casts, so that a dental laboratory could prefabricate restorations for immediate-loading procedures prior to implant placement. As with restorations planned from computer-generated surgical guides, this technique has not been adequately investigated.

Computer-Aided Design and Computer-Assisted Manufacturing in Prosthetic Implant Dentistry

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Purpose: *The aim of this systematic review was to evaluate the existing scientific evidence on human clinical studies describing the application of computer-aided design/computer-assisted manufacturing (CAD/CAM) technology in restorative implant dentistry.* ***Materials and Methods:*** *Electronic searches for clinical studies from 1966 through May 2008 focusing on long-term follow-up were performed using the PubMed search engine. Concentrating on the restorative aspect of the CAD/CAM technology applicable to implant dentistry, pertinent literature was divided into articles related to implant abutments and implant frameworks.* ***Results:*** *Of the 885 articles initially reviewed, 5 articles (3 CAD/CAM framework and 2 CAD/CAM abutment) satisfied the search criteria of the literature search performed. Combining the results from the framework clinical trial studies, there were a total of 189 prostheses supported by 888 implants. The follow-up varied between 12 and 60 months. Four implants were lost prior to the insertion of the prosthesis and 46 after the insertion. One prosthesis failure was reported. Similarly, in the 2 abutment clinical trial studies there were a total of 53 ceramic abutments supported by 53 implants. The patients were followed between 12 and 44 months. No significant failures or complications were reported in association with the implants and their restorations.* ***Conclusions:*** *Based on a systematic review of literature concerning CAD/CAM used for fabrication of frameworks and abutments, preliminary proof of concept was established. Clinical studies on the use of these techniques were too preliminary and underpowered to provide meaningful conclusions regarding the performance of these abutments/frameworks.* Int J Oral Maxillofac Implants 2009;24(suppl):110–117

Key words: *CAD/CAM, implant dentistry, implant-supported abutment, implant-supported framework*

Restoration of dental implants remains one of the most challenging aspects of implant dentistry. Since its introduction in dentistry almost 22 years ago, CAD/CAM technology has played an important role in the evolution of dental technology.[1]

Implant abutments and frameworks are required to fulfill biological, functional, and esthetic demands.[2] For this reason, the implant abutments and/or frameworks should be made from biocompatible materials with adequate mechanical properties.[3] Even more, they should accurately and passively fit on their mating implants to prevent complications such as screw loosening, bone loss, and abutment fracture during function.[4] Finally, for optimal mucogingival esthetics, implant abutments should have the appropriate emergence profile needed to support the surrounding soft tissue, and preferably be made from a tooth-colored material to prevent the bluish translucency of the overlying mucosa.[3–5]

Implant abutments can be either stock or custom abutments. There are two types of custom abutments: cast custom and CAD/CAM custom abutments.[6] According to their fabrication technique, implant frameworks are of four types: *(1)* conventional cast frameworks, *(2)* frameworks made from carbon/graphite fiber-reinforced polymethylmethacrylate,[7]

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(3) laser-welded titanium frameworks,[8] and most recently, *(4)* CAD/CAM milled frameworks.[9–11]

CAD/CAM technology was incorporated in the production of implant abutments and frameworks in the early 1990s[6] with the aim to facilitate their fabrication. While scientific evidence for CAD/CAM implant-supported restorations has been widely validated with in vitro studies, the clinical outcomes of such protocols are still being investigated.

Several in vitro studies have investigated CAD/CAM-fabricated implant frameworks and abutments. A study by Jemt et al reported a comparable fit of CAD/CAM-fabricated implant frameworks and conventional cast frameworks,[10] whereas a few other studies found the fit of CAD/CAM-fabricated implant frameworks to be statistically superior to that of the conventional cast frameworks.[12–14] Vigolo et al[15,16] assessed the precision at the implant-abutment interface of CAD/CAM abutments. In one study all three types of abutments—zirconia, alumina, and titanium—were connected to external hexed implants and showed less than 3 degrees of rotational freedom.[15] In a more recent study, a CAD/CAM titanium abutment was compared to a gold-machined abutment (UCLA abutment, University of California, Los Angeles, CA, USA), with both showing 1 degree of rotational freedom in cases of external-hexagonal connection and internal-hexagonal connection.[16] Yuzugullu and Avci compared the microgap values at the implant-abutment interface of ceramic abutments and titanium abutments subjected to dynamic loading. They found values to be comparable between the two groups, indicating that ceramic and titanium abutments possess similar tolerance to functional loading.[17]

The objective of this systematic review was to evaluate the existing scientific evidence in human clinical studies describing the application of CAD/CAM technology in restorative implant dentistry. These applications include CAD/CAM-fabricated abutments and/or frameworks.

MATERIALS AND METHODS

Search Strategy

Electronic searches for clinical studies published between 1966 and May 2008 were performed using the PubMed search engine. The search terms used were controlled subject vocabulary terms. These terms were identified after searching the MeSH database. Once their definition was approved, the vocabulary terms were inserted into the PubMed search box. The terms were combined in the following ways:

- *cad cam* AND *dental implants*
- *cad cam* AND *dental prosthesis*
- *cad cam* AND *dental prosthesis, implant-supported*
- *cad cam* AND *dental prosthesis design*
- *cad cam* AND *dental abutments*

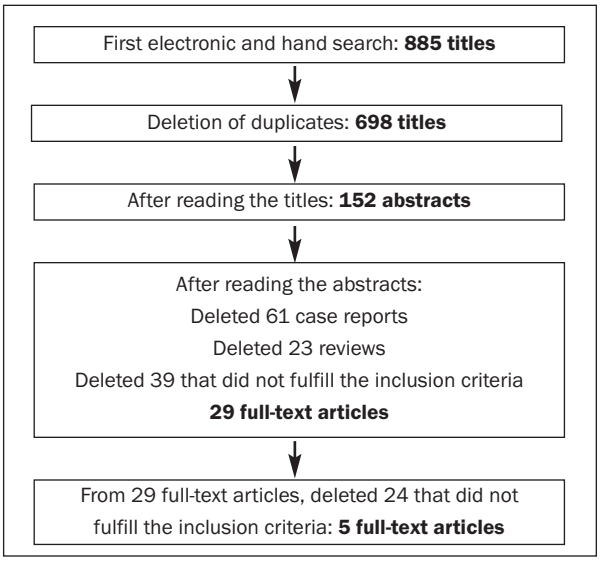

Fig 1 Literature search and selection of articles.

In addition, all offline journals relevant to the topic and relevant bibliographies of reviewed articles were hand searched. The following inclusion criteria were used to identify the publications of interest:

- All levels of the hierarchy of evidence except expert opinion and case reports
- Studies with 10 case series or more
- Studies reporting a minimum of 12 months of follow-up

Selected publications were collected in a reference manager software (Endnote XI, Thomson Research Soft), and duplicates were electronically discarded. All titles obtained from the electronic search for inclusion in the study were assessed to narrow down the list of studies matching the selection parameters. A full-text analysis was performed for the final articles selected.

Search Results

The electronic and hand searches provided a total of 885 titles. Duplicates were deleted, which resulted in 698 titles. Of those, 152 scientific publications were selected based on their titles. Of the 152 abstracts, 123 did not fulfill the inclusion criteria and were excluded from the study. More specifically, 61 articles were case reports with fewer than 10 patients, 23 articles were reviews, and 39 were either in vitro/finite elements studies, restorations on natural teeth, technical notes, or expert opinions. The full texts of the remaining 29

Table 1 Articles That Satisfied the Inclusion Criteria of the Performed Literature Search

Study	Year	Journal	City/Country	Study design
Engquist et al[19]	2004	CIDRR	Linkoping, Sweden	Prospective cohort
Henriksson and Jemt[20]	2003	IJP	Göteborg, Sweden	Prospective cohort
Ortorp and Jemt[21]	2004	CIDRR	Göteborg, Sweden	Prospective control
Sanna et al [22]	2007	JPD	Leuven, Belgium	Prospective cohort
Canullo[18]	2007	IJP	Rome, Italy (private practice)	Prospective cohort

CIDRR = *Clinical Implant Dentistry and Related Research*; IJP = *International Journal of Prosthodontics*; JPD = *Journal of Prosthetic Dentistry.*

Table 2 Clinical Trial Studies Included Under the CAD/CAM Framework Category

Study	Framework	No. of patients	No. of prostheses	No. of dropouts	No. of implants after dropout	No. of prostheses after dropout	Age range (y)	Mean age (y)	Follow-up period (mo)	System
Engquist et al (2004)[19]	Ti	108	108	0	418	108 (108/108 or 100%)	25–75	NR	12	Procera, Nobel Biocare
Ortorp and Jemt (2004)[21]	Ti	65	67	12	287	55 (55/67 or 82.1%)	49–85	68	60	All-in-One Procera, Nobel Biocare
Sanna et al (2007)[22]	Ti	30	30	4	183	26 (26/30 or 86.7%)	38–74	56	26.4 (mean)	Procera, Nobel Biocare
Total	—	203	205	16 (16/205 or 7.8%)	888	189 (189/205 or 92.2%)	—	—	—	

NR = not reported.

Table 3 Patient Characteristics of the Reviewed CAD/CAM Framework Studies

Study	Single tooth	Partially edentulous	Completely edentulous	Maxilla	Mandible	Implant type	Immediate restoration (< 1 wk)	Early restoration (1 week to 2 mo)	Conventional restoration (> 2 mo)
Engquist et al (2004)[19]	N	N	Y	N	Y	Nobel Biocare (Brånemark)	N	3 wk (24 d mean)	12 wk
Ortorp and Jemt (2004)[21]	N	N	Y	Y	Y	Nobel Biocare (Brånemark)	NR	NR	NR
Sanna et al (2007)[22]	N	N	Y	Y	Y	Nobel Biocare (TiUnite)	Y	N	N

N = no; Y = yes; NR = not reported.

articles were reviewed, and 5 articles satisfied the inclusion criteria for this search (Fig 1).[18–22] The 5 articles of interest are summarized in Table 1.

RESULTS

CAD/CAM Frameworks

Three articles were included under clinical trials of CAD/CAM frameworks. Two of them were prospective cohort studies and the third was a prospective controlled study. These articles were published between 2004 and 2007.

Engquist et al[19] reported on 108 patients who received 108 prostheses and were followed for up to 12 months. Ortorp and Jemt[21] presented a prospective study with 65 patients receiving 67 prostheses; of those, 12 were dropouts. The remaining 53 (55 prostheses) were followed up for a period of 5 years (60 months). Similarly, Sanna et al[22] performed a cohort study in which they restored 30 patients. The patients were followed up for a mean period of 2.2 years (26.4 months). Four of them dropped out, bringing the final number of patients to 26 (26 prostheses).

In all studies, the implant-supported prostheses were made of titanium frameworks using CAD/CAM technology. All restorations were made by Procera, Nobel Biocare (Table 2).

No studies were found that described CAD/CAM framework applications in partially edentulous patients. All three investigations used CAD/CAM technology to restore completely edentulous patients. In two studies, both the maxilla and the mandible were restored (Ortorp and Jemt[21] and Sanna et al[22]), and in one study only mandibles were restored (Engquist et al[19]) (Table 3).

Table 4 Complications and Failures of the Reviewed CAD/CAM Framework Studies

Study	No. of implant complications prior to insertion	No. of implant failures	No. of implant complications	No. of prosthetic failures	No. of prosthetic complications
Engquist et al (2004)[19]	NR	24	NR	0	0
Ortorp and Jemt (2004)[21]	4	13	0	1	19
Sanna et al (2007)[22]	0	9	NR	NR	NR
Total	4 (4/888 or 0.45%)	46 (46/888 or 5.2%)	0	1 (1/189 or 0.53%)	19 (19/189 or 10.1%)

NR = not reported.

The loading time of the prostheses varied significantly in the three articles. Sanna et al[22] restored their patients using immediate loading protocols, whereas Engquist et al[19] applied both early (mean 24 days) and conventional (12 weeks) restoration protocols as a restorative option. Finally, Ortorp and Jemt[21] used both two-stage (58 patients) as well as one-stage (7 patients) surgical protocols but did not report the restoration protocol that was used (Table 3). The definitions of the terms *immediate loading*, *early loading*, and *conventional loading* are based on the 2007 Cochrane Review.[23]

From a total of 287 implants, Ortorp and Jemt[21] reported 4 failures prior to the insertion of the prosthesis. The remaining studies either did not report any (Engquist et al[19]) or did not have any (Sanna et al[22]). The number of implant failures rose after the delivery of the prosthesis, with Engquist et al[19] reporting 24 out of 418, Ortorp and Jemt[21] 13 out of 287, and Sanna et al[22] 9 out of 183.

Two studies—Engquist et al[19] and Sanna et al[22]—failed to report any implant complications after the delivery of the prosthesis. Concurrently, Ortorp and Jemt[21] did not find any implant complications after the prosthesis was delivered. One prosthetic failure was described by Ortorp and Jemt[21]: one patient lost all six of his implants, which also resulted in the failure of the prosthesis, although there were no issues with the prosthesis itself. Engquist[19] and Sanna[22] did not mention any failures.

Nineteen prosthetic complications were reported by Ortorp and Jemt.[21] Seventeen patients presented with 19 occurrences of prosthodontic complications involving resin veneer fractures (12) and loss of access hole fillings (7). Engquist et al[19] and Sanna et al[22] did not report any prosthetic complications (Table 4).

The numbers of implants used to restore the edentulous patients also varied among the three studies. Engquist et al[19] concluded that 4 implants were enough to support full fixed prostheses in the mandible even in early loading. Ortorp and Jemt[21] placed an average of 6.6 implants in the maxilla (153 implants in 23 patients) and 4.8 in the mandible (215 implants in 44 patients). Sanna et al[22] placed an average of 7 implants per arch (212 implants in 30 patients).

When Ortorp and Jemt[21] compared the titanium framework test group with a control group restored with cast alloy frameworks, they found no significant difference in the survival of implants between titanium and cast frameworks. Furthermore, the titanium framework group had fewer complications and maintenance appointments, with the exception of veneer fracturing, which was greater in the test group. Finally, there were more failures in the maxilla than the mandible.

Engquist et al[19] described no statistically significant differences between the early loading (after 3 weeks) and delayed loading (after 3 months) patient groups.

Combining the results from the three clinical trial studies, there were a total of 189 prostheses supported by 888 implants. The patients were followed from 12 to 60 months. Four implants were lost prior to the insertion of the prosthesis and 46 after the insertion. Only 1 prosthesis failure was reported, and the failure was due to the fact that the patient had lost all the implants that supported the prosthesis.

CAD/CAM Abutments

Two articles on CAD/CAM abutments satisfied the search criteria. The study by Henriksson and Jemt[20] is a prospective cohort study of 20 patients who received 24 single-implant restorations with CAD/CAM customized alumina abutments (Procera, Nobel Biocare). The study reported 1 dropout over the 1-year follow-up period, which reduced the number of patients from 20 to 19 and the number of implants from 24 to 23. Canullo,[18] in another prospective cohort study, reported 25 patients who received 30 single-implant restorations. The abutments were customized titanium-zirconia complexes (Zirkonzahn). The mean clinical follow-up period was 40 months, and the number of dropouts was not reported (Table 5).

Patients in both studies received single implants and single-unit restorations. No edentulous or partially

Table 5 Clinical Trial Studies Included Under the CAD/CAM Abutment Category

Study	Abutment	No. of patients	No. of prostheses	No. of dropouts	No. of implants/ restorations after dropout	No. of prostheses after dropout	Age range (y)	Mean age (y)	Follow-up period (mo)	System
Henriksson and Jemt (2003)[20]	Aluminum oxide abutments	20	24	1	23	23 (23/24 or 95.8%)	18–62	29	12	Procera Nobel Biocare
Canullo (2007)[18]	Ti-Zirconia abutment complexes	25	30	NR	NR	30 (30/30 or 100%)	25–70	52.28	36–44	Zirkozahn
Total	-	45	54	1	23	53	-	-	-	-

NR = not reported.

edentulous patients were included in either study. Henriksson and Jemt[20] placed the implants in the maxillary anterior region using the two-stage surgical protocol. Nine patients (13 implants) received ceramic crowns cemented on ceramic abutments (Procera crown [PC] group) and 11 patients (11 implants) received ceramic crowns that were directly fused onto the abutments (fused crown [FC] group). The prosthetic treatment started about 2 weeks after the second-stage surgery. Similarly, Canullo[18] used the submerged surgical protocol, and each implant was restored following the second-stage exposure surgery. Eighteen implants were placed in the maxilla and 12 in the mandible in both anterior and posterior regions. The abutment complexes were made of titanium posts (ProUnic abutment, Impladent) with CAD/CAM-fabricated zirconia abutments. In group 1, the lower margin of the zirconia abutment was positioned directly on the implant margin, while in group 2 the metallic structure was positioned on the implant neck and the zirconia margin was more coronally positioned on the titanium post.

No screw loosenings or fractures (prosthetic complications) were recorded in Canullo's study, which resulted in a survival rate of 100%. However, a single case of marginal porcelain chipping was observed at the 1-year follow-up. The periodontal indices mPI and mGI indicated healthy soft tissue conditions at neighboring teeth and zirconia abutments.

In the study of Henriksson and Jemt, all crowns remained "stable during the 12-month period, with no severe problems reported." One patient in the PC group (cemented crowns) developed a buccal fistula, which healed after recementing the crown. In addition, two patients from the PC group presented with soft tissue recession in association with the crown-abutment margin. The authors suggested that these results might raise concerns regarding the "unfavorable biologic effect of a cement margin and possible cement remnants in the implant area."[20] One more interesting observation is that even though all abutment screws of the FC group were tightened by hand when inserted, the authors reported similar crown stability and lack of porcelain fracture in the groups. This clinical investigation reported encouraging results for the use of alumina oxide custom abutments that were followed for 1 year. In addition, it provided some data that presented similar complications and survival rates for two different delivery techniques of CAD/CAM custom abutments.

Combining the results from the two clinical trial studies, there were a total of 53 ceramic abutments supported by 53 implants. The patients were followed from 12 to 44 months. No significant failures or complications were reported in association with the implants and their restorations.

DISCUSSION

Clinical trials describing the performance of CAD/CAM implant abutments and frameworks in the literature are scarce. However, the interest in CAD/CAM technology for implant restorations is substantially increasing, for several reasons. First, CAD/CAM-produced implant frameworks are made from a solid block of material. With this specific fabrication technique, the material is more homogeneous and has high mechanical properties. Second, inaccuracies are largely minimized since there is no waxing, investing, or casting. This fact translates into reduced production costs overall. Furthermore, with CAD/CAM technology the unfavorable implant angulations can be corrected and the proper emergence profile can be achieved. Finally, CAD/CAM ceramic abutments provide the optimal optical properties of a natural tooth and a predictable esthetic result for the surrounding soft tissues.

An important point concerns the prosthesis that is opposing the CAD/CAM restoration. Engquist et al[19]

Table 6 Summary of Currently Available CAD/CAM Systems for Dental Implants

CAD/CAM system	Provider	Implant restoration type	Restoration material
Procera	Nobel Biocare	Abutments Fixed partial denture frameworks Milled bars	Titanium Alumina Zirconia
Atlantis	Astra Tech	Abutments	Titanium Titanium with gold coating Zirconia
Encode	Biomet 3i	Abutments	Titanium Titanium with gold coating
CAM StructSURE	Biomet 3i	Milled bars	Titanium
CARES	Straumann	Abutments	Titanium Zirconia
Etkon	Straumann	Frameworks Abutments	Zirconia Titanium
BioCad	BioCad Medical	Abutments Milled bars	Titanium

stated that "most of the patients used a full upper denture with acrylic teeth." Ortorp and Jemt[21] reported that the titanium framework restorations were opposing 26 complete dentures, 1 overdenture, 8 removable partial dentures, 12 implant-supported prostheses, 19 fixed prostheses with natural teeth, and 1 implant-supported prosthesis that was combined with natural teeth. Sanna et al[22] failed to describe the patient's opposing arch at the time of implant placement or later.

In addition to the survival and failure rates of the CAD/CAM restorations, equally interesting are the complications of the final CAD/CAM restorative outcome. In the literature, numerous systematic reviews have evaluated "biological," "technical," as well as "esthetic" complications of dental restorations/implants.[24–26] We would like to see a similar effort for the CAD/CAM restorations reported in long-term prospective studies. These complications need to be presented in greater detail, in a systematic manner, and with an adequate follow-up time.

To determine if there is a difference regarding the influence of CAD/CAM design on the tissues, the "biological" complications could be subdivided into peri-implant mucosal lesions, gingival inflammation, soft tissue dehiscence, formation fistulas, and marginal bone height. Similarly, the "technical" complications could be separated into groups such as abutment/screw loosening, fracture of the veneer material, fracture of the CAD/CAM framework/abutment, and loss of retention due to cementation.

Although the esthetic outcome has become a main focus of interest in implant dentistry, none of the included studies evaluated the esthetic appearance of CAD/CAM-fabricated prostheses. This is a difficult task, since there is a lack of standardized esthetic criteria. Hence, there is a need for widely accepted and reproducible esthetic scores, not only for the evaluation of CAD/CAM restorations, but also for the peri-implant soft tissues.[27]

Currently, several CAD/CAM systems are available for dental implants. The following are a few examples reported in the literature, listed according to their fabrication capabilities (abutments versus frameworks). Table 6 summarizes information about these currently available CAD/CAM systems.

CAD/CAM Custom Implant Abutment Systems

The ***Procera*** system (Nobel Biocare) provides custom abutments in titanium, alumina, and zirconia. A master cast is developed after making an implant-level impression. The master cast is then scanned and the custom abutment is designed by a 3D CAD program.[2,20,28] Alternatively, a machined base cylinder is screwed to the implant analog and the abutment is waxed up. The pattern is then removed from the master cast and scanned by the Procera scanner.[29,30] The design is sent to the production facility for the abutment fabrication.[2,20] The abutment can be further digitized, and finally a titanium or ceramic coping is produced using the same system.[6]

The ***Atlantis*** abutment (Astra Tech) is milled in titanium alloy or zirconia. Gold anodized coatings can be added to mask the silver color of the titanium abutment, giving natural shades through all-ceramic restoration.[31] In this system an implant-level impression is made and then both the diagnostic model and the master cast are scanned. In this way a computer

accurately captures the implant location, orientation, angle, and depth. The abutment is then designed on a software system known as VAD and precision machined by a computer-controlled milling machine from a solid block of titanium alloy.[32]

The ***Encode*** Restorative System (ARCHITECH PSR, Biomet 3i) is a CAD/CAM system limited to a specific implant (Biomet 3i).[33] In this system the clinician needs to make an intraoral impression of a special healing abutment. This abutment has notches on its occlusal surface that serve as codes. When these embedded codes are scanned they give information about the implant platform diameter, the position of the hex, and the collar height of the healing abutment. The CAD/CAM abutment is designed on the computer and is milled from a solid block of titanium alloy.[6,33,34]

CARES (Computer Aided Restoration Service; Straumann) offers exclusively customized implant prosthetics for the Straumann dental implant system. It provides two types of abutments: zirconium oxide and titanium RNSynOcta custom abutments. After fabrication of an implant-level impression, a duplicate model of the master cast, known as a scan model, is made from a scanable plaster. A scan body, which is used to record the implant position during the scanning procedure, is attached to the implant analog on the master cast before the duplication or to the scan model after the duplication. The scan model is digitized using laser scanners from Sirona. The custom abutment is designed on-screen using 3D software. Generated data are electronically transmitted to the Straumann production center, where the custom abutment is manufactured. Intraorally, the ceramic custom abutment needs to be fixed to the SynOcta 1.5 abutment, whereas the RNSynOcta 1.5 is not required if the titanium custom abutment is used, as the titanium custom abutment is screwed directly into the implant.

Etkon is another system that supports the prosthetic portfolio of the Straumann dental implant, among others. Using the laser light-band principle to scan, it can fabricate abutments made of zirconia or titanium. After an implant-level impression is made, a master cast is produced. A plastic cylinder is placed into the implant analog and the abutment is waxed up. The generated pattern is then removed and scanned. The resulting design is sent electronically to a manufacturing facility to produce the final custom abutment.

CAD/CAM Custom Implant Framework Systems

Procera implant partial prostheses are available in zirconia or titanium. CAD/CAM custom Procera partial prostheses are screw-retained implant-supported restorations that can be used with a wide range of implant systems. The zirconia implant prosthesis is available at the implant level, while the titanium implant prosthesis is available at the implant and abutment levels (www.nobelbiocare.com). Using acrylic resin, a framework pattern is fabricated directly on temporary implant cylinders.[9] The acrylic resin framework pattern is then laser scanned, and the framework is milled in a CNC-milling machine with 5 degrees of freedom.[9–11]

CAM StructSURE precision milled bars (Biomet 3i) are available in Hader and Dolder designs for overdenture bars and primary bars and in fixed hybrid designs. With this system, the technician does not need to wax or resin design the framework; instead, the design is made on-screen with a sophisticated software program.[35]

BioCad milled bars (BioCad Medical). BioCad software permits the design of bars for most implant systems. They are made from a surgical grade titanium alloy milled on industrial machines. BioCad implant bars are available in Hader, Dolder, fixed, and round styles.

The ***Etkon*** system can produce frameworks[36] up to 16 units from a variety of materials, such as zirconia and titanium.

CONCLUSIONS

Based on a systematic review of literature on the use of CAD/CAM for fabrication of frameworks and abutments, preliminary proof of concept was established.

Clinical studies on the use of these techniques were too preliminary and underpowered to provide meaningful conclusions regarding the performance of these abutments/frameworks.

The influence of the implant CAD/CAM abutment on peri-implant tissues as well as the effect of the CAD/CAM-fabricated frameworks on the survival of veneered porcelain has not yet been assessed in the scientific literature. There is a need for long-term prospective studies that examine:

- Survival outcomes of CAD/CAM abutments (alumina oxide, zirconia, titanium)
- The influence of the abutment material (zirconia/titanium) on the peri-implant tissues (shade, tissue color)
- The effect of zirconia versus titanium on the porcelain veneer material survival rate and on long-term clinical performance

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Flapless Surgery and Its Effect on Dental Implant Outcomes

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Purpose: *The aim of this article was to review the current literature with regard to the efficacy and effectiveness of flapless surgery for endosseous dental implants. The available data were evaluated for short- and long-term outcomes.* ***Materials and Methods:*** *A MEDLINE search was conducted on studies published between 1966 and 2008. For the purpose of this review, only clinical (human) studies with five or more subjects were included, and clinical opinion papers were excluded. Clinical studies or reports were further rated in terms of the level or weight of evidence using criteria defined by the Oxford Center for Evidence-Based Medicine in 2001.* ***Results:*** *The available data on flapless technique indicate high implant survival overall. The prospective cohort studies demonstrated approximately 98.6% (95% CI: 97.6 to 99.6) survival, suggesting clinical efficacy, while the retrospective studies or case series demonstrated 95.9% (95% CI: 94.8 to 97.0) survival, suggesting effective treatment. Six studies reported mean radiographic alveolar bone loss ranging from 0.7 to 2.6 mm after 1 year of implant placement. Intraoperative complications were reported in four studies, and these included perforation of the buccal or lingual bony plate. Overall, the incidence of intraoperative complications was 3.8% of reported surgical procedures.* ***Conclusion:*** *Flapless surgery appears to be a plausible treatment modality for implant placement, demonstrating both efficacy and clinical effectiveness. However, these data are derived from short-term studies with a mean interval of 19 months, and a successful outcome with this technique is dependent on advanced imaging, clinical training, and surgical judgment.* Int J Oral Maxillofac Implants 2009;24(suppl):118–125

Key words: *dental implants, flapless surgery, implant complications, implant success, literature review, meta-analysis*

In the late 1970s, Brånemark established the use of extensive surgical flaps to visualize the surgical field during implant surgery.[1] According to this protocol, an incision in the mucosa or the mucobuccal fold was made, and then a flap was reflected to expose the underlying bone. The implants were then placed and the flaps repositioned with sutures.[1–3]

Over the past three decades there have been several alterations to this flap design, now integrating esthetic considerations in the critical esthetic zones of the dentition. In situations with limited bone quantity, the elevation of a mucoperiosteal flap can facilitate implant placement by allowing the surgeon to visually assess bone quantity and morphology at the site. The feasibility of achieving an ideal implant position in conjunction with primary stability and maximum bone-to-implant contact could then be assessed. Furthermore, visualization of the surgical field with flap elevation may reduce the risk of occurrence of bone fenestrations and dehiscences. However, flap elevation is always associated with some degree of morbidity and discomfort, and requires suturing to close the surgical wound. In the early 1970s, studies demonstrated a correlation between flap elevation and gingival recession, as well as bone resorption around natural teeth.[4] Furthermore, there has been a report of postsurgical tissue loss from flap elevation, implying that the use of flap surgery for implant placement may negatively influence implant esthetic outcomes, especially in the anterior maxilla.[5]

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Over the past 30 years, flap designs for implant surgery have been modified, and more recently the concept of implant placement without flap elevation and exposure of the bony tissues was introduced. Flapless procedures have already been used for some time with tooth extractions and site preservation, and have shown less morbidity.[6] In addition, surgeons have also considered a flapless approach for immediate implants in order to preserve the vascular supply and existing soft tissue contours.[7] Surgeons use either rotary instruments or a tissue punch to perforate the gingival tissues to gain access to bone.

Over the past few years, dental radiographic imaging has made large technological advances, with sophisticated compilations of three-dimensional (3D) imaging in the form of computed tomography (CT) as well as newly developed dental implant treatment planning software allowing 3D evaluation of potential implant sites. These new developments have contributed to the popularization of flapless implant surgery. Although the flapless technique was initially suggested for and embraced by novice implant surgeons, a successful outcome often requires advanced clinical experience and surgical judgment.[7]

Flapless surgery has several potential advantages, including *(1)* reduction of complications at the patient level, ie, swelling and pain, *(2)* reduction of intraoperative bleeding, *(3)* reduction of surgical time and need for suturing, *(4)* preservation of soft and hard tissues, and *(5)* maintenance of blood supply.

However, despite these advantages, the flapless technique also has several potential shortcomings. These may include *(1)* the inability of the surgeon to visualize anatomical landmarks and vital structures, *(2)* the potential for thermal trauma to the bone due to limited external irrigation during preparation of the osteotomy with guided surgery, *(3)* an inability to ideally visualize the vertical endpoint of the implant placement (too shallow/too deep), *(4)* decreased access to the bony contours for alveoloplasty, *(5)* difficulties in performing an internal sinus lift with a stabilized template (screw fixated), and *(6)* inability to manipulate the circumferential soft tissues to ensure the ideal dimensions of keratinized mucosa around the implant. The importance of keratinized mucosa around implants is debated, as some studies have shown that the absence of keratinized gingiva is not critical to the health of the gingiva and the implant outcome,[8,9] while others suggest that the failure rate is higher when there is a lack of keratinized gingiva or only a small amount is present.[10–15]

The aim of this review was to evaluate the current literature with regard to the efficacy of flapless surgery for endosseous dental implants.

MATERIALS AND METHODS

Literature Review

For the purpose of this review, a literature search was conducted using the MEDLINE database for the interval 1966 to August 28, 2008, in the English language. Citations were searched by key word or title using the following combinations of words: *flapless* or *incisionless* or *minimally invasive* in combination with *dental implants*. In addition, key dental journals (ie, dental implant, oral and maxillofacial surgery, periodontics, and prosthodontics) from the same interval were hand-searched to identify pertinent citations. Studies were classified by subject (animal versus human) and design (preclinical, case report, case series, cohort, clinical trial, or meta-analysis). For the purpose of this review, only clinical (human) studies with five or more subjects were included, and clinical opinion papers were excluded. Clinical studies or reports were further rated in terms of the level or weight of evidence using criteria defined by the Oxford Center for Evidence-Based Medicine.[16]

The data from the identified studies were tabulated in an extraction table according to the following criteria: study design, number of patients, number of dropouts, mean/average age, follow-up periods, type of implant case, primary and secondary outcomes, intraoperative and postoperative complications, and implant failures.

For the purpose of this article, the term *conventional implant surgery* encompasses surgical procedures that involve elevation of a mucoperiosteal flap for the preparation of the implant osteotomy and implant placement. *Flapless implant surgery* is defined as a surgical procedure used to prepare the implant osteotomy and to place the implant without elevation of a mucoperiosteal flap.

Search Results

Following the preliminary identification of 110 articles, 17 studies were identified as meeting the inclusion criteria. One of these studies was a systematic review not presenting primary evidence, and was therefore excluded. Of the remaining 16 articles, 2 were comparative cohort studies (level 2) primarily designed to document immediate postoperative clinical courses. The remaining 14 articles included 7 prospective cohort studies (level 2) and 7 retrospective or case series studies (level 4) that evaluated clinical outcomes related to implant survival and other clinical parameters (Table 1).

Two of the studies were short in duration (< 7 days) and were designed to assess intraoperative or postoperative morbidity or complications (level 2 for intended objectives).[17,18] The other 14 studies

Table 1 Study Demographics

Study	Study design	No. of patients	No. of dropouts	No. of implants after dropout	Age range (y)	Mean age (y)	Follow-up period (max)
Becker et al (2005)[22]	Prospective cohort	57	0	79	24–86	NR	24 mo
Campelo and Camara (2002)[21]	Retrospective cohort	377	18	770	27–83	54.7	60 mo
Cannizzaro et al (2007)[23]	Prospective cohort	35	0	202	39–70	56.6	12 mo
Fortin et al (2006)[18]	Prospective comparative cohort	60	0	152	19–82	NR	6 d
Malo et al (2007)[24]	Prospective cohort	23	0	92	NR	NR	21 mo
Nkenke et al (2007)[17]	Prospective comparative cohort	10	0	NR	NR	65	7 d
Oh et al (2006)[25]	Nonrandomized trial	24	0	24	25–72	45	6 mo
Ozan et al (2007)[26]	Case series	5	0	14	NR	NR	14 mo
Rao and Benzi (2008)[27]	Prospective cohort	46	1	50	22–66	42	12 mo
Rocci et al (2003)[28]	Prospective cohort	46	0	97	24–77	51	36 mo
Sanna et al (2007)[29]	Retrospective cohort	30	4	183	38–74	56	26.4 mo
Sennerby et al (2008)[30]	Retrospective cohort	43	0	117	NR	50	18 mo
van Steenberghe et al (2005)[31]	Prospective	27	3	164	34–89	63	12 mo
Wittwer et al (2006)[33]	Prospective cohort	20	0	80	53–75	61.4	4 mo
Wittwer et al (2007)[32]	Prospective cohort	20	0	80	56–77	64.3	0 mo
Wittwer et al (2007)[34]	Prospective	25	3	88	55–77	62.1	25 mo
Total		848		2,192			

NR = not reported.

reported on long-term clinical outcomes. Of these studies, 7 were prospective cohorts (level 2). The other 7 studies were retrospective studies or case series (level 4). The majority of studies included guided surgical techniques in their treatment planning (11 of 16). The study designs differed with respect to the treatment of complete edentulous arches and single sites (Table 2).

RESULTS

Morbidity and Patient Comfort

During implant surgeries, surgical trauma and patient morbidity should be confined to a minimum.[19] One technique that can be used to achieve this is flapless implant placement, which was described several years ago as a surgical technique for the edentulous mandible.[20] Unfortunately, the available literature comparing patient morbidity resulting from flapless implant surgery and conventional implant surgery was limited to two studies.[17,18] Also, additional objective assessments of short-term postoperative complications (eg, edema) were not routinely reported.

Nkenke et al[17] evaluated the differences in patient morbidity between flapless and conventional implant surgery using a questionnaire, and determined the differences in visible facial swelling of the upper lip and cheeks using optical 3D imaging. Ten patients were assigned to either the flapless or the conventional group. All patients were edentulous in the maxilla, and six implants were placed in each patient with the respective technique. Immediately after surgery, 1 and 7 days postoperatively, the patients were asked to evaluate pain and discomfort using a visual analog scale (VAS). Within the same day, an optical 3D image was assessed. In this small study, the flapless surgery reduced the amount of pain and postoperative swelling significantly ($P < .05$).

In another study, Fortin et al[18] assessed the postoperative discomfort and use of analgesics after flapless or conventional implant surgery. Sixty patients were randomly assigned to one of the above-mentioned techniques for implant placement. The patients used a VAS to describe their postoperative pain, starting on the day of surgery and daily thereafter for a total of 6 days. Along with the VAS evaluation, the patients were asked to report their use of analgesics postoperatively. The patients in the flapless group experienced significantly less pain ($P < .01$) than the patients in the conventional group. In addition, the flapless group also used less analgesics and for a shorter period of time.

Implant Survival

The 14 studies that evaluated long-term outcome[21–34] included a total of 778 patients and 2,040 dental implants over a mean observational period of 19 months (see Table 1).

In general, the data showed a high survival rate for the evaluated patient pool. The prospective cohort studies demonstrated approximately 98.6% survival (95% CI: 97.6 to 99.6), suggesting clinical efficacy, while the retrospective studies or case series demon-

Table 2 Case Types and Outcomes

Study	Single-tooth	Partially edentulous	Completely edentulous	Maxilla	Mandible	Outcome 1	Outcome 2
Becker et al (2005)[22]	NR	NR	NR	47 (implants)	32 (implants)	No significant changes in PD, BI from 1 to 6.5 mo	Radiographic bone loss = 0.07 mm, not significant
Campelo and Camara (2002)[21]	NR	NR	NR	282 (implants)	488 (implants)	Implant failure overall 37 (4.8%) over 10 y	No analgesic use: 90%
Cannizzaro et al (2007)[23]	0	0	33	33	0	Pain: none–slight (79%), moderate–severe (21%)	Postsurgical swelling: none–slight (58%), moderate–severe (42%)
Fortin et al (2006)[18]	NR	NR	NR	NR	NR	Pain (VAS): significant less and of shorter duration pain in flapless group, significant fewer analgesics in flapless	NR
Malo et al (2007)[24]	0	0	23	18	5	Implant survival = 98%; maxilla 97%; mandible 100%	Radiographic bone loss = 1.9 mm at 12 mo
Nkenke et al (2007)[17]	0	0	10	0	10	Pain (VAS) (6 h, 1 d, 7 d); AUC analysis significant less pain in flapless group vs flap over 7 d	Postsurgical swelling (days 1 and 7); significant less facial edema in the flapless over 7 d
Oh et al (2006)[25]	24	0	0	24	0	Trend for Papillary Index (PPI) to increase over 6 mo	No changes in ML, PD, mPI, mBI, WKM
Ozan et al (2007)[26]	NR	NR	NR	Yes	Yes	5 of 5 implants survived at average 9 mo	NR
Rao and Benzi (2008)[27]	46	46	0	0	46	Radiographic bone loss = 1.12 mm at 12 mo and 0.89 mm at 24 mo	NR
Rocci et al (2003)[28]	27 (implants)	70 (implants)	0	97 (implants)	0	Cumulative survival rate: 91% at 36 mo	Radiographic bone loss; 1.0 mm at 12 mo, 0.4 mm at 24 mo, 0.1 mm at 36 mo
Sanna et al (2007)[29]	0	0	30	26	4	Radiographic bone loss at 4 y: 2.64 mm smokers; 1.3 mm nonsmokers	Cumulative survival rate 91.5% over 66 mo
Sennerby et al (2008)[30]	18 (implants)	99 (implants)	0	45 (implants)	72 (implants)	> 2 mm radiographic bone loss at 53% implants; > 3 mm radiographic bone loss at 37% implants	NR
van Steenberghe et al (2005)[31]	0	0	27	27	0	Radiographic bone loss 1.2 mm at 12 mo	NR
Wittwer et al (2006)[33]	0	0	80	0	80	NR	NR
Wittwer et al (2007)[32]	0	0	20	0	20	NR	NR
Wittwer et al (2007)[34]	0	0	25	0	25	Success rate = 97.7%	NR

PD = probing depth; BI = bleeding index; ML = attachment level, mPI = modified plaque index; mBI = modified bleeding index; AUC = area under curve; WKM = width of keratinized mucosa; NR = not reported.

strated 95.9% survival (95% CI: 94.8 to 97.0), suggesting effective treatment.

Interestingly, one group of authors[33] associated the only two implant failures (n = 78 implants) with the limitations of the transmucosal flapless technique rather than with the navigated surgical protocol for the implant placement. The authors noted that this technique might not be suitable for all bone morphologies.

Marginal Bone Loss

The radiographic marginal alveolar bone loss over 1 year ranged from 0.7 mm[29] to 2.6 mm.[30] Six of the studies[24, 27–31,35] included a documented 12-month follow-up of the marginal bone loss. Four of the studies [24,27,29,31] evaluated the flapless surgical approach utilizing guided surgery in edentulous arches. In addition, the implants placed in these studies were all immediately loaded.

One of these studies[29] compared smokers (13 patients) and nonsmokers (7 patients) with regard to their annual bone loss after flapless implant insertion utilizing guided surgery. Sanna et al[29] did not observe significant changes in the mean marginal bone levels between smoking and non-smoking patients at baseline and after a 1-year follow-up (smokers—*baseline* 0.1 mm [SD 0.4 mm], *1 year* –1.1 mm [SD 1.4 mm]; nonsmokers—*baseline* 0.1 mm [SD 0.5 mm], *1 year* –0.8 mm [SD 1.1 mm]).

There was only one study[30] that compared the average marginal bone loss occurring with conventional versus flapless implant surgery. The authors reported slightly less bone loss for the flapless approach (–2.1 mm, SD 1.4 mm; n = 70 implants) versus the conventional approach (–2.8 mm, SD 1.5 mm; n = 39 implants).

Noteworthy was the marginal bone loss in one specific study[30] that reported a mean bone loss of 3 mm (SD 1.4 mm) after a follow-up of more than 12 months (n = 22 implants). The authors of this study also remarked that of all implants placed (n = 109), 27% demonstrated more than 2 mm bone loss, and 14% more than 3 mm bone loss over time. There was less bone loss noted for implants placed with conventional flap elevation and with a delayed loading protocol. The authors concluded that immediate loading and a flapless surgical approach for the one-piece implant used in the study were potential risk factors for failure for this implant type.[30]

Soft Tissue Changes

Only two of the included studies reported soft tissue changes.[25,35] Oh et al[25] randomly assigned patients to one of two groups: immediate loading or delayed (after 4 months) loading. A flapless approach was chosen for both groups. The authors assessed probing depths, modified bleeding index, modified plaque index, and the width of keratinized gingiva. There were no significant differences between the groups at each time and over 6 months.

In another study,[22] 79 implants were placed via the flapless approach with a delayed loading protocol. Probing depths were measured at baseline and up to 1 month after the delivery of the final restoration. The change between those two time points was clinically insignificant (baseline 2.2 mm [SD 0.9 mm]; up to 1 month 2.3 mm [SD 0.8 mm]).

Intraoperative Complications

Four studies evaluated intraoperative complications, including perforation of the buccal or lingual bony plate.[21,23,32,33] In addition, the aforementioned studies also included incidences of primary stability at the time of implant placement, which forced the surgeons to remove or submerge these implants in the given situation.

The overall incidence of intraoperative complications was 3.8% for the reported surgical procedures. However, it should be noted that the majority of the aforementioned complications were clustered in one specific study.[21] In the study by Campelo and Camara,[21] 770 dental implants were placed in edentulous and partially edentulous arches, all utilizing a flapless approach, and the patients were followed for 10 years. For each patient, the surgeons either obtained a CT scan or used a two-dimensional radiograph (eg, periapical radiograph) for diagnostic purposes prior to the surgical intervention. A surgical stent was routinely used during the procedure. However, the authors noted 21 fenestrations, and in these situations the authors altered the surgical protocol and performed a guided bone regeneration procedure at the time of implant placement. Dehiscences of the bone occurred for 15 implants, either resulting in an alteration of the selection of the implant site or in a delay of the implant placement in that specific site for 3 months after healing.

Presence or absence of perforations of the bone was not reported in the majority of the studies. As only 4 of 16 studies account for these intraoperative complications, the data should be interpreted with caution (Table 3).

DISCUSSION AND CONCLUSIONS

This systematic review evaluated the efficacy and clinical effectiveness of flapless surgery. Of the 17 studies identified as meeting the inclusion criteria, 1 of these was a systematic review not presenting pri-

Table 3 Complications and Failures

Study	Intraoperative complications	Postoperative complications: outcome measure	No. of implant failures	No. of biological complications	No. of technical complications	No. of esthetic complications
Becker et al 2005[22]	NR	NR	1	0	NR	NR
Campelo and Camara 2002[21]	36 perforations (21 fenestrations, 15 dehishences)	NR	37	NR	NR	NR
Cannizzaro et al 2007[23]	1 perforation 1 treatment aborted	NR	2	5 (intermittent pain = 1, hyperplastic tissue = 1 , peri-implant mucositis = 1, peri-implant peri-implantitis = 2); all < 10 mo and resolved	10 (unrelated to flapless placement)	NR
Fortin et al 2006[18]	NR	NR	0	NR	NR	NR
Malo et al 2007[24]	NR	0	2	0	8 (fracture of acrylic denture)	NR
Nkenke et al 2007[17]	NR	NR	NR	NR	NR	NR
Oh et al 2006[24]	NR	NR	3	NR	NR	2 (patient subjective; patient elected to have prosthetic redone)
Ozan et al 2007[26]	NR	NR	NR	NR	NR	NR
Rao/Benzi 2008[27]	NR	0	0	0	7 (5 screw loosening and 2 crown fractures)	NR
Rocci et al 2003[28]	NR	NR	9	NR	NR	NR
Sanna et al 2007[29]	NR	NR	9	NR	NR	NR
Sennerby et al 2008[30]	NR	NR	6	6 (same failed; immediate loading with flapless)	NR	NR
van Steenberghe et al 2005[31]	NR	marginal fistula (1), resolved	0	4 (inflamed hyperplastic gingiva)	4 (2 occlusal material fracture, 1 screw loosening, 1 patient decision for different prosthesis)	NR
Wittwer et al 2006[33]	2 perforations	NR	NR	2 (2.5%)	0	2 (implants not placed where intended)
Wittwer et al 2007[32]	2 treatments aborted (perforations, instability)	NR	NR	NR	NR	NR
Wittwer et al 2007[34]	NR	4 implants loose with immediate loading, all submerged, 2 lost	2	0	NR	0

NR = not reported.

mary evidence, and was therefore excluded. Of the remaining 16 articles, 2 were comparative cohort studies (level 2) primarily designed to document immediate postoperative clinical courses. The remaining 14 articles—7 prospective cohort studies (level 2) and 7 retrospective or case series studies (level 4)—evaluated clinical outcomes related to implant survival and other parameters (see Table 1).

All studies that assessed clinical implant performance utilized extensive presurgical planning, with the majority of the studies specifically utilizing computer-assisted planning.

The data extracted from the two studies documenting the postoperative clinical course demonstrated a statistically significant reduction in immediate postoperative discomfort, duration of discomfort, facial edema, and the use of analgesics when flapless surgery was performed.[17,18] Based on this preliminary and limited information, flapless surgery may have benefits in decreasing patient discomfort in the immediate postoperative period.

Information gathered from assessing the clinical performance of implants in the remaining 14 studies, which had a mean observation period of 19 months, showed high survival for implants placed utilizing a flapless technique. A 98.6% survival rate (95% CI: 97.6 to 99.6) based on the prospective cohort studies suggest clinical efficacy of the technique. The retrospec-

tive studies or case series demonstrated a 95.9% survival rate (95% CI: 94.8 to 97.0), suggesting effective treatment.

At this time, long-term data comparing soft tissue responses with flapless and conventional surgery are unavailable.

Complications with flapless surgery may be intraoperative, postoperative, or delayed (see Table 3). Four studies reported intraoperative complications, with perforation of the buccal or lingual bony plate occurring in 3.8% of surgical procedures; however, one should note that the majority of the complications were clustered in a single study.[21] Furthermore, the presence or absence of perforations was not reported in the majority of studies, and it is unclear what implications perforations may have for implant survival or occurrence of complications. Immediate postoperative and delayed complications appear to be similar to those encountered with a conventional surgical approach.

One limitation of this review is that the flapless surgical approach for implant placement was utilized in different clinical scenarios. This technique was employed for navigation and 3D guided surgery as well as for standard surgical protocols, which may or may not include the use of a surgical stent or guide. In addition, the loading protocols for the implants varied greatly in the 16 studies, and included immediate, delayed, and conventional loading. All of these factors, in addition to other confounding elements, have implications for the outcome of any given surgery, so it is questionable to extrapolate the clinical outcomes without considering the aforementioned variables.

Overall, to accurately assess the merits of the flapless technique, more studies with similar loading protocols that objectively compare conventional surgery with a flapless approach are needed.

Importantly, the available short-term data demonstrate that flapless surgery, initially recommended for novice surgeons, actually requires more experience and presurgical planning than was originally assumed. Furthermore, this technique is often more demanding than the conventional surgical approach. Therefore, the use of flapless implant placement as a "routine" procedure in daily practice is not recommended.

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Consensus Statements and Recommended Clinical Procedures Regarding Computer-Assisted Implant Dentistry

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INTRODUCTORY REMARKS

Technological advances often significantly influence the approach to implant treatment. One of the fields presently experiencing rapid development is computer-assisted implant dentistry. Recent advances in computer technology have allowed increased beneficial use of computers for planning and executing various steps involved in providing dental reconstructions borne on implants. Novel possibilities include computer assistance for the planning of surgical implant placement, for the implementation of the placement, for capturing the intraoral situation, for processing data to design temporary and final prostheses, and for the manufacturing of prosthetic components.

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These statements are part of the Proceedings of the Fourth ITI Consensus Conference, sponsored by the International Team for Implantology (ITI) and held August 26–28, 2008, in Stuttgart, Germany.

Because these developments are increasingly affecting implant therapy, a group at the 2009 ITI Consensus Conference was given the task of assessing the current clinical value and advantages and disadvantages of computer-assisted implant dentistry, based on the available literature.

The group consisted of individuals competent in various specialties in dental medicine and originating from different regions of the world. The environment that was created allowed the formulation of a comprehensive and unbiased consensus report on the topic.

Prior to the conference, three groups of researchers wrote comprehensive systematic reviews summarizing the available literature on three topics: *(1)* computer technology applications in surgical implant dentistry, *(2)* computer-assisted design and computer-assisted manufacturing in prosthetic implant dentistry, and *(3)* flapless surgery.

First, the reviewers presented their manuscripts, explaining how the task was approached, how the literature search was performed, what the search revealed, and what conclusions could be drawn. The group then assessed the validity of the process and either accepted or rejected the review. Thereafter, during a meticulous discussion of the manuscripts, possible additional contributions by group members were evaluated and, when found appropriate, added to the reviews. Finally, the group prepared consensus statements and recommendations for the clinic and for research and presented these to the plenum. Following input from the plenum, a final document was drafted.

In all three areas under review, the group felt that important contributions had been made that have an influence on clinicians in the application of computer-assisted implant dentistry. In addition, pertinent fields of research were identified for which a major need for further development and improvement exists.

Disclosure

All the group members were asked to reveal any conflicts of interest potentially influencing the outcomes of the consensus work. No such conflicts were identified.

COMPUTER TECHNOLOGY APPLICATIONS IN SURGICAL IMPLANT DENTISTRY

Definition of Terms

It was important to establish appropriate definitions for the terms to be used in this discussion of the applications of computer technology in implant surgery. The following definitions from the *Glossary of Oral and Maxillofacial Implants*, 2007,[1] were considered:

- **Image guidance**: The general technique of using preoperative diagnostic imaging with computer-based planning tools to facilitate surgical and restorative plans and procedures.
- **Computer-aided navigation**: Computer systems for intraoperative navigation, which provides the surgeon with current positions of the instruments and operation site on a three-dimensional reconstructed image of the patient that is displayed on a monitor (in the operating room). The systems aim to transfer preoperative planning on radiographs or computed tomography scans on the patient, in real time, and independent of the position of the patient's head.

It was felt by the group that these definitions no longer represented the current situation. For the purpose of this consensus review, these definitions were modified to:

- **Computer-guided (static) surgery**: The use of a static surgical template that reproduces the virtual implant position directly from computerized tomographic data and does not allow for intraoperative modification of the implant position.
- **Computer-navigated (dynamic) surgery**: The use of a surgical navigation system that reproduces the virtual implant position directly from computerized tomographic data and allows for intraoperative changes in implant position.

The group felt that the integration of computerized planning using these systems offers several potential perceived advantages and may result in less complex surgery. By visualizing bone volume preoperatively, it may be possible to place implants more precisely in the available bone, with a consequent reduction in any grafting requirements. Computerized planning also helps avoid anatomical complications and can be used with flapless surgery, which can lead to reduced morbidity. It might even allow for the provision of implant therapy where complex anatomical limitations had previously precluded treatment. The subsequent improved accuracy of implant placement should improve the prosthetic outcome and could also facilitate prefabrication of the prosthesis. Finally, increased surgical precision may lead to improvements in implant survival rates. In time, these systems might have the potential as teaching tools.

Consensus Statements

The systematic review paper by Jung et al indicated that in selected situations, computer technology applications are sufficiently accurate to justify use. There were, however, concerns over some of the reported figures for accuracy, which indicated a maximum deviation from the planned position that exceeded clinically acceptable parameters. It was suggested by the author of the paper that this might be due to intraoperative movement of the "static" surgical template. When the mean errors were considered, these could be considered adequate for many clinical applications. There was, however, a feeling that the learning curve for this technique-sensitive procedure could be quite steep, so caution should be exercised in the early stages of acquiring these skills.

The reviewed papers failed to demonstrate any long-term data to support an assumption that implant and prosthetic survival and success with computer-guided and computer-navigated surgical techniques are similar to those of traditional surgical interventions. It was felt by the group that although many components of this emerging computer-aided technique are the same as in conventional practice, it would be wrong to assume that the survival and especially the success rates would be the same.

Unfortunately, the rapid development of this poorly documented technology in such a commercially driven marketplace has led to unrealistic clinical expectations for the efficacy and ease of use of this technology. Again, the group advised caution when interpreting the claims made by companies promoting this computer technology for implant surgery.

Clinical Recommendations

It was generally felt by the group that both computer-guided and computer-navigated surgery may optimize several treatment processes, and with appropriate training, experience, and presurgical planning, could be useful in situations where there is complex anatomy and where minimally invasive surgery is desirable. They can also be used for the optimization of implant placement in critical esthetic cases and for immediate loading with preformed restorations.

Recommendations for Future Research

It was felt, after having discussed the systematic review by Jung et al, that a number of recommendations should be made to guide future research, pertaining

to both the areas to be investigated and the methodology employed.

1. Standardized data collection is needed to facilitate meta-analysis. This should include consistent "outcomes" together with "outcomes relative to time".
2. Where appropriate, the recording of data should make a distinction between that obtained from navigation or guidance systems.
3. To avoid inaccurate data collection, investigators should have appropriate training and skills with a system prior to initiating research.
4. The evaluation of clinical results should focus on patient-centered outcomes.
5. It would be useful for future studies to look at the evaluation of radiation exposure versus patient benefit.
6. It would also be valuable to assess the cost-effectiveness of this computer technology for patient treatment.

CAD/CAM MANUFACTURING IN PROSTHETIC IMPLANT DENTISTRY

Overview

Computer-assisted design (CAD) and computer-assisted manufacturing (CAM) have been applied in implant dentistry for the design and fabrication of prosthetic frameworks and prosthetic abutments.

A number of perceived advantages of these techniques were identified by the group. These included a potential for improved quality and precision by controlling the processing environment, and using specific software to determine the material dimensions required based on the physical and mechanical properties. It was anticipated that these advantages would result from the enhanced consistency of the more homogenous material and a shift from the traditional individual laboratory processes to one that is more industrialized. This should facilitate a minimized inventory and allow for remote communication and collaboration between clinicians, technicians, and other parties, with a potential reduction in cost.

Similarly, the group identified a number of perceived disadvantages of CAD/CAM manufacturing, including the cost and maintenance of equipment, along with the education and training necessary for its operation, and the potentially short life spans of the software and hardware. Due to the industrialized process there would be a lack of clinician control over some of the specific technical outcomes, and as some of the materials and material combinations are still clinically undocumented and possibly subject to inconsistency, concern was also expressed about their use.

Consensus Statements

The systematic review by Kapos et al was discussed by the group members, who suggested that while preliminary evidence for CAD/CAM in implant dentistry appears promising, the review of the literature concerning its use for the fabrication of frameworks and abutments fails to provide meaningful clinical evidence of safety and effectiveness associated with the routine use of this technology. The currently available information is insufficient to provide data for long-term documentation.

At present, technical developments are outpacing clinical research in the field of CAD/CAM implant abutments and frameworks, and it is recommended that users of this technology acknowledge this limitation in interpreting clinical research data. Clinicians and technicians also need to be aware that new materials and techniques are now being combined in a manner that has not been previously documented.

Clinical Recommendations

With the information available to the group from the systematic review by Kapos et al, it was felt that for clinical situations requiring highly individualized components, CAD/CAM can be considered the method of choice. Similarly, where the material of choice is zirconia or titanium, CAD/CAM could again be the preferred option. However, the steep learning curve necessary for the use of CAD/CAM technology requires both the clinician and the technician to undertake appropriate training prior to implementation of the system. Furthermore, the rapid progression of this technology necessitates continuous training to ensure optimal outcomes and, due to the high set-up costs, it is recommended that users have an understanding of the product support requirements for their system of choice.

While there is preliminary "proof of concept" that CAD/CAM technology is viable, it is recommended that clinicians be cautious in its clinical application, since these newly reported techniques provide no evidence for long-term clinical performance.

Recommendations for Future Research

Unfortunately, current literature describing the use of CAD/CAM technology for fabrication of abutments and frameworks consists primarily of laboratory and case studies. Even the clinical studies regarding the use of these techniques comprise only one prospective controlled study and four prospective cohort studies. For this reason, it is recommended that future clinical research be performed at the highest level of evidence possible, ie, randomized controlled clinical trials. In addition, laboratory investigations should continue to ensure safety and effectiveness of the

materials used in fabrication of these devices. Furthermore, research should specifically be targeted toward:

1. Linking material properties with manufacturing guidelines (enabling software limitations to be introduced for the maximum angulation and/or minimal wall thickness relative to the strength of different materials)
2. Clinical research to determine soft and hard tissue response within the entire craniofacial complex
3. Long-term assessment of complications (mechanical, technical, and material)
4. Clinical research to assess the esthetic, biologic, and mechanical benefits of this technology and these materials
5. Evaluation of the impact of this technology on patient quality of life using patient-centered outcomes

FLAPLESS SURGERY

Overview

Flapless surgery (ie, without the elevation of a mucoperiosteal flap) has been advocated as a method for implant placement that is quicker and less traumatic than the conventional approach, in which a soft tissue flap is raised. As a result, it has been proposed that this technique can often replace other conventional methods for implant surgery.

Flapless surgery has been recommended to reduce patient discomfort and postoperative sequelae, and to improve soft tissue response. A number of authors have demonstrated favorable results using this approach; frequently, they have specified that the precision of the surgery is dependent on the skills of the clinician and on comprehensive presurgical planning involving the use of computer-generated three-dimensional imaging.

Consensus Statements

After discussion of the systematic review by Brodala, it was felt by the group that the data on implant survival suggest that flapless implant surgery is efficacious and clinically effective in patients; however, this information was derived from relatively short-term studies (mean interval of 19 months), and based on the systematic review no comparative evidence was identified regarding soft tissue response. The measured incidence of intraoperative complications (3.2%) may be clinically relevant.

It is unclear from the systematic review by Brodala whether there is a higher rate of bony perforations using a flapless surgical technique, as the majority of articles did not report the presence or absence of this complication. It is also unclear whether such bony perforations will have long-term adverse effects on implants.

The systematic review by Brodala indicated that for the immediate postoperative period, available data demonstrated a statistically significant improvement in patient comfort with flapless versus conventional implant surgery. This was based on evidence from two high-level studies, but the same systematic review identified no comparative evidence regarding the soft tissue response.

The group also felt it was important that conclusions derived for flapless surgery not be extrapolated from other long-term studies utilizing the traditional surgical approach.

Clinical Recommendations

The group felt that the flapless surgery technique should normally be reserved for skilled and experienced implant surgeons who utilize comprehensive three-dimensional planning. From the review, it was apparent that implant survival using this technique appeared to be efficacious and clinically effective; however, this information was derived from relatively short-term studies.

Recommendations for Future Research

Implant survival alone should not be the specific outcome of interest in future flapless surgery studies.

1. Frequently the current literature identifies intraoperative circumstances that result in an alteration of the treatment approach. These represent a failure of the "intention to treat" as outlined in the research protocol. It is rare that this results in a comprehensive appraisal of treatment outcomes; ie, it is not interpreted as a failure, although it clearly is a protocol failure. Future studies must ensure that this oversight does not persist.
2. Further research into patient-centered outcomes associated with flapless surgery should be undertaken.
3. Studies that assess survival and complications (biological, technical, and esthetic) resulting from this technique are required.
4. Further studies are needed to determine the accuracy and precision of the surgical procedure.
5. It is strongly recommended that given the current uncertainty in the literature associated with the effects of bony perforations from this practice, long-term investigations of implants placed this way should be conducted.

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GROUP 3

Implant Loading Protocols

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Review Papers Submitted for Discussion:

Loading Protocols for Dental Implants in Edentulous Patients
German O. Gallucci/Dean Morton/Hans-Peter Weber

Implant Loading Protocols for Partially Edentulous Maxillary Posterior Sites
Mario Roccuzzo/Marco Aglietta/Luca Cordaro

Implant Loading Protocols for the Partially Edentulous Posterior Mandible
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Implant Loading Protocols for the Partially Edentulous Esthetic Zone
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Loading Protocols for Dental Implants in Edentulous Patients

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Purpose: *The objective of this systematic review was to present the current scientific and clinical evidence related to implant-supported rehabilitations for the edentulous mandible and maxilla.* ***Materials and Methods:*** *An electronic search of several databases covered the period from January 1966 to August 2008. From a total of 2,371 publications identified from this search, 61 articles fulfilled the inclusion criteria set forth by the authors. It should be noted that only studies reporting on implants with rough surfaces were included in the final selection for this review.* ***Results:*** *Selected studies yielded data from 2,278 patients and 9,701 implants. Studies were grouped according to treatment protocol and prosthodontic design, and results on conventional, early, and immediate loading were assessed separately for fixed and removable dental prostheses. Clinical recommendations for implant loading in different edentulous indications were established using a special validation protocol of the published scientific and clinical evidence for different treatment modalities, which was based on the study design, sample size, and outcome homogeneity between studies.* ***Conclusions:*** *The highest level of scientific and clinical validation was found for conventional loading with mandibular overdentures and maxillary fixed dental prostheses. Insufficient scientific or clinical documentation/validation was found for immediate loading of maxillary overdentures, as well as for immediate loading of immediately placed implants combined with fixed or removable dental prostheses in either jaw. All other loading protocols for edentulous arches showed different degrees of clinical documentation.* Int J Oral Maxillofac Implants 2009;24(SUPPL):132–146

Key words: *dental implants, edentulism, fixed dental prosthesis, loading protocol, mandible, maxilla, removable prosthesis, systematic review*

Loading protocols for the dental implant treatment of edentulous jaws have been widely discussed in the dental literature. Initial implant stability, implant surface characteristics, bone quality, bone healing, interim prosthesis design, and occlusion pattern during the healing phase have been identified as influential factors in successfully achieving osseointegration with modified loading protocols.[1]

While several randomized controlled trials (RCTs) and reviews have demonstrated clinical efficiency in shortening the time of loading for edentulous patients,[2–5] the related scientific evidence is mostly presented from the perspective of implant survival or success, and with only limited information about the prosthodontic treatment outcome. In order to accurately assess the impact of modified loading protocols in edentulous patients, data should ideally be analyzed separately according to: *(1)* maxillary and mandibular protocols, *(2)* fixed and removable rehabilitations, *(3)* machined and rough-surfaced implants, and *(4)* implant placement into healed sites and extraction sockets that are not yet healed. These factors have often been presented as having a direct influence on the implant and prosthodontic survival rate.

In addition, special consideration should be given to the patient's initial clinical status. Here, two groups can be well differentiated: patients who have been edentulous for a certain period of time, and patients

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who will become edentulous due to a failing dentition. These different initial situations will have a direct influence on the treatment sequence.

The objective of this review on loading protocols in edentulous patients was to present well-structured scientific and clinical evidence related to implant-supported rehabilitations for the edentulous mandible and maxilla. The specific aim was to assess the survival outcome of various loading protocols according to their treatment sequence and prosthodontic design.

MATERIALS AND METHODS

Search Strategy and Data Analysis

An electronic search for clinical trials on edentulous patients was performed using MEDLINE, PubMed, the Cochrane Controlled Trials Register, and the Cochrane Health Group Specialized Register from 1966 through June 2008. The search terminology included:

- *complete edentulous* AND *implant*
- *complete edentulous* AND *full-arch*
- *complete implant prostheses* OR *complete implant bridge*
- *fixed complete prostheses* AND *implant*
- *edentulous jaws* AND *implant*
- *edentulous jaws* AND *immediate implant loading*
- *edentulous jaws* AND *delayed implant loading*
- *edentulous jaws* AND *early implant loading*
- *edentulous jaws* AND *staged approach*
- *edentulous jaws* AND *loading protocols*
- *complete implant overdentures* OR *complete implant removable prostheses*

Hand-searching of all offline journals and bibliographies of reviewed articles relevant to the topic completed the general search. References appraised in related systematic reviews were also considered.

The search strategy was limited to clinical trials investigating the compatibility of different loading protocols with the achievement of osseointegration. For prospective data, only studies reporting implant and prosthetic survival outcomes after 12 or more months were included. Only clinical trials using endosseous root-shaped implants with rough surfaces were considered for this review. All levels of the hierarchy of evidence, with the exception of expert opinions, were included. For case reports, only studies with a minimum of 10 patients and edentulous arches were accepted.

Selected publications were collected in reference management software, and duplicates were electronically discarded.

After title and abstract screening of 2,371 publications obtained from the electronic search, 295 were selected for full-text reading. Sixty-one articles including data from 2,278 patients and 9,701 implants appeared to fulfill the inclusion criteria. Selected studies on loading protocols for edentulous patients were broken down according to jaw location and prosthodontic design (Table 1).

Validation Criteria

To formulate conclusions and propose clinical recommendations for various loading protocols in combination with prosthodontic treatment options for the edentulous mandible and maxilla, the included studies were ranked according to their design, sample size, and outcome homogeneity (OH). The outcome homogeneity was considered positive (OH+) when the variation of implant survival rates for the same treatment protocol was 10% or less, and negative (OH–) when the variation was greater than 10%.

Using these criteria, scientific and/or clinical validation was determined as follows:

Scientifically and Clinically Validated (SCV):

- Systematic reviews of RCTs or
- Two or more RCTs + ≥ 100 patients + OH+ or
- One RCT and two or more prospective studies + ≥ 150 patients + OH+

Clinically Well Documented (CWD):

- One RCT and two or more prospective studies + ≥ 40 patients + OH+ or
- No RCTs but at least three prospective studies + ≥ 60 patients + OH+ or
- No RCTs but two or fewer prospective studies + ≥ 100 patients + OH+

Clinically Documented (CD):

- No RCTs, at least two prospective + any retrospective studies + ≤ 40 patients + OH– or
- No RCTs, retrospective studies + ≥ 60 patients + OH–/+

Clinically Insufficiently Documented (CID):

- None of the above, expert opinion only, case report only

Each treatment modality described in Table 1 was subsequently categorized according to the above validation criteria and presented in Table 2.

Table 1 Number of Selected Publications Broken Down by Loading Protocol and Prosthodontic Treatment Modality

	Removable		Fixed	
	Maxilla	Mandible	Maxilla	Mandible
Conventional loading	3 studies 0 (RCTs) 2 (Prosp) 1 (Retro) 110 Pts/530 Impls 94.8%–97.7% OH+	10 studies 4 (RCTs) 4 (Prosp) 2 (Retro) 671 Pts/1,396 Impls 97.1%–100% OH+	4 studies 1 (RCT) 3 (Prosp) 0 (Retro) 104 Pts/719 Impls 95.5%– 97.9% OH+	4 studies 1 (RCT) 2 (Prosp) 1 (Retro) 207 Pts/1,254 Impls 97.2%–98.7% OH+
Early loading	2 studies 0 (RCTs) 2 (Prosp) 0 (Retro) 49 Pts/185 Impls 87.2%–95% OH-	4 studies 1 (RCT) 3 (Prosp) 0 (Retro) 68 Pts/136 Impls 97.1%–100% OH+	4 studies 1 (RCT) 1 (Prosp) 2 (Retro) 54 Pts/344 Impls 93.4%–99% OH+	3 studies 0 (RCTs) 2 (Prosp) 1 (Retro) 176 Pts/802 Impls 98.6%–100% OH+
Immediate loading	1 study 0 (RCTs) 1 (Prosp) 0 (Retro) 12 Pts/48 Impls 95.6% OH N/A	7 studies 0 (RCTs) 6 (Prosp) 1 (Retro) 329 Pts/1,161 Impls 96%–100% OH+	6 studies 0 (RCTs) 5 (Prosp) 1 (Retro) 153 Pts/893 Impls 95.4%–100% OH+	7 studies 0 (RCTs) 5 (Prosp) 2 (Retro) 181 Pts/942 Impls 98%–100% OH+
Immediate loading of immediately placed implants	N/A	N/A	4 studies 0 (RCTs) 1 (Prosp) 3 (Retro) 149 Pts/1,194 Impls 87.5%–98.4% OH-	2 studies 0 (RCTs) 0 (Prosp) 2 (Retro) 15 Pts/97 Impls 97.7%–100% OH+
Total subgroups	6	21	18	16
Total main groups	27		34	
Total	61			

RCT = randomized controlled trial; Prosp = prospective study; Retro = retrospective study; Pts = patients; Impls = implants; OH = outcome homogeneity (+ [less than 10% variation], – [more than 10% variation]).

Table 2 Validation of Loading Protocols for Different Prosthodontic Treatments in the Edentulous Mandible or Maxilla

	Removable		Fixed	
	Maxilla	Mandible	Maxilla	Mandible
Conventional loading	CWD	SCV	SCV	CWD
Early loading	CD	CWD	CD	CD
Immediate loading	CID	CWD	CWD	CWD
Immediate loading of immediately placed implants	CID	CID	CD	CID

SCV = scientifically and clinically validated; CWD = clinically well documented; CD = clinically documented; CID = clinically insufficiently documented (includes loading protocols that are not documented).

RESULTS: REMOVABLE IMPLANT PROSTHESES

Conventional Loading of Mandibular Implant Overdentures

This loading protocol describes the use of two to four implants placed in edentulous mandibles, to be connected to an overdenture after a healing period of 3 to 6 months. Several implant prosthetic designs have been proposed, such as two implants with single ball-shaped or locator attachments,[6–10] two implants splinted with a rigid bar construction,[8–17] four or more implants connected with a rigid bar construction,[12,14–17] and four or more single implants with ball-shaped or locator attachments (Table 3).[8]

Mericske-Stern[6] reported a clinical comparison of bar or single ball-shaped precision attachments placed onto two implants versus three or four

Table 3 Conventional Loading of Implant-Supported Mandibular Overdentures

Study	Study design	Implant type	No. of patients	No. of implants placed	Follow-up (y)	Implant failures	Implant survival rate (%)	Prosthodontic failures	Prosthodontic survival rate (%)
Mericske-Stern (1990)[6]	Retro	Straumann	62	140	1 to 5.5	2	98.6	NR	NR
Naert et al (1999)[11]	RCT	Dyna/ Nobel Biocare	36	72	5	1	98.6	NR	NR
Ferrigno et al (2002)[12]	Prosp	Straumann	129	348	10	7	97.1	2	97.7
Payne et al (2002)[7]	RCT	Straumann	12	24	2	0	100	NR	NR
Karabuda et al (2002)[8]	Retro	PittEasy Frialit 2	36	94	2-4	2	97.8	NR	NR
Heydenrijk et al (2002)[13]	Prosp	IMZ	40	80	1	2	97.5	NR	NR
Behneke et al (2002)[17]	Prosp	IMZ	100	340	5	4	98.8	NR	NR
Walton (2003)[9]	RCT	Nobel Biocare	100	200	3	0	100	12	88
Visser et al (2005)[15]	Prosp	IMZ	60	180	5	1	99.4	0	100
Stoker et al (2007)[16]	RCT	Straumann	96	258	8	3	98.8	6	93.7

RCT = randomized controlled trial; Prosp = prospective study; Retro = retrospective study; NR = not reported.

Table 4 Conventional Loading of Implant-Supported Maxillary Overdentures

Study	Study design	Implant type	No. of patients	No. of implants placed	Follow-up (y)	Implant failures	Implant survival rate (%)	Prosthodontic failures	Prosthodontic survival rate (%)
Ferrigno et al (2002)[12]	Prosp	Straumann	35	178	10	9	94.9	3	91.4
Mericske-Stern (2002)[20]	Retro	Straumann	41	173	1 to 9	9	94.8	NR	NR
Krennmair et al (2008)[21]	Prosp	IMZ	34	179	5	4	97.7	NR	NR

Prosp = prospective study; Retro = retrospective study; NR = not reported.

implants splinted with a bar. The author suggested that two implants could adequately serve as retention for a mandibular overdenture. Naert et al,[10] Karabuda et al,[8] and Lachmann et al[18] concluded in independent studies that the retention system for mandibular overdentures in splinted versus freestanding implants did not influence the peri-implant tissue outcome when using a conventional loading approach. However, prosthodontic considerations were not reported in these studies.

In a long-term prospective study, Visser and coworkers[15] addressed the question of the number of implants required for ensuring a long-lasting outcome. The authors concluded that there was no difference in the clinical and radiographic status of patients treated with an overdenture on two or four implants during a 5-year evaluation period.

In summary, 10 articles were included in the group of mandibular implant overdentures: 4 RCTs, 4 prospective studies, and 2 retrospective studies indicating a high level of evidence. Results from 671 patients who received 1,396 implants showed an implant survival rate ranging from 97.1% to 100% during a mean follow-up period of 1 to 10 years. The prosthetic survival rate was reported in only 4 of 9 selected articles, and showed a mean survival rate of 95.7% (88% to 100%).

Conclusions for conventional loading of implant overdentures in the edentulous mandible:

- Conventional loading of mandibular implant overdentures is scientifically and clinically validated (SCV).
- Implant survival rates (1 to 10 years) range from 97.1% to 100%.
- Prosthodontic survival rates range from 88% to 100%.
- Two implants, single or splinted, will serve as effectively as four splinted implants.

Conventional Loading of Maxillary Implant Overdentures

This loading protocol describes the use of four to six implants placed in the edentulous maxilla and restored with an overdenture after a healing period of 3 to 6 months. The implant-prosthetic design includes four or more freestanding implants[19] or four to six implants connected by a bar device (Table 4).[12,20,21]

Ferrigno et al[12] conducted a multicenter study with a conventional loading approach and reported a 10-year outcome with a lower survival rate than mandibular implant overdentures.

Mericske-Stern and coworkers[20] stated that optimal survival rates of maxillary implants supporting an overdenture can be enhanced with well-planned

Table 5 Early Loading of Implant-Supported Mandibular Overdentures

Study	Study design	Implant type	No. of patients	No. of implants placed	Follow-up (y)	Time of loading (wk)	Implant failures	Implant survival rate (%)	Prosthodontic failures	Prosthodontic survival rate (%)
Roynesdal et al (2001)[22]	Prosp	Straumann	11	22	1	3	0	100	NR	NR
Payne et al (2002)[7]	RCT	Straumann	12	24	2	6	0	100	0	100%
Attard and Zarb (2005)[4]	Prosp	Nobel Biocare	35	70	1	1.5	2	97.1	6	82.6
Turkyilmaz and Tumer (2007)[23]	Prosp	Nobel Biocare	10	20	2	1	0	100	NR	NR

RCT = randomized controlled trial; Prosp = prospective study; NR = not reported.

treatment concepts including conventional loading. Recently, Cavallaro and Tarnow[19] proposed using a minimum of four freestanding implants with locator abutments to support palate-free maxillary overdentures. After a conventional healing time, prostheses were attached to the implants, resulting in a 100% survival rate in a 12- to 48-month follow-up time. However, that article reports results from only five consecutive cases/arches, and for that reason was not part of this review.

In summary, three articles were included in the group of maxillary implant overdentures.[12,20,21] The level of evidence was lower than for mandibular overdentures, since only prospective and retrospective studies were available for analysis. Results from 110 patients receiving 530 implants showed a mean implant survival rate ranging from 94.8% to 97.7% during a mean follow-up period of 5 years (range 1 to 10 years). Only one study reported a prosthetic survival rate, which was found to be 91.4%.

Conclusions for conventional loading of implant overdentures in the edentulous maxilla:

- Conventional loading of maxillary implant overdentures is clinically well documented (CWD).
- Implant survival rates (1 to 10 years) range from 94.8% to 97.7%.
- Prosthodontic survival rates were described in one prospective study (91.4%, 3-year follow-up).
- More clinical trials are needed to scientifically and clinically validate the use of freestanding implants supporting maxillary overdentures with or without palatal coverage.

Early Loading of Mandibular Implant Overdentures

This approach describes mandibular implant overdentures that were functionally loaded no earlier than 48 hours after implant placement and no later than 3 months afterward. Two implants combined with an overdenture retained by single ball-shaped or locator abutments[7,22–24] was the only prosthodontic design identified (Table 5).

Roynesdal et al[22] compared conventional and early loading of two solid-screw dental implants supporting a mandibular overdenture. The authors concluded that the survival rate of rough-surfaced implants loaded 3 weeks after implant placement was similar to that of implants loaded in a conventional time frame, on the assumption that primary stability was achieved. Payne and coworkers,[7] in a randomized controlled trial, reported that pairs of unsplinted SLA-surfaced implants can be successfully loaded with mandibular overdentures 6 weeks after surgery. Turkyilmaz and Tumer[23] concluded that the implant survival rate in the anterior mandible was not compromised when using a 1-week functional early loading protocol with unsplinted implants supporting an overdenture.

In summary, for the group of mandibular implant overdentures with an early loading approach, four publications reported results with rough-surfaced implants.[7,22–24] An optimal level of evidence was supported by one RCT and three prospective controlled studies. While promising results were reported in the selected publications, this scientific evidence is based on 68 patients and 136 implants with a 2-year follow-up. The prosthodontic survival rate was reported in only two of the four selected articles.

Conclusions for early loading of implant overdentures in the edentulous mandible:

- Early loading (1 to 6 weeks) of mandibular implant overdentures is clinically well documented (CWD).
- Implant survival rates (1 to 2 years) range from 97.1% to 100%.
- Prosthodontic survival rates range from 82.6% to 100%.
- Two freestanding implants in the anterior mandible are sufficient for such a protocol.

Table 6 Early Loading of Implant-Supported Maxillary Overdentures

Study	Study design	Implant type	No. of patients	No. of implants placed	Follow-up (y)	Time of loading (wk)	Implant failures	Implant survival rate (%)	Prosthodontic failures	Prosthodontic survival rate (%)
Raghoebar et al (2003)[25]	Prosp	Biomet 3i	10	68	1	8	3	95.6	NR	NR
Payne et al (2004)[26]	Prosp	Nobel Biocare	39	117	2	12	15	87.2	NR	NR

Prosp = prospective study; NR = not reported.

Early Loading of Maxillary Implant Overdentures

This approach describes maxillary implant overdentures that were functionally loaded no earlier than 48 hours after implant placement and no later than 3 months afterward. Implant-prosthetic designs included four to six implants connected by a bar construction[25] and three freestanding implants with single ball or locator attachments (Table 6).[26]

Raghoebar et al[25] reported on an early loading protocol with overdentures supported by splinted implants. The authors concluded that in selected cases early loading of implants could develop into a predictable treatment modality. In a different approach with early loading, Payne et al[26] investigated the use of freestanding narrow-diameter implants loaded at 12 weeks with maxillary overdentures. The implant survival rate after a 2-year follow-up was 87.2%.

During the 2004 ITI Consensus Meeting on edentulous patients,[1] no publications were available for early loading protocols with maxillary overdentures. Results from the actual search revealed two references with a publication date subsequent to Chiapasco's.[1] These prospective studies describe results from 49 patients who received 185 rough-surfaced implants. The time of loading varied from 8 to 12 weeks, with an implant survival rate ranging from 87.2% to 95.6%. No data related to the prosthodontic survival rate could be retrieved.

Conclusions for early loading of implant overdentures in the edentulous maxilla:

- Early loading (8 to 12 weeks) of maxillary implant overdentures is clinically documented (CD).
- Implant survival rates (1 to 2 years) range from 87.2% to 95.6%.
- No prosthodontic survival rates are reported.
- More clinical trials are needed to scientifically and clinically validate the use of freestanding implants supporting maxillary overdentures with or without palatal coverage.

Immediate Loading of Mandibular Implant Overdentures

Immediate loading with mandibular implant overdentures is a protocol in which implants are connected to the prosthesis and placed in occlusal contact within 48 hours after implant placement. Implant prosthetic designs included immediate prosthetic loading of a single implant in the anterior mandible,[27] two single implants with ball and locator attachments,[28] two immediately loaded and splinted implants,[29] three free-standing implants immediately loaded with a ball or locator attachment,[30] and four or more implants connected with a bar construction (Table 7).[31–33]

Chiapasco and coworkers[31] presented results for immediately loaded implants splinted by a bar construction. The authors concluded that four splinted implants showed survival rates similar to delayed loading. Similar results were later presented by Gatti et al[32] and Romeo et al.[33] Stephan and coworkers[30] proposed an immediate loading protocol with 3 freestanding implants supporting a mandibular overdenture. It was concluded in this publication that the survival rate of three unsplinted immediately loaded implants with a mandibular overdenture was similar to rates of conventionally loaded implants. However, such a protocol is supported by a single publication reporting on 17 patients with no implant lost after a 2-year follow-up. Stricker et al[29] proposed a similar approach to Chiapasco et al,[31] but using two splinted implants. The conclusions suggested that two splinted implants can be successfully used. Marzola et al[28] proposed the immediate loading of two implants by means of a ball attachment–retained mandibular complete denture and concluded that this approach may become a predictable treatment option. Liddelow and Henry[27] reported the use of immediate loading with a single implant supporting a mandibular overdenture. Based on a single publication, this protocol showed lower survival rates for both implants (89.3%) and prostheses (89.3%).

In summary, the use of mandibular overdentures in combination with an immediate loading approach

Table 7 Immediate Loading of Implant-Supported Mandibular Overdentures

Study	Study design	Implant type	No. of patients	No. of implants placed	Follow-up (y)	Time of loading (d)	Implant failures	Implant survival rate (%)	Prosthodontic failures	Prosthodontic survival rate (%)
Chiapasco et al (1997)[31]	Retro	Straumann	226	904	2–13	1	24	96.9	3	98.5%
Gatti et al (2000)[32]	Prosp	Straumann	21	84	2–5	1	3	96.0	NR	NR
Romeo et al (2002)[33]	Prosp	Straumann	10	40	2	2	1	97.5	0	100%
Stricker et al (2004)[29]	Prosp	Straumann	10	20	2	1	0	100	1	90%
Stephan et al (2007)[30]	Prosp	Nobel Biocare	17	51	2	2	0	100	NR	NR
Liddelow and Henry (2007)[27]	Prosp	Nobel Biocare	28	28	1	1	3	89.3	3	89.3
Marzola et al (2007)[28]	Prosp	Nobel Biocare	17	34	1	1	0	100	2	88.3

Prosp = prospective study; Retro = retrospective study; NR = not reported.

Table 8 Immediate Loading of Implant-Supported Maxillary Overdentures

Study	Study design	Implant type	No. of patients	No. of implants placed	Follow-up (y)	Time of loading (d)	Implant failures	Implant survival rate (%)	Prosthodontic failures	Prosthodontic survival rate (%)
Cannizzaro et al (2007)[34]	Prosp	Zimmer	12	48	1	1	1	95.6	0	100

Prosp = prospective study.

on rough-surfaced implants was supported in seven publications. Six were prospective studies, and one was retrospective. Data were extracted from 329 patients receiving 1,161 implants. The scientific evidence can be divided between the well-documented immediate loading protocol using four splinted implants and the more recent proposals with immediate loading using fewer than four implants.

Conclusions for immediate loading of implant overdentures in the edentulous mandible:

- Immediate loading (1 to 2 days) of mandibular implant overdentures is scientifically and clinically validated (SCV).
- Implant survival rates (1 to 13 years) range from 96% to 100%.
- Prosthodontic survival rates range from 88.3% to 100%.
- The number of implants (two to four) and whether they are single or splinted has no effect on the implant survival.

Immediate Loading of Maxillary Implant Overdentures

Immediate loading with maxillary implant overdentures describes a protocol in which a removable prosthesis is attached to the implants and placed in occlusal contact within 48 hours after implant placement (Table 8).

Use of four implants splinted by a bar construction and immediate loading was supported by one single publication.[34] Although the selected article for this category fulfilled the inclusion criteria, the small sample of the patient population and the number of implants precluded the drawing of any conclusions.

Conclusions for immediate loading of implant overdentures in the edentulous maxilla:

- Immediate loading (1 to 2 days) of maxillary implant overdentures is clinically insufficiently documented (CID).

RESULTS: FIXED IMPLANT PROSTHESES

Conventional Loading of Mandibular Fixed Implant Prostheses

This loading protocol describes the use of dental implants placed in an edentulous mandible to support a fixed dental prosthesis after a healing period of 3 to 6 months. Implant prosthetic designs included four to six implants with a one-piece full-arch fixed prosthesis[35–37] and eight implants with a one-piece full-arch fixed prosthesis (Table 9).[12]

Table 9 Conventional Loading of Implant-Supported Fixed Prostheses in the Edentulous Mandible

Study	Study design	Implant type	No. of patients	No. of implants placed	No. of implants per patient	Follow-up (y)	Implant failures	Implant survival rate (%)	Prosthodontic failures	Prosthodontic survival rate (%)
Arvidson et al (1998)[35]	Retro	Astra Tech	107	618	4–6	5	8	98.7	0	100
Ferrigno et al (2002)[12]	Prosp	Straumann	40	320	8	10	5	98.5	0	100
Moberg et al (2001)[36]	RCT	Straumann/ Nobel Biocare	40	208	4–6	3	5	97.5	0	100
Rasmusson et al (2005)[37]	Prosp	Astra Tech	20	108	4–6	10	3	97.2	0	100

RCT = randomized controlled trial; Prosp = prospective study; Retro = retrospective study.

Table 10 Conventional Loading of Implant-Supported Fixed Prostheses in the Edentulous Maxilla

Study	Study design	Implant type	No. of patients	No. of implants placed	No. of implants per patient	Follow-up (y)	Implant failures	Implant survival rate (%)	Prosthodontic failures	Prosthodontic survival rate (%)
Ferrigno et al (2002)[12]	Prosp	Straumann	55	440	8	10	9	97.9	2	96.3
Bergkvist et al (2004)[38]	Prosp	Straumann	25	146	5–7	2	5	96.6	0	100
Rasmusson et al (2005)[37]	Prosp	Astra Tech	16	88	4–6	10	3	96.6	0	100
Fischer et al (2008)[2]	RCT	Straumann	8*	45	5-6	3	2	95.5	NR	NR

*Patients belonging to a larger sample population of 32 patients with a different loading protocol.
RCT = randomized controlled trial; Prosp = prospective study; NR = not reported.

Arvidson et al,[35] Ferrigno et al,[12] Moberg et al,[36] and Rasmussen et al[37] concluded in similar clinical trials that the long-term clinical results of mandibular implant-supported fixed rehabilitations were highly successful in terms of prosthetic function and implant stability.

In summary, scientific evidence on fixed implant rehabilitations for the edentulous mandible with conventional loading and rough-surfaced implants was supported by one RCT, two prospective studies, and one retrospective study with follow-ups of 3 to 10 years. These clinical trials reported data from 207 patients and 1,254 rough-surfaced implants. The implant survival rate ranged from 97.2% to 98.7% and the prosthodontic survival rate was 100% for all four clinical trials.

Conclusions for conventional loading of fixed implant prostheses in the edentulous mandible:

- Conventional loading of mandibular fixed implant prostheses is scientifically and clinically validated (SCV).
- Implant survival rates (3 to 10 years) range from 97.2% to 98.7%.
- The prosthodontic survival rate is 100%.
- The prosthesis design was full arch, one piece, supported by four to eight implants.

Conventional Loading of Maxillary Fixed Implant Prostheses

This loading protocol describes implant-supported rehabilitations in edentulous maxillae that have been in occlusal function after a healing period of 3 to 6 months. Implant prosthetic designs included four to seven implants supporting a one-piece prosthesis[2,37,38] and eight implants with a fixed full-arch rehabilitation (Table 10).[12]

In a longitudinal study, Ferrigno et al[12] concluded that a maxillary fixed full-arch prosthesis supported by eight implants with an anterior-posterior distribution allows for an optimal long-term implant survival rate. Accordingly, Bergkvist et al,[38] Rasmusson et al,[37] and Fischer et al[2] reported successful survival rates and concluded that rough-surfaced solid-screw implants in combination with fixed prostheses represent a viable treatment alternative in the edentulous maxilla.

In summary, scientific evidence on fixed implant rehabilitations in the edentulous maxilla was supported by three prospective studies and one RCT, with follow-up of up to 10 years. Implant survival rates were similar for all four independent publications, ranging from 95.5% to 97.9%, and included 719 rough-surfaced implants placed in 104 patients. Implant-prosthetic designs were exclusively found in

Table 11 Early Loading of Implant-Supported Fixed Prostheses in the Edentulous Mandible

Study	Study design	Implant type	No. of patients	No. of implants placed	No. of implants per patient	Follow-up (y)	Time of loading (wk)	Implant failures	Implant survival rate (%)	Prostho-dontic failures	Prosthodontic survival rate (%)
Collaert and De Bruyn (2002)[41]	Retro	Astra Tech	25	108	4–5	2	4	0	100	0	100
Friberg and Jemt (2008)[40]	Prosp	Nobel Biocare	90	450	5	1	1	0	100	2	97.8
Arvidson et al (2008)[39]	Prosp	Straumann	61	244	4–5	3	1	3	98.6	0	100

Prosp = prospective study; Retro = retrospective study.

one-piece full-arch rehabilitations and varied in the number of implants and their distribution.

Conclusions for conventional loading of fixed implant prostheses in the edentulous maxilla:

- Conventional loading of maxillary fixed implant prostheses is scientifically and clinically validated (SCV).
- Implant survival rates (3 to 10 years) range from 95.5% to 97.9%.
- Prosthodontic survival rates range from 96.3% to 100%.
- The prosthesis design was generally full arch, one piece, and supported by four to eight implants.

Early Loading of Fixed Implant-Supported Prostheses in the Edentulous Mandible

This loading protocol describes mandibular fixed implant rehabilitations that have been in functional loading 48 hours after implant placement, but no longer than 3 months. Implant prosthetic protocols were described as four to five implants supporting a fixed one-piece rehabilitation (Table 11).[39–41]

In a 3-year follow-up, Collaert and De Bruyn[41] reported that early loading of four to five implants in the edentulous mandible with cross-arch fixed prostheses was a predictable procedure. Friberg and Jemt[40] compared the outcomes of early loading with rough- and machined-surface implants. In this 1-year follow-up study the authors concluded that the implant survival rate was significantly higher for rough-surfaced implants. In a similar clinical trial, Arvidson et al[39] reported that treatment outcomes for early loading in the edentulous mandible with fixed prostheses are comparable with conventional protocols. In addition, no increase in the incidence of implant–prosthetic complications was reported when compared to conventional protocols. Patient benefits included reduced treatment time and improved quality of life.

In summary, one retrospective and two prospective studies supported the scientific evidence on early loading of implants in the edentulous mandible with fixed implant rehabilitations. They included data from 176 patients and 802 rough-surfaced implants with a 1- to 3-year follow-up. The time of loading varied from 1 to 4 weeks and the implant survival rate ranged from 98.6% to 100%.

Conclusions for early loading of mandibular fixed implant-supported rehabilitations:

- Early loading of mandibular fixed implant prostheses is clinically documented (CD).
- Implant survival rates (1 to 3 years) range from 98.6% to 100%.
- Prosthodontic survival rates range from 97.8% to 100%.
- Prosthesis design was full arch, one piece, supported by four to five implants.

Early Loading of Fixed Implant-Supported Prostheses in the Edentulous Maxilla

Early implant loading with fixed rehabilitations describes a protocol in which implants have been in occlusal contact no earlier than 48 hours and no later than 3 months. Implant prosthetic protocols included five to eight implants supporting maxillary fixed implant rehabilitations (Table 12).[2,42–44]

Olsson et al[44] and Nordin et al[43] concluded that early loading protocols can be applied with predictable results using rough-surfaced implants for the rehabilitation of the edentulous maxilla with fixed prostheses. In an RCT, Fischer at al[2] showed no important differences between early and delayed loading of implants in the edentulous maxilla after 5 years of function.

In summary, the sample population for early loading with fixed implant-supported rehabilitation in the edentulous maxilla included 54 patients and 344 rough-surfaced implants. One RCT, one prospective,

Table 12 Early Loading of Implant-Supported Fixed Prostheses in the Edentulous Maxilla

Study	Study design	Implant type	No. of patients	No. of implants placed	No. of implants per patient	Follow-up (y)	Time of loading (wk)	Implant failures	Implant survival rate (%)	Prostho-dontic failures	Prosthodontic survival rate (%)
Olsson et al (2003)[44]	Retro	Nobel Biocare	10	61	6–8	1	2	4	93.4	NR	NR
Nordin et al (2004)[43]	Retro	Straumann	16	98	6	1	2	1	99.0	NR	NR
Fischer et al (2008)[2]	RCT	Straumann	16	94	5–6	5	2	5	94.7	NR	NR
Lai et al (2008)[42]	Prosp	Straumann	12	91	6–8	3	6	1	98.9	0	100%

RCT = randomized controlled trial; Prosp = prospective study; Retro = retrospective study; NR = not reported.

Table 13 Immediate Loading of Implant-Supported Fixed Prostheses in the Edentulous Mandible

Study	Study design	Implant type	No. of patients	No. of implants placed	No. of implants per patient	Follow-up (y)	Time of loading (wk)	Implant failures	Implant survival rate (%)	Prostho-dontic failures	Prosthodontic survival rate (%)
Ganeles et al (2001)[45]	Retro	Straumann, Astra, Frialit-2	27	161	5–8	2	1	1	99.4	NR	NR
Gallucci et al (2004)[47]	Prosp	Straumann	6*	34	6	1	1	0	100	0	100
Testori et al (2004[48]	Prosp	Biomet 3i	62	325	5–6	1	2	2	99.4	NR	NR
Drago and Lazzara (2006)[46]	Prosp	Biomet 3i	27	151	5–6	1	1	3	98	0	100
Degidi et al (2006)[51]	Retro	Nobel Biocare	9	50	4–5	3	1	0	100	?	?
Capelli et al (2007)[49]	Prosp	Biomet 3i	24	96	4	3	2	0	100	0	100
De Bruyn et al (2008)[50]	Prosp	Astra Tech	25	125	5	3	1	0	100	0	100

*Patients belonging to a larger sample population of 11 edentulous arches.
Prosp = prospective study; Retro = retrospective study; NR = not reported.

and two retrospective studies with a follow-up time of 1 to 5 years yielded implant survival rates ranging from 93% to 99%.

Conclusions for early loading of maxillary fixed implant-supported rehabilitations:

- Early loading of maxillary fixed implant prostheses is clinically documented (CD).
- Implant survival rates (1 to 3 years) range from 93.4% to 99%.
- Prosthodontic survival rates are not reported.
- The prosthesis designs were full-arch one-piece or segmented supported by five to eight implants.

Immediate Loading of Fixed Implant-Supported Prostheses in the Edentulous Mandible

Immediate loading with mandibular implant overdentures describes a protocol in which a fixed provisional contact is attached to the implants and placed in occlusal function within 48 hours after implant placement. Implant-prosthetic protocols were described as cross-arch fixed rehabilitations with anterior-posterior distribution of five to eight implants,[45,46] segmented rehabilitations with anterior-posterior distribution of six implants,[47] and full-arch prostheses with anterior implants and distal cantilevers (Table 13).[48–51]

Ganeles and coworkers[45] reported that with appropriate stabilization and distribution of occlusal load, mandibular implants can be immediately loaded in a complete-arch configuration with no apparent detrimental effect on the rate of osseointegration. In a similar clinical trial but with a smaller sample population, Gallucci et al[47] concluded that osseointegration with immediate implant loading via fixed provisional restorations can be successfully achieved. Furthermore, the authors suggested that neither the metal-free design of the provisional prostheses nor the removal of the provisional prostheses during the healing phase adversely affected osseointegration. Testori et al,[48] Drago and Lazzara,[46] Degidi et al,[51] and De Bruyn et al,[50] each using different implant systems, stated that the rehabilitation of the

Table 14 Immediate Loading of Implant-Supported Fixed Prostheses in the Edentulous Maxilla

Study	Study design	Implant type	No. of patients	No. of implants placed	No. of implants per patient	Follow-up (y)	Time of loading (d)	Implant failures	Implant survival rate (%)	Prostho-dontic failures	Prosthodontic survival rate (%)
Gallucci et al (2004)[47]	Prosp	Straumann	5*	40	8	1	1	2	95.4	0	100
Malo et al (2005)[52]	Retro	Nobel Biocare	32	128	4	1	1	3	97.6	4	87.5
Ostman et al (2005)[53]	Prosp	Nobel Biocare	20	123	6–7	1	1	1	99.2	NR	NR
van Steenberghe et al (2005)[54]	Prosp	Nobel Biocare	27	184	6–8	1	1	0	100	0	100
Capelli et al (2007)[49]	Prosp	Biomet 3i	41	246	4–6	3	2	5	97.9	0	100
Bergkvist et al (2009)[55]	Prosp	Straumann	28	168	6	2	1	3	98.2	NR	NR

*Patients belonging to a larger sample population of 11 edentulous arches.
Prosp = prospective study; Retro = retrospective study; NR = not reported.

edentulous mandible with an immediate, occlusally loaded provisional hybrid prosthesis is a viable treatment alternative to the classical delayed protocols. Capelli and coworkers[49] presented similar results for immediate loading using only four implants (two straight and two tilted).

In summary, immediate loading of rough-surfaced implants with a fixed provisional restoration was well supported by seven publications, mostly prospective studies. With a sample population of 181 patients and 942 implants and a follow-up of 1 to 3 years, the implant survival rate ranged from 99.4% to 100%. One interesting finding with this protocol is that there were no prosthetic failures during the follow-up period.

Conclusions for immediate loading of fixed mandibular implant-supported rehabilitations:

- Immediate loading of mandibular fixed implant prostheses is scientifically and clinically validated (SCV).
- Implant survival rates (1 to 3 years) range from 98% to 100%.
- The prosthodontic survival rate is 100%.
- Prosthesis designs were full-arch one-piece or segmented supported by four to eight implants.

Immediate Loading of Fixed Implant-Supported Prostheses in the Edentulous Maxilla

This loading protocol describes maxillary implants that have been placed in occlusal function via fixed prostheses no later than 48 hours after surgery. Implant prosthetic designs have been proposed as four to six implants with full-arch prostheses and distal cantilevers,[49–52] five to eight implants with a one-piece full-arch prosthesis,[53–55] and eight implants distributed along the edentulous maxilla to support a segmented rehabilitation (Table 14).[47]

Various implant-prosthetic protocols have been proposed for immediate implant loading in the edentulous maxilla. Gallucci and coworkers[47] loaded maxillary implants immediately via a full-arch fixed interim prosthesis that was later replaced by a segmented final rehabilitation, as first described by Belser et al.[56] The authors concluded that this approach was compatible with the achievement of osseointegration, although the sample population was considered small. In a similar clinical trial, Ostman et al[53] and Bergkvist et al[55] concluded that six to seven implants for immediate loading of a fixed provisional prosthesis is a viable option for implant treatment of the edentulous maxilla, at least when good primary implant stability can be ensured. Malo et al,[52] using a protocol of four immediately loaded implants and some rescue ones left unloaded, presented comparable implant survival rates. Similar results were found by Capelli et al[49] when using four to six implants. Van Steenberghe et al[54] reported on immediate loading using models derived from three-dimensional oral implant planning software. The authors concluded that this protocol is a reliable treatment option. On the other hand, this was the sole publication yielded by the search on such a protocol.

In summary, scientific background for immediate loading with fixed interim prostheses in the edentulous maxilla was supported by one retrospective and five prospective studies. No RCTs were available at the time of the search. Only one study had a follow-up of 3 years, one had a 2-year follow-up, and four had 1-year follow-ups. The sample population included 153 patients receiving 893 immediately loaded rough-surfaced implants. The implant survival rate ranged from 95.4% to 100%, and the prosthodontic survival rate ranged from 87.5% to 100%. One notable finding

Table 15 Immediate Implant Placement and Loading with Fixed Prostheses in the Mandible

Study	Study design	Implant type	No. of patients	No. of implants placed	No. of implants per patient	Mean follow-up (y)	Time of loading (d)	Implant failures	Implant survival rate (%)	Prostho-dontic failures	Prosthodontic survival rate (%)
Grunder (2001)[58]	Retro	Biomet 3i	5*	43	8–10	2	1	1	97.7	NR	NR
Cooper et al (2002)[57]	Retro	Astra Tech	10	54	4–6	1.5	1	0	100	0	100

*Patients belonging to a larger sample population of 10 edentulous patients.
Retro = retrospective study; NR = not reported.

was that most of the failed implants were located in the posterior maxilla.

Conclusions for immediate loading of maxillary implant-supported rehabilitations:

- Immediate loading of maxillary fixed implant prostheses is scientifically and clinically validated (SCV).
- Implant survival rates (1 to 3 years) range from 95.4% to 100%.
- Prosthodontic survival rates range from 87.5% to 100%.
- Prosthesis designs were full-arch one-piece or segmented supported by four to eight implants.

Immediate Loading of Immediately Placed Implants with Fixed Prostheses in the Edentulous Mandible

This loading protocol describes maxillary implants that have been immediately placed into extraction sockets and into occlusal function with fixed prostheses no later than 48 hours after surgery. The implant-prosthetic protocol included 4 to 6 immediately placed implants supporting fixed prostheses with distal cantilevers[57] and 8 to 10 implants splinted by a one-piece full-arch fixed rehabilitation (Table 15).[58]

Grunder[58] reported on the immediate placement and loading of rough-surfaced implants supporting a fixed rehabilitation. The authors showed that the immediate functional loading of immediate implants without the use of any bone substitutes or barrier membranes for fixed full-arch reconstructions can be successful over a 2-year period. In a similar loading protocol but with a different prosthetic design, Cooper et al[57] concluded that in selected healthy patients, significant time and clinical visits may be saved by simultaneous extraction, implant placement, and restoration with a simple acrylic-resin provisional prosthesis.

In summary, two retrospective studies were identified from the electronic search. They reported data from 15 patients and 97 immediately placed and loaded implants with a follow-up ranging from 1.5 to 2 years. The implant survival rate ranged from 97.7% to 100%. One article reported no prosthodontic failures.

Conclusions for immediate loading of immediately placed implants with fixed prostheses in the edentulous mandible:

- Immediate loading of immediately placed implants with fixed implant prostheses is clinically insufficiently documented (CID).
- Implant survival rates (1.5 to 2 years) range from 97.7% to 100% (15 patients only).
- The prosthodontic survival rate is 100%.
- The prosthesis design was full-arch one-piece supported by 4 to 10 implants.

Immediate Loading of Immediately Placed Implants with Fixed Prostheses in the Edentulous Maxilla

This protocol describes maxillary implants that have been inserted immediately into extraction sockets and placed in occlusal function no later than 48 hours with a fixed prostheses. Implant-prosthetic designs were described as 6 to 8 implants splinted by a full-arch prosthesis[59] and 8 to 12 implants splinted by a one-piece full-arch fixed rehabilitation (Table 16).[58,60,61]

The reliability of this loading protocol has been supported by Degidi et al[60] with the conclusion that wider implants had a higher risk of failure. Grunder[58] and Jaffin et al[59] reported similar results, concluding that immediate loading of immediately placed implants in the edentulous maxilla was a viable treatment alternative. Balshi et al,[61] in a prospective study of full-arch maxillary immediate loading, suggested that this protocol was suitable for most patients in need of full maxillary implant reconstruction to provide long-term stability of screw-retained fixed prostheses.

In summary, data for immediate placement and loading of rough-surfaced implants in the edentulous maxilla were supported by one prospective and three retrospective studies. In 2 to 5 years of follow-up, the sample population consisted of 149 patients receiving

Table 16 Immediate Implant Placement and Loading with Fixed Prostheses in the Maxilla

Study	Study design	Implant type	No. of patients	No. of implants placed	No. of implants per patient	Mean follow-up (y)	Time of loading (d)	Implant failures	Implant survival rate (%)	Prostho-dontic failures	Prosthodontic survival rate (%)
Grunder (2001)[58]	Retro	Biomet 3i	5*	48	8–11	2	1	6	87.5	NR	NR
Jaffin et al (2004)[59]	Retro	Straumann	34	236	6–8	2	2	16	93.2	NR	NR
Degidi et al (2005)[60]	Retro	Several	55	388	6–12	5	2	6	98.4	NR	NR
Balshi et al (2005)[61]	Prosp	Nobel Biocare	55	522	8–11	3	1	8	98.4	0	100

*Patients belonging to a larger sample population of 10 edentulous patients.
Prosp = prospective study; Retro = retrospective study; NR = not reported.

1,194 implants. Thirty-six failures were recorded, yielding an implant survival rate ranging from 87.5% to 98.3%. Implant-prosthetic designs were diverse, particularly in terms of the number of implants per patient (8 to 12). The prosthodontic outcomes were rarely described.

Conclusions for immediate loading of immediately placed implants with fixed prostheses in the edentulous maxilla:

- Immediate loading of immediately placed implants with fixed prostheses is clinically documented (CD).
- Implant survival rates (2 to 5 years) range from 87.5% to 98.4%.
- The prosthodontic survival rate, reported in only one study, is 100%.
- The prosthesis design was full-arch one-piece supported by 6 to 12 implants.

Staged Approach for Fixed Implant Rehabilitations in Edentulous Jaws

This approach describes a treatment sequence for patients who present a failing dentition and are receiving fixed implant rehabilitation. According to Cordaro et al,[62] the main advantage of this protocol is the avoidance of a removable provisional phase. In addition, the protocol was presented as an alternative to immediate implant placement and loading.[62,63]

The electronic search performed for this review failed to show any relevant clinical trials for this treatment modality.

Conclusions for staged approach for fixed implant rehabilitations in edentulous jaws:

- More clinical trials are needed to scientifically and clinically validate this protocol.

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Implant Loading Protocols for Partially Edentulous Maxillary Posterior Sites

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Purpose: *To evaluate early and immediate loading of implants in the posterior maxilla and to investigate whether there is a difference in success rates, survival rates, and peri-implant parameters, including marginal bone level changes.* ***Materials and Methods:*** *A comprehensive systematic review of the literature was conducted. The selection of publications reporting on human clinical studies was based on predetermined inclusion criteria and was agreed upon by two reviewers.* ***Results:*** *Twelve papers were identified on early loading (two randomized controlled clinical trials [RCTs] and 10 prospective case series studies). Six papers were found on immediate loading (one RCT, four prospective case series, and one retrospective study).* ***Conclusions:*** *Under certain circumstances it is possible to successfully load dental implants in the posterior maxilla early or immediately after their placement in selected patients. The success rate appears to be technique sensitive, although no study has directly assessed this. A high degree of primary implant stability (high value of insertion torque) and implant surface characteristics play an important role. It is not possible to draw evidence-based conclusions concerning contraindications, threshold values for implant stability, bone quality and quantity needed, or impact of occlusal loading forces. As for the impact of the surgical technique on implant outcome in different bone densities, no studies prove significant superior results with one technique over another. Well-designed RCTs with a large number of patients are necessary to make early/immediate loading protocols in posterior maxilla evidence based, but ethical and practical considerations may limit the real possibility of such studies in the near future.* Int J Oral Maxillofac Implants 2009;24(suppl):147–157

Key words: *dental implants, fixed dental prostheses, loading protocol, partial edentulism, posterior maxilla, single crown, systematic review*

Patients' levels of knowledge and expectations for treatment with dental implants have increased tremendously in recent years. Successful modern therapy can no longer be judged simply by whether implants osseointegrate.

Historically, it has been proposed that implants require a two-stage surgical protocol and an extended load-free healing phase for successful tissue integration. To minimize the risk of failure, the healing period in the maxilla was originally proposed to be 6 months.[1] Since then, the introduction of new implant surfaces has made it possible to modify loading protocols, although the prerequisites for achieving good results and the limitations of such protocols are not yet known. A number of articles have provided evidence that survival outcomes of implants loaded early in posterior regions are similar to those of implants placed in anterior sites under standard protocols. Therefore, it would be useful to assess whether the healing period could be shortened without jeopardizing implant success rates, even in areas of low bone density.

Jaffin and Berman[2] first described the high rate of implant loss in type 4 bone, with a thin cortex and low trabecular density, as is often found in the posterior maxilla. Interestingly, the presence of type 4 bone was described not only in the maxilla and in the posterior mandible, but also in the area anterior to the mental foramina. The authors concluded that knowledge of the presence of type 4 bone prior to surgery can lead to an alternative treatment plan, possibly one that does not include implants. Drago[3] found that successful osseointegration was most dependent on

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anatomical location in the jaws, as posterior maxillary implants placed according to the Brånemark protocol failed 28.6% of the time. On the other hand, a year later Bahat[4] found that the failure rate of similar implants placed in type 4 bone was only slightly higher than that in type 2 and type 3 bone, even though not all patients were considered good candidates for implants in the posterior maxillae. Type 4 bone was also found in sites corresponding to the premolar region.

It must be noted, however, that the possibility of reliable, clinically practical differentiation between the various types of bone has been questioned by Trisi and Rao.[5] Nevertheless, many recent studies have presented data that differentiate among the four bone types. A recent consensus paper[6] questioned the validity of the Lekholm and Zarb[7] classification and its additional ability to determine bone quality. The negative influence of low-density bone in the maxilla was also confirmed in a recent study by Herrmann and associates.[8] Post-hoc analyses confirmed that type 4 jawbone exhibited the highest failure rate.

Based on the assumption that placement of implants in the maxillary molar region requires considerably more caution in terms of performing the surgery, several authors have suggested a thorough evaluation of the bone prior to surgery in this region. Ikumi and Tsutsumi[9] advocated the use of a routine preoperative computed tomography (CT) examination to predict bone quality and expected initial implant stability. Shapurian and coworkers[10] stated that knowledge of the Hounsfield value can provide the surgeon with an objective assessment of the bone density, which could result in modification of the surgical techniques or extended healing time, especially in situations where poor bone quality is suspected. Turkyilmaz et al[11] observed that bone density is lowest in the posterior maxilla (455 ± 122 HU), and about half of the density in the anterior mandible (945 ± 207 HU). More recently, Turkyilmaz and McGlumphy[12] concluded that there is a lower threshold value of bone density for early loading and that "early loading of dental implants may be possible in sites where bone density is over 528 HU." A common assumption is that a pretreatment CT examination is always cost-effective, even though no scientific evidence definitively supports the claim.

Resonance frequency analysis has been proposed to measure implant stability based on the capacity to identify differences in bone density at the recipient sites.[13]

Many papers in the literature define bone quality as equivalent to bone density. Nevertheless, it was recently pointed out during the European Academy of Osseointegration (EAO) Consensus Meeting[6] that many factors are important when investigating bone quality other than bone density alone (eg, bone metabolism, cell turnover, mineralization, maturation, intercellular matrix, and vascularity). These factors, and possibly others, may well influence implant survival, especially in the context of immediate or early loading.

The 2003 ITI Consensus Conference proposed that "in the partially dentate maxilla and mandible, the immediate restoration or loading of implants supporting fixed prostheses is not well documented. In contrast, the early restoration or loading of titanium implants with a roughened surface supporting fixed prostheses after 6 to 8 weeks of healing is well documented and predictable in the partially dentate maxilla and mandible."[14] No clinical recommendations were given for immediate restoration or loading in the edentulous or partially dentate maxilla. For early restoration or loading in the partially dentate maxilla, the ITI Consensus recommended a fixed prosthesis: "Implant number and distribution are dependent on patient circumstances, including bone quality and quantity, number of missing teeth, condition of opposing dentition, type of occlusion, and bruxism. Implants must be characterized by a rough titanium surface and are allowed to heal for at least 6 weeks and in type 1, 2, or 3 bone."[14]

Since then, several systematic reviews on immediate and early loading protocols[15–20] have been published. All of these attempted to compare conventional with early and immediate loading protocols by analyzing the outcomes of selected clinical studies. Each of these reviews, however, was based on the selection and inclusion of a number of articles with great variability in intraoral implant location (maxilla versus mandible, anterior versus posterior), local oral conditions, implant systems used, type of prosthesis, etc, thus introducing the possibility of inconsistent interpretation of the outcomes.

Moreover, selection criteria varied from author to author. Attard and Zarb[15] searched for articles in English in MEDLINE and manually, but did not clearly state their selection procedure. They divided the studies into three categories: *(1)* fixed prostheses, *(2)* single crowns, and *(3)* overdentures. Ioannidou and Doufexi[16] as well as Del Fabbro et al[17] included various types of studies, while Nkenke and Fenner[18] based their analysis on prospective controlled studies and prospective studies without controls. Jokstad and Carr[19] decided to include only clinical trials that attempted to compare early or immediate loading of implants versus a delayed procedure and that incorporated any element of time (ruling out cross-sectional studies). Only Esposito and colleagues[20] limited the analysis to randomized controlled clinical trials (RCTs), based on the assumption that this type of

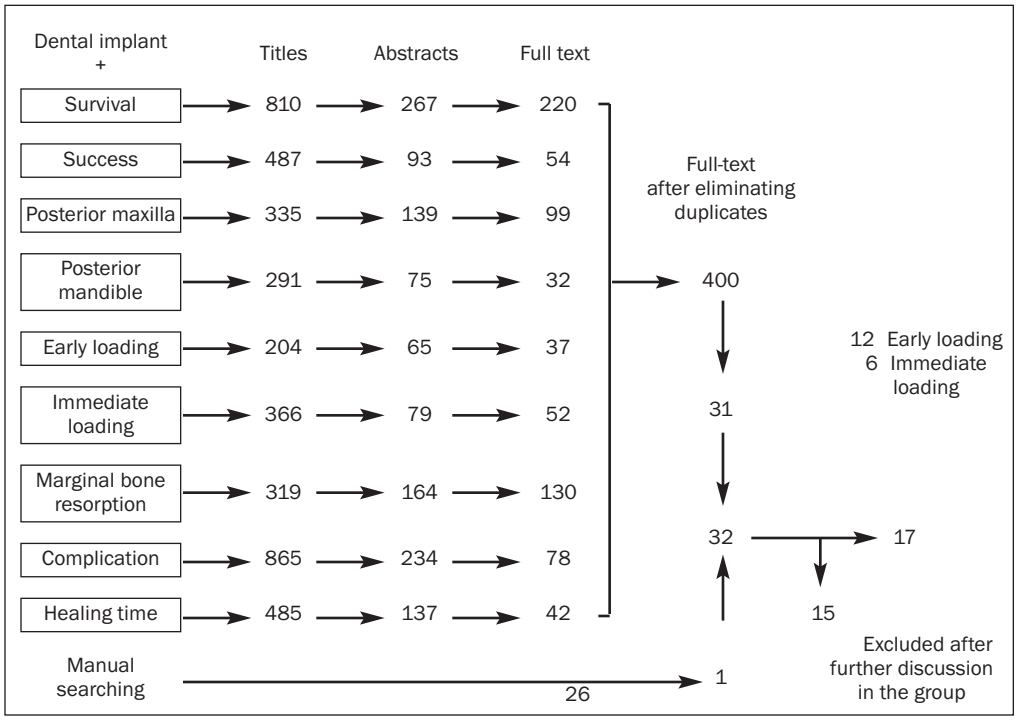

Fig 1 Search strategy for early and immediate loading protocols in posterior sites.

study presents the highest level of evidence. It is worth noting that, according to the Cochrane Collaboration protocol, both published and unpublished articles were included. As a result, the comparison between immediate and early loading was based on a meta-analysis of only two short-term, unpublished RCTs. In the present authors' opinion it is debatable whether data from a limited number of RCTs are more significant than data from a wider range of studies, such as case series with a large sample size. In any case, results have to be interpreted with caution.

Since uniformly accepted time frames for various loading protocols have not been unequivocally defined, different authors present "personal" definitions of "immediate" loading.[21] For example, recent research involving immediately loaded implants restored with crowns 4 days after surgery in dogs concluded that it was "unlikely that different results would have been obtained if the crowns were connected earlier."[22] In one of the above-mentioned reports it was acknowledged that "future research and clinical experience with peri-implant tissue healing may provide more appropriate definitions."[14] In the present authors' opinion, however, a universally acceptable definition would only be reachable through consensus by a conference of experts. It would certainly be an auspicious occasion to create a common platform on which to interpret various protocols and achieve a worldwide consensus.

To increase the possibility of achieving excellent primary stability, various clinical techniques have been suggested, such as the under-preparation of the implant site,[23] the use of a non-occluding temporary prosthesis during the first 2 months of healing,[24] the preparation of the implant site by means of osteotomes,[25–27] or the progressive loading of a prosthesis.[28]

While the success of immediately loaded implants in the mandible has been well documented, less evidence is available regarding the efficacy of early or immediate loading of maxillary implants, especially in the posterior region.

The aim of this systematic review was to evaluate the predictability of early and immediate loading protocols for implants in the posterior maxilla and to investigate whether there is a difference in success rates, survival rates, and peri-implant parameters, including marginal bone level changes, between the respective protocols. The loading definitions established by the 2003 ITI Consensus Conference were used for this review.[14]

MATERIALS AND METHODS

Search Strategy and Procedures (Fig 1)

A critical review of the literature including pertinent articles published in English was conducted. The most recent electronic search leading to this paper was undertaken on May 1, 2008.

Searching was performed using the electronic database MEDLINE (PubMed). Key words used in the search included: *dental implants, early loading, healing time, immediate loading, posterior maxilla, marginal bone resorption, complications, success rate,* and *survival rate*.

A hand search of the following journals for publications from 1991 to present was also conducted: *Clinical Oral Implants Research, International Journal of Periodontics & Restorative Dentistry, Journal of Periodontology, Journal of Clinical Periodontology,* and *International Journal of Oral & Maxillofacial Implants*.

Bibliographies from selected articles, the proceedings of the second (1997) and third (2003) ITI Consensus Conference, the position papers of the American Academy of Periodontology, and the Proceedings of the Third European Workshop on Periodontology (1999) were screened as well.

All levels of hierarchy of evidence, except for expert opinions, were accepted. Only studies with 10 or more cases in the posterior maxilla, reporting outcomes at 12 or more months, were accepted. If multiple papers included the same population, only the most recent one was used. The search was limited to studies involving human subjects published in English that included the evaluation of various healing times between surgery and loading.

Outcome measures were survival rate, success rate, and marginal bone loss.

Data Collection and Analysis

Titles and abstracts obtained through the described search were screened by two independent reviewers (Marco Aglietta, Ferruccio Torsello). The screening was performed using hard copies of the selected titles and abstracts, and included studies meeting the following criteria:

- Human trials
- Loading time
- Longitudinal studies
- Clinical outcomes

Articles involving implants in extraction sockets, guided bone regeneration, sinus floor elevation, zygomatic implants, and full-arch reconstructions were excluded. Full-text articles of studies with possible relevance were assessed by two reviewers (Mario Roccuzzo and Luca Cordaro). Any disagreement was discussed and resolved, and authors were contacted to provide, if possible, missing data. Two emails were attempted to each author for a request of further information.

The methodical quality of the studies was assessed to appraise:

- Method of randomization in controlled clinical trials. This was classified as *adequate* when a random number table, coin toss, or shuffled cards were used; *inadequate* when other methods of randomization such as alternate assignment, hospital number, odd/even birth date, etc, were applied; and *unclear* when the method of randomization was not reported or not explained.
- Allocation concealment in controlled clinical trials. This was classified as *adequate* when examiners were kept unaware of the randomization sequence, eg, by means of central randomization, sequential numbering, or opaque envelopes; *inadequate* when other methods of allocation concealment were used, such as alternate assignment, odd/even birth date, etc; and *unclear* when the method of allocation concealment was not reported or not explained.
- Completeness of follow-up was considered present if the number of patients was reported both at baseline and at completion of the follow-up, and if the analysis took into account the dropouts.

Significant data from the selected articles were recorded for the following two loading categories:

1. Early loading of implants placed in posterior maxillary sites
2. Immediate loading of implants placed in posterior maxillary sites

RESULTS

Of the 400 papers selected for the full-text analysis, most were excluded because they did not clearly report the applied loading protocols and/or made it impossible to separate data for the posterior maxilla from the whole sample. For a few papers, the application of inclusion/exclusion criteria was particularly difficult and became possible only after personal communication with the corresponding authors.

In the early loading group, the following publications were not included: Bornstein et al,[29] because data of interest for this review were from only 9 patients; Luongo at al,[30] which did not clearly state the location of failures; Testori et al[31] and Galli at al,[32] due to the insertion of implants in fresh extraction sockets; Fradera et al[33] because the study was described as prospective in the Materials and Methods section but retrospective in the title and it was not possible to get clarification from the publication itself or from the authors. Vanden Bogaerde et al[34] was not included because it was not possible to know the number of patients included in the specific group

of interest, and Levine et al[35] placed several maxillary implants in conjunction with internal sinus augmentation using a bone-adding osteotome technique.

In the immediate loading group, the following articles were excluded: Glauser et al[36] due to the presence of cases with simultaneous guided bone regeneration; Degidi and Piattelli[37] and Matchei et al[38] because they had only nine patients in their material; and Calandriello et al,[39] Testori et al,[24,31] Galli et al,[32] and Boronat et al[40] because it was not possible to identify the number of patients included in the group of interest. Finne et al[41] presented cases including full-arch reconstructions and a combined survival rate for maxilla and mandible. Degidi and Piattelli[42] as well as Degidi et al[43] reported interesting data regarding immediate functional and nonfunctional loading of 646 and 1,005 dental implants, respectively, with significant follow-ups. Both articles had to be excluded, however, because the detailed analysis of the tables revealed that an unidentified number of implants were placed in extraction sites.

Early Loading

Twelve papers were identified and included (Table 1). Only two of them were RCTs.[44,45] The remaining 10 were prospective single-technique case series.[26,27,46–53]

Cochran et al[46] reported on a longitudinal, prospective, multicenter study of early loading of 383 sandblasted and acid-etched (SLA) implants placed in the posterior jaws of 307 patients. Of these, 44 were placed in the posterior maxilla and were allowed to heal for 42 to 63 days in classes 1 to 3 bone and for 84 to 105 days in class 4 bone prior to restoration. Patients who were heavy smokers or who had inadequate bone volume, bruxism, or immediate placement indications were excluded. No implant was lost at 1-year analysis.

Testori and coworkers[47] presented a longitudinal, prospective, multicenter early loading study of 475 Osseotite implants (Biomet 3i) placed in the posterior jaws. Of these, 123 were placed in the maxillary premolar and molar area and 2 failed to integrate, giving an estimated cumulative survival rate of 98.4% after 3 years.

Roccuzzo and Wilson[26] reported on 36 implants placed in 19 nonsmoking patients in areas corresponding to the second and third molars, using a specific surgical protocol. In order to increase initial implant stability in an area where bone has low density, drilling was limited to the minimum, and most of the site preparation was produced with osteotomes to compact and compress maxillary trabecular bone. Abutment connection was carried out at 15 Ncm after 43 days, and the implants were restored with provisional restorations. After 6 additional weeks, the abutments were torqued to 35 Ncm for definitive restoration. One implant rotated with pain at abutment connection and was subsequently removed. The other 35 implants were restored uneventfully, leading to a 1-year survival rate of 97.2%. The authors reported implant clinical indices similar to the 6-week period, and interproximal marginal bone loss was 0.55 ± 0.49 mm after 1 year of loading.

Nedir et al[48] presented a 7-year life table analysis from a prospective study on ITI implants, with special emphasis on the use of short implants loaded within 63 days. All early loaded implants, including implants 6 mm in length, resisted the applied 35 Ncm without rotation or pain.

Vanden Bogaerde and coworkers[49] published a prospective study of 31 nonsmoking, nonbruxing patients with 36 edentulous areas treated with Brånemark Mk IV implants (Nobel Biocare) provisionally restored 4 to 16 days after surgical placement. Thirty-nine implants were placed in 18 patients in the area of the premolar and first molar, with an estimated survival rate of 97.5%.

Nordin et al[50] presented the 1-year results of a 3-arm study on early loading of SLA implants. A group of 19 patients, partially edentulous in the posterior maxilla, were treated with 37 implants. The implant survival rate was 98.3%.

Sullivan et al[51] published a 5-year report on early loading of Osseotite implants 2 months after placement in the maxilla and mandible in 10 private practice centers. A total of 526 implants were placed. Of these, 123 were located in the posterior maxilla. The authors found only one implant failure.

Turkyilmaz and coworkers[52] conducted a prospective clinical and radiologic study of maxillary implants supporting single-tooth crowns using early (6 weeks) and delayed (6 months) loading protocols. Data on 10 patients who received 21 implants in premolar and molar regions revealed a survival rate of 95.2% at the 4-year follow-up.

Cochran and coworkers[53] reported on a longitudinal, prospective, multicenter study of early loading of SLA implants. A total of 706 patients were enrolled, and 1,406 implants were placed. In the final analyses, 590 patients with 990 implants met the inclusion criteria. The cumulative survival rate was 99.3% at 5 years.

Roccuzzo and coworkers[54] conducted a prospective study with split-mouth design, comparing 6-week loading of SLA implants to 3-month loading of titanium plasma sprayed (TPS) implants in 32 healthy patients. No implants were placed in the areas corresponding to the maxillary second and third molars. The results of the 5-year follow-up on 27 patients were presented in a recent paper.[44] Data regarding

Table 1 Selected Articles on Early Loading in the Posterior Maxilla

Study	Study type	Implant surface	No. of patients included	Sites	Smallest implant	No. of implants placed	No of implants loaded	Time of loading	Follow-up	Occlusal contacts	Type of prostheses	Splinted	Survival rate	Early failures	Results
Cochran et al (2002)[46]*	Pros	SLA	21	Premolars and molars†	Ø 4.1× 8 mm	44	44	46–63 d	1 y	NR	FDP	Yes	100%‖	0	NR
Testori et al (2002)[47]	Pros	Osseotite	> 10†	Premolars and molars	Ø 8.5 × 3.75 mm	123	121	2 mo	up to 3 y	NR	SC/FDP	NR	98.4%	2	NR
Roccuzzo and Wilson (2002)[26]	Pros	SLA	19	Second and third molars§	Ø 4.1 × 10 mm	36	35	43 ± 1 d	1 y	Yes	SC/FDP	No	97.2%	1	Bone loss: 0.55 ± 49 mm
Nedir et al (2004)[48]*	Pros	SLA	> 10†	Posterior maxilla	Ø 6 × NR mm	42	42	< 3 mo	Up to 7 y	Yes	SC/FDP	Not necessarily	100%	0	NR
Vanden Bogaerde et al (2004)[49]*	Pros	TiUnite	18	No second and third molars	Ø 4 × 8.5 mm	39	39	4–16 d	18 mo	No	Multiple	Yes	97.5%	0	NR
Nordin et al (2004)[50]	Pros	SLA	19	Posterior maxilla	NR	37	NR	4–22 d	1 y	Yes	SC/FDP	Yes	98.3%	NR	NR
Sullivan et al (2005)[51]	Pros	Osseotite	> 10†	Premolars and molars	NR	123	122	2.1 ± 0.5 mo	Up to 5 y	Yes	SC/FDP	No	99%	1	NR
Turkyilmaz et al (2007)[52]	Pros	TiUnite	10	Premolars and molars	Ø 4 × 10 mm	21	21	6 wk	4 y	Yes	SC	No	95.2%	0	NR
Cochran et al (2007)[53]*	Pros	SLA	> 10†	Premolars and molars	Ø 4.1 × 8 mm	68	68	6–8 wk	Up to 6 y	Yes	NR	NR	100%	0	NR
Roccuzzo et al (2008)[44]*	RCT	SLA	13	No second and third molars	Ø 4.1 × 8 mm	22	19¶	6 wk	5 y	Yes	SC/FDP	No	100%	0	NR
Ganeles et al (2008)[45]*	RCT	SLActive	> 10†	No second and third molars	Ø 4.1 × 8 mm	52	52	28–34 d	12 mo	No	SC/FDP	No	98.1%	1	NR
Roccuzzo and Wilson (2009)[27]	Pros	SLActive	35	Molars§	Ø 4.1 × 10 mm	35	29#	21 ± 1 d	1 y	Yes	SC/FDP	No	100%	0	Bone loss: 0.22 ± 35 mm

Pros = prospective; RCT = randomized controlled clinical trial; FDP = fixed dental prosthesis; SC = single crown; NR = not reported; Ø = diameter.
*Additional specific data provided by the authors upon request.
†Data deduced from the analysis of the text.
‡No type 4 bone.
§Site preparation by combining milling and osteotome technique.
‖One spinner at the time of abutment connection.
¶Three spinners: these implants were loaded after 6 additional weeks.
#Six spinners: these implants were loaded after 4 additional weeks.

the posterior maxillary region included 13 patients with 22 implants. Of these, 19 were loaded early (at 6 weeks) while 3 exhibited "spinning" at the abutment connection. At the 60-month follow-up, all implants were in full function.

In a prospective study, Roccuzzo and Wilson[27] reported on 35 patients receiving SLActive implants (Straumann, Andover, MA, USA) in the maxillary molar areas. Preparation of implant sites with drills was limited to a minimum; most of the site preparation was produced with osteotomes. No screw-tapping was performed. Primary stability was predictably achieved with this technique. Abutment connection was carried out at 21 (± 2) days after surgery using 15 Ncm torque, and provisional restorations were delivered with occlusal contact. During abutment connection, 6 of the 35 patients reported minor pain, and provisional placement was postponed for 4 additional weeks. Further abutment tightening at 35 Ncm was performed after 4 to 6 additional weeks prior to final restoration. Radiographic measurements taken at baseline and at the 1-year follow-up revealed marginal bone loss of 0.22 ± 0.35 mm versus the immediate postoperative radiographs.

In a recent paper, Ganeles and coworkers[45] presented the 1-year results from a prospective multicenter study on immediate and early loading of SLActive implants in the posterior mandible and maxilla. No implant was placed in the position corresponding to the third molar. Patients received a temporary restoration (single crown or 2- to 4-unit fixed partial denture) out of occlusal contact 28 to 34 days later. Any patient with implants lacking primary stability, tested intraoperatively by hand, was excluded. Fifty-two implants were placed in the posterior maxilla, and the 1-year survival rate was 98.1%.

Immediate Loading

Six papers were identified and included (Table 2). Only the study of Ganeles and coworkers[45] was an RCT; four were prospective single-technique case series[55–58] and one was a retrospective study.[59]

Buchs and coworkers[55] presented a prospective multicenter study on the placement and immediate loading of 143 implants. Of these, 44 were in the posterior maxilla, but none was in the position corresponding to the third molar. The implants were followed for a period of 10 to 29 months.

Proussaefs and Lozada[56] reported on immediate loading with threaded hydroxyapatite-coated root-form implants for single first premolar replacement. Ten implants in 10 patients were followed for 3 years. Patients with a history of bruxism were excluded, as were surgical sites exhibiting type 4 bone, as assessed during surgery. Mean bone loss was 1 ± 0.26 mm.

Table 2 Selected Articles on Immediate Loading in the Posterior Maxilla

Study	Study type	Implant surface	No. of patients included	Sites	Bone quality/ primary stability	Smallest implant	No of implants placed	Restoration time limit	Follow-up	Occlusal contacts	Type of prostheses	Splinted	Survival rate
Buchs et al (2001)[55]	Pros	Altiva NTR	> 10†	No third molars		Ø 4 × 10 mm	44	< 24 h	10–29 mo	NR	NR	NR	93%–100%
Rocci et al (2003)[59]	Retr	Mk IV (machined)	> 10†	Premolars and molars	No type 4 bone	Ø 4 × 8.5 mm	67	NR	24–36 mo	NR	SC/FDP	NR	88%
Proussaefs and Lozada (2004)[56]	Pros	HA-coated	10†	First premolars	No type 4 bone	NR	10	NR	3 y	No	SC	No	100%§
Calandriello and Tomatis (2005)[57]*	Pros	TiUnite	11†	No second and third molars		Ø 4 × 10 mm	26‡	NR	1 y	Light	FDP	Yes	100%
Achilli et al (2007)[58]*	Pros	Various	10	Premolars and molars	No type 4 bone/ torque > 30 Ncm	Ø 3.5 × 10 mm	23	< 24 h	1 y	Light	FDP	NR	100%
Ganeles et al (2008)[45]*	RCT	SLActive	> 10†	No second and third molars		Ø 4.1 × 8 mm	71	NR	12 mo	No	SC/FDP	NR	97.2%

Pros = prospective; Retr = retrospective; RCT = randomized controlled clinical trial; FDP = fixed dental prosthesis; SC = single crown; Ø = diameter.
*Additional specific data provided by the authors upon request.
†Data deduced from the analysis of the text.
‡ Also tilted implants.
§ Mean bone loss: 1.0 (SD 0.26).

Rocci and coworkers[59] presented a retrospective 3-year clinical study on immediate loading in the maxilla using flapless surgery. Sixty-seven implants were placed in the posterior maxilla. No implants were inserted in areas of type 4 bone. During the 2 to 3 years of follow-up, eight implants were lost, yielding a survival rate of 88%.

Calandriello and Tomatis[57] proposed the use of tilted implants placed in immediate/early function. The prospective 1-year clinical study included 60 implants placed in 18 patients to support 19 fixed partial or full-arch prostheses. The authors provided information regarding 11 patients, who received 26 implants to support fixed partial dentures in light occlusal contact. At 1-year evaluation no implant was lost.

Achilli and colleagues[58] conducted a prospective multicenter study on immediate/early function with tapered implants involving maxillary and mandibular posterior fixed partial dentures. Data regarding immediate loading in the posterior maxilla were provided by the author, and referred to 23 implants placed in 10 patients. Implant stability was tested with a reverse torque of 30 Ncm. No implants were placed in type 4 bone. The occlusal surfaces of the provisional prostheses allowed light occlusal contact and minimal or no lateral excursive contacts. At the 1-year follow-up no implant was lost.

In a recent RCT, Ganeles and coworkers[45] presented the 1-year results of a prospective multicenter study on immediate and early loading of SLActive implants in the posterior mandible and maxilla. Data regarding immediate loading in the posterior maxilla were provided by the authors. The smallest implants used were 8 mm in length and 4.1 mm in diameter. At 12 months, the survival rate was 97.2%. A significant center effect was observed involving differences in bone level changes between immediate and early loading that were partially dependent on the center. The authors suggested that the immediate loading group was more heterogeneous. No implant was immediately loaded in positions corresponding to the second and third molars.

DISCUSSION

Several previous systematic reviews sought to test the hypothesis that there is no difference in the clinical performance of implants loaded at different times. In all cases, definitive conclusions could not be drawn concerning success rates of implants loaded immediately/early compared to conventionally loaded implants. Moreover, no information was obtainable regarding specific indications in high-risk situations, such as the posterior maxilla.

Several authors have proposed variations to implant placement techniques in order to adapt the standard surgical protocol to soft bone conditions. In these situations, therefore, one can assume that the risk of failure is increased. This review attempted to find the best available evidence relative to clinical outcomes for fixed implant-supported prostheses in the posterior maxilla under immediate/early loading protocols. Drawing definitive conclusions from the selected articles is difficult, as the articles are not directly comparable due to the diversity of inclusion criteria, treatment protocols, and defined outcomes. These are basically the same limitations Ganeles and Wismeijer[60] identified in their literature review.

One important issue is the definition of *posterior maxilla*. Traditionally, the segment of the alveolar process distal to and including the first premolar is considered posterior.[10,61] Even though this assumption seems reasonable from a prosthetic point of view, from an anatomical point of view the quality of the bone in the premolar area appears more similar to the canine region than to the posterior molar region.

Jaffin and Berman[2] were the first to notice that poor bone quantity and especially poor bone quality are the main risk factors for implant failure with standard protocols. Since then, many articles have been published with various conclusions. More recently, Ikumi and Tsutsumi[9] stated that "implants in the maxillary molar region in particular appear to have a lower osseointegration rate before loading and a lower survival rate over time as compared to other sites."

Esposito and coworkers[20] concluded that a high degree of primary stability at implant insertion is a key prerequisite for a successful immediate or early loading procedure. "The main outcome for this type of study is the success of the prosthesis, since implant loss may not always jeopardize prosthesis success." It is hard to understand why after such strict selection criteria such a broad definition of success was employed.

In two recent RCTs, Testori et al[31] and Galli et al[32] suggested that there are no major clinical differences between immediately restored non-occlusally loaded implants and early (2 months) loaded implants. However, to be immediately loaded, single implants had to be inserted with a torque of ≥ 30 Ncm, and splinted implants with a torque of ≥ 20 Ncm. In the protocol formulation phase, it was decided that implants randomized to the immediately loaded group having lower torque resistance should instead be treated as part of the early loaded group. Therefore, no conclusions can be drawn for implants in type 4 bone, as it is usually found in the posterior maxilla.

In most of the studies on early/immediate loading, good bone quality has been mentioned as an important prognostic factor, although the level of evidence

that supports this assumption is limited. Moreover, no controlled clinical trial, to the best of our knowledge, has compared the relationship between different implant stability levels and the implant survival rate.

Of the six selected articles on immediate loading, three avoided areas with type 4 bone,[56,58,59] one required a minimal insertion torque,[58] one did not include the area of the third molar,[55] and two did not include the area of both the second and third molars.[45,57] All these different specific exclusion criteria make comparisons difficult. Moreover, the clinician should be aware of the risk of reproducing the loading protocols in these studies in daily practice without exercising the same exclusion criteria.

A common belief is that treatment with immediate loading improves patient satisfaction and is cost-effective, even though no scientific evidence supports this claim. This is especially true in the posterior maxilla, where early loading can include the possibility of a long-span fixed partial denture (four or five elements) supported by only two implants. However, the question of how many teeth can safely be supported by two implants is still an open one. In addition, no data are available to assess if short (< 8 mm) and/or narrow (< 3.5 mm) implants could also be included in similar protocols. Finally, limited spinning at abutment connection in the case of early loading, particularly in low-density bone, has been described in several papers. Recent publications, however, confirmed that if it is properly handled, this produces no detrimental effect on the clinical outcome.[44]

Degidi and Piattelli[42] attempted to address important questions related to immediate loading. In particular they suggested that the PU/I (the ratio between the number of prosthetic units and the number of implants) should be as close as possible to 1 and should not exceed 1.4 in the maxilla, independent of functional or nonfunctional loading. The authors further advised that every effort should be made to deliver the prosthesis on the same day as the surgery. These conclusions, however, need to be validated by future studies.

CONCLUSIONS

Under certain circumstances, it is possible to successfully load dental implants in the posterior maxilla early or even immediately after their placement in selected patients, although only skilled clinicians can achieve optimal results. The success rate seems to be technique sensitive, even though no data are available regarding this aspect. A high degree of primary implant stability (high value of insertion torque) seems to be one of the prerequisites for a successful immediate/early loading procedure. Preliminary results seem to indicate that implant surface characteristics may play an important role in the success rate of the procedure.

At this point, it is not possible to draw conclusions concerning exclusion criteria, threshold values for implant stability, bone quality and quantity needed, or impact of occlusal loading forces. As for the impact of the surgical technique on implant outcome in different bone densities, no studies prove significant superior results with one technique over another.

Well-designed RCTs with a large number of patients are necessary to make early/immediate loading protocols in the posterior maxilla evidence based, but ethical and practical considerations may limit the real possibility of such studies in the near future.

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Implant Loading Protocols for the Partially Edentulous Posterior Mandible

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Purpose: *To evaluate the predictability of early and immediate loading protocols of implants in the posterior mandible and to investigate whether there is a difference in success rates, survival rates, and peri-implant parameters, including marginal bone level changes, between loading protocols.* ***Materials and Methods****: A comprehensive systematic review of the literature was conducted. The selection of publications reporting on human clinical studies was based on predetermined inclusion criteria and was agreed upon by two reviewers.* ***Results:*** *A total of 19 papers were selected: 8 on early loading, 9 addressing immediate loading, and 2 comparing immediate and early loading. Of the 19 studies, 5 were randomized clinical trials and 14 were prospective studies.* ***Conclusions:*** *Existing literature supports the early loading of microroughened dental implants in the partially edentulous posterior mandible at 6 to 8 weeks in the absence of modifying factors. Therefore, loading within this time frame can be considered routine for the majority of clinical situations in the posterior mandible, either with single crowns or fixed dental prostheses. Immediate loading of microroughened dental implants in the partially edentulous posterior mandible proved to be a viable treatment alternative. Caution is necessary when interpreting published outcomes for immediate loading, as the inclusion exclusion criteria are inconsistent and many subjective confounding factors are evident. Additional studies with longer follow-ups, specifically randomized clinical trials, are needed to consolidate the data for immediate loading. Priority should be given to trials testing immediate loading.* Int J Oral Maxillofac Implants 2009;24(suppl):158–168

Key words: *dental implants, fixed dental prostheses, loading protocol, partial edentulism, posterior mandible, single crown, systematic review*

There are several factors that may influence the process of successful osseointegration of oral implants. Bone quality, implant surface characteristics, and the amount of micromovement during healing are involved in this complex phenomenon. Functional and anatomical factors vary between the different sectors of the jaws. It has been demonstrated that the chewing load on teeth is maximal on the second molars and progressively decreases in the anterior region of the jaws.[1] This situation is maintained when teeth are replaced with implants.[2] It has also been shown that bone density varies between different regions of the jaws. Various attempts have been made to classify the various bone types with regard to bone density. The first widely used classification, by Lekholm and Zarb,[3] was questioned by Trisi and Rao[4] because of its subjective nature and the absence of a direct correlation to the anatomy and histology of the site.

More recently, different approaches, less dependent on the subjective examination of the clinician, have been used to determine bone density. Computed tomography may be used, and measurements can be performed using the Hounsfield Scale. A recent study demonstrated that the anterior mandible is the site with the highest bone density (927 ± 237 HU), followed by the posterior mandible (721 ± 291), the anterior maxilla (708 ± 277), and the posterior maxilla (505 ± 274 HU).[5] These data confirmed a previous study that found mandibular posterior bone density to be greater than posterior maxilla density.[6]

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None of the authors reported a conflict of interest.

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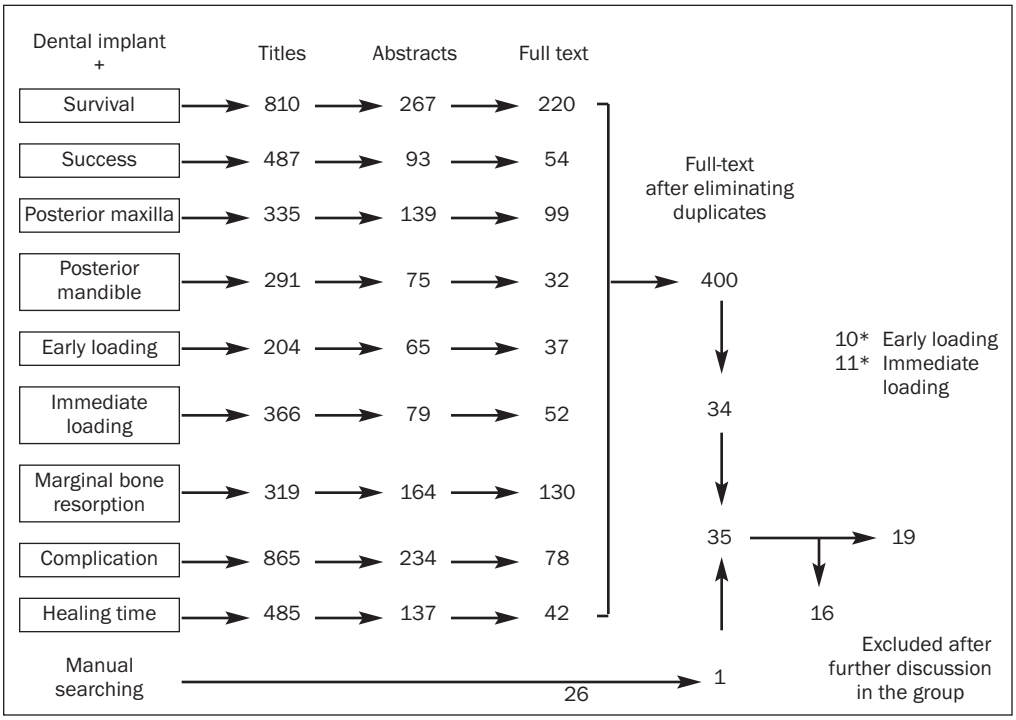

Fig 1 Search strategy and procedures. Two papers (*) deal with immediate and early loading in the posterior mandible.

Other means are used to measure implant stability, such as insertion torque values or resonance frequency analysis (RFA), and are partly correlated to bone density.[7] Usually, better outcomes are found in the posterior mandible than in the posterior maxilla. However, it should be noted that primary implant stability is largely dependent not only on bone density but also on implant design and surface, as well as on the technique and accuracy of the osteotomy preparation.

Usually, the posterior mandible presents with sufficient bone density but faces a very demanding loading situation. This contrasts with the posterior maxilla, in which the loading conditions are similar to the posterior mandible, but the bone is usually of lower density.

Shortening the interval between implant insertion and prosthetic loading may lead to improved patient comfort. Several systematic reviews on immediate and early loading protocols have been published.[8–12] All of these aimed to compare conventional and early/immediate loading by compiling the outcomes of selected clinical studies. Each systematic review, however, was based on the selection and inclusion of a number of articles with a great variety in baseline parameters, such as local oral condition, implant system used, prosthesis type, jaw location, or other factors that could affect loading mechanics and potentially result in misleading interpretation of outcomes. This suggests that it is clinically not useful to evaluate the performance of early or immediate loading per se. The evaluation has to be performed for different clinical indications to provide the practitioner with the appropriate evidence that is related to those indications.

The aim of this systematic review was to evaluate the predictability of early and immediate loading protocols for implants in the posterior mandible and to investigate whether there is a difference in success rates, survival rates, and peri-implant parameters, including marginal bone level changes, between the respective protocols. The loading definitions established by the 2003 ITI Consensus Conference were used for the purpose of this review.[13]

MATERIALS AND METHODS

Search Strategy and Procedures

A comprehensive review of the literature was conducted to select pertinent full-length articles published in English. The most recent electronic search was undertaken on May 1, 2008.

Searching was performed using the electronic databases MEDLINE (PubMed) and Specialist Register of the Cochrane OHG. Key words used in the search included: *dental implants, early loading, healing time, immediate loading, posterior mandible, marginal bone resorption, complications, success rate,* and *survival rate* (Fig 1).

To expand this, a hand search of the following journals was undertaken, covering the years 1991 to present: *Clinical Oral Implants Research, International Journal of Periodontics & Restorative Dentistry, Journal of Periodontology, Journal of Clinical Periodontology,* and *International Journal of Oral & Maxillofacial Implants*.

Bibliographies from selected articles, the proceedings of the second (1997) and third (2003) ITI Consensus Conference, the position papers of the American Academy of Periodontology, and the Proceedings of the Third European Workshop on Periodontology (1999) were also screened. Every attempt was made to obtain recent studies that had been accepted but not yet published, through personal contacts of the authors.

All levels of the hierarchy of evidence except for expert opinions were included. For case reports, only studies with 10 or more cases specifically in the posterior mandible were accepted. For prospective data, only studies reporting outcomes after 12 or more months were included.

The search was limited to human subject studies published in English that evaluated various healing times between surgery and loading. Outcome measures were survival rate, success rate, and marginal bone loss.

Data Collection and Analysis

Titles and abstracts obtained through the described search were screened by two independent reviewers (Marco Aglietta, Ferruccio Torsello). The screening was performed on a printout of the titles and abstracts, and included studies meeting the following criteria:

- Human trials
- Loading time
- Longitudinal studies
- Clinical outcomes

Studies including implants in extraction sockets, guided bone regeneration (GBR), or full-arch reconstructions were excluded. Moreover, articles that reported combined data from the posterior and anterior mandible, and/or from the maxilla and mandible, without the possibility to extract the results for the area of interest were not included.

Full-text copies of studies with possible relevance were evaluated by two reviewers (Mario Roccuzzo and Luca Cordaro). Any disagreement was discussed and resolved. Authors were contacted to provide missing information when possible. Two email attempts were made to contact each author.

The methodological quality of the studies was assessed to appraise:

- Method of randomization. This was classified as *adequate* when a random number table, a coin toss, or shuffled cards were used; as *inadequate* when other methods of randomization such as alternate assignment, hospital number, or odd/even birth date were applied; and as *unclear* when the method of randomization was not reported or explained.
- Allocation concealment. This was classified as *adequate* when examiners were kept unaware of the randomization sequence; as *inadequate* when other methods of allocation concealment were used, such as alternate assignment, hospital number, or odd/even birth date; and as *unclear* when the method of allocation concealment was not reported or explained.
- Completeness of follow-up was considered present if the number of patients was reported both at baseline and at completion of the follow-up, and if the analysis took into account the dropouts.

Significant data from the selected articles were recorded for the following two categories:

1. Early loading of implants placed in the posterior mandible (Table 1)
2. Immediate loading of implants placed in the posterior mandible (Table 2)

RESULTS

A total of 19 papers[14–32] were included in the present review: 8 on early loading, 9 addressing immediate loading, and 2 comparing immediate and early loading. Of the 19 studies, 5 were randomized controlled clinical trials (RCTs) and 14 were prospective studies.

A number of valuable articles had to be excluded because they did not meet the inclusion criteria. Some papers could not be considered because in some of the treated subjects the early or immediate loading protocols were associated with implant placement in fresh extraction sockets, and results could not be separated from implants placed in native bone,[33–37] or in other instances because simultaneous bone augmentation was performed.[38] In other studies it was not possible to determine the exact number of implants placed in the posterior mandible and their specific survival rate in this anatomical region.[39–41] A further study had to be excluded because different loading protocols were used for different sites, and it was not possible to separate out the number of early loaded implants in the posterior mandible.[42]

Table 1 Selected Articles on Early Loading in the Partially Edentulous Posterior Mandible

Study	Study type	Implant surface	No. of patients included	Sites	Smallest implant	No. of implants placed	No of implants loaded	Time of loading	Follow-up	Occlusal contacts	Type of prostheses	Splinted	Survival rate	Failures	Other results
Cochran et al (2002)[14]	Pros	SLA	80	Posterior mandible	ø 4.1 × 8 mm	198	198	6 wk; 12 wk if bone quality = 4	2 y	Yes	FDP	Yes	99% 1 y (n =166) 99% 2 y (n = 94)*	1	Success rate: 99%
Nordin et al (2004)[15]	Pros	SLA	15	Posterior mandible	NR	41	41	9 d (range 4–22 d)	12 mo	NR	FDP	Yes	100%	0	NR
Salvi et al (2004)[16]	RCT	SLA	27	No third molars	ø 4.1 × 8 mm	31	29	2 wk	12 mo	Yes	SC	No	100%	0	BL 0.57 mm
Salvi et al (2004) [16]	RCT	SLA	27	No third molars	ø 4.1 × 8 mm	36	35	6 wk	12 mo	Yes	SC	No	100%	0	BL 0.72 mm
Vanden Bogaerde et al (2003)[17]*	Pros	TiUnite	> 10†	Posterior mandible	8.5 mm	42	42	4–16 d (mean 9 d)	18 mo	Light	FDP	Yes	100%	0	NR
Vanden Bogaerde et al (2004)[18]	Pros	Machined	> 10†	Posterior mandible	8.5 mm	56	55	< 20 d (average 11 d)	18 mo	Light	FDP	Yes	98%	1	NR
Bornstein et al (2005)[19]	Pros	SLA	45	No third molars	ø 4.1 × 4.8 mm	89	88	6 wk	5 y	NR	SC-FDP only	FDP	99%	1	Success rate: 99% bone resorption: 0.15 mm
Sullivan et al (2005)[20]	Pros	Osseotite	> 10†	Posterior mandible	NR	262	257	2 mo	5 y	NR	SC-FDP	FPD only	98.8% of loaded implants; 96.9% of inserted implants	5 early failures; 3 after loading	NR
Achilli et al (2007)[21]	Pros	TiUnite	15	No third molars	ø 3.5 × 10 mm	32	32	6 wk	12 mo	Light	FPD	Yes	100%	0	NR
Roccuzzo et al (2008)[22]	RCT	SLA	14	No third molars	ø 4.1 × 8 mm	33	32	6 wk	5 y	Yes	SC-FDP	No	100%§	0	NR
Ganeles et al (2008)[23]	RCT	SLActive	> 10†	No second and third molars	ø 4.1 × 8 mm	134	134	28–34 d	12 mo	No	SC-FDP	NR	96%‖	4 early failures; 1 after loading	NR

Pros = prospective; RCT = randomized controlled clinical trial; FDP = fixed dental prosthesis; SC = single crown; NR = not reported; BL = bone loss.
* Additional specific data provided by the authors on request.
† Data deduced from analysis of the text.
‡ One lost implant. Two spinners at the time of abutment connection: loading was postponed and implants successfully healed.
§ One spinner; successfully loaded with definitive crown after 6 additional weeks of healing.
‖ Data extrapolated from Zollner et al (2008)[44] on the same patient population.

Table 2 Selected Articles on Immediate Loading in the Partially Edentulous Posterior Mandible

Study	Study type	Implant surface	No. of patients included	Sites	Bone quality/ primary stability	Smallest implant	No. of implants placed	Restoration time limit	Follow-up	Occlusal contacts	Type of prostheses	Splinted	Survival rate	Other results
Buchs et al (2001)[24]	Pros	Altiva NTR	> 10†	No third molars	NR	NR	82	< 24 h	10–29 mo	Light	SC-FDP	NR	92.7%	—
Calandriello et al (2003)[25]	Pros	Machined	> 10†	Premolars and molars	Torque > 45 Ncm	ø 5 × 10 or ø 3.75 × 13 mm	21	< 24 h	12–24 mo	Light	SC-FDP	NR	100%	—
Calandriello et al (2003)[26]	Pros	TiUnite	> 10†	First or second molars	Torque > 35 Ncm	ø 5 × 10 mm	24α	< 24 h	12 mo	Light	SC	No	100%§	1.1 mm without GBR and 1.8 mm with GBR
Rocci et al (2003)[27]	RCT	TiUnite	22	Premolars and molars	Primary stability checked by hand	7 mm	66‡	< 24 h	12 mo	NR	FDP	Yes	95.5 %	Bone resorption: 0.9 (0.7) mm Success rate 95.5%
Rocci et al (2003)[27]	RCT	Machined	22	Premolars and molars	Primary stability checked by hand	7 mm	55‡	< 24 h	12 mo	NR	FDP	Yes	85.5 %	Bone resorption: 1 (0.9) mm Success rate 85.5%
Cornelini et al (2004)[28]	Pros	SLA	30	First molars	ISQ > 62	ø 4.1 × 12 or ø 4.8 × 10 mm	30	< 24 h	12 mo	Yes	SC	No	97%	Bone resorption: 0.22 mm Success rate 96.7%
Abboud et al (2005)[29]	Pros	Sandblasted Ankylos	11	Premolars and first molars	NR	9.5 mm	11	< 24 h	12 mo	Light	SC	No	100%	0.03
Cornelini et al (2006)[30]	Pros	SLA	20	Premolars and molars	ISQ > 62	ø 4.1 × 12 or 4.8 × 10 mm	40	< 24 h	12 mo	Yes	FDP	Yes	98%	Bone resorption: 0.1 mm mesial and 0.5 mm distal Success rate 97.5%
Romanos and Nentwig (2006)[31]	Pros	Sandblasted Ankylos	12	Premolars and molars	No tapping in soft bone	ø 3.5 × 11 or ø 4.5 × 9.5 mm	36	< 24 h	24 mo	Light	FDP	Yes	100%	22.2% minimal horizontal BL (< 2 mm); 19.4% minimal vertical BL (< 2 mm)
Achilli et al (2007)[21]*	Pros	TiUnite	25	No third molars	No type 4 bone torque > 30 Ncm	ø 3.5 × 10 mm	56	< 24 h	12 mo	Light	FDP	Yes	100%	NR
Schincaglia et al (2007)[32]	RCT	TiUnite	10	No third molars	ISQ > 60 and torque > 30 Ncm	8.5 mm	20	< 24 h	12 mo	Light	FDP	Yes	100%	1.06 mm
Schincaglia et al (2007)[32]	RCT	Machined	10	No third molars	ISQ > 60 and torque > 30 Ncm	10 mm	22	< 24 h	12 mo	Light	FDP	Yes	91%	0.92 mm
Ganeles et al (2009)[23]*	RCT	SLActive	> 10†	No second or third molars	Sufficient primary stability checked by hand	ø 4.1 × 8 mm	127	< 24 h	12 mo	No	SC-FDP	NR	98%‖	NR

Pros = prospective; RCT = randomized controlled clinical trial; FDP = fixed dental prosthesis; SC = single crown; NR = not reported; ISQ= Implant Stability Quotient (measured with resonance frequency analysis); BL = bone loss.

* Additional specific data provided by the authors upon request.

† Data deduced from analysis of the text.

‡ Flapless surgery.

§ Only implants with at least 12 months of follow-up were considered.

‖ Data extrapolated from Zollner et al (2008)[44] on the same patient population.

Early Loading

Ten papers fulfilled the inclusion criteria and were evaluated with regard to outcome of implants restored with an early loading protocol. Of these, three were RCTs and seven were prospective clinical trials. The three RCTs contained an adequate method of randomization and complete follow-up, but the allocation concealment was unclear.[16,22,23] Some of these studies did not solely include implants placed in the posterior mandible. But it was possible to extrapolate the requested data from each of these publications. If there was any remaining uncertainty, the respective authors were contacted by email and asked to provide the missing data.

In one of those publications, a multicenter prospective clinical trial by Cochran and coworkers, implants with a sandblasted and acid-etched (SLA) surface were inserted in different zones of the jaws and divided in groups.[14] A total of 198 implants were inserted in the posterior mandible and loaded with fixed dental prostheses (FDP) after 6 weeks when bone type 1, 2, or 3 was found at the time of surgery. In the case of type 4 bone, loading was postponed to 12 weeks postinsertion. Implants had completed the 12-month (n = 166) or 24-month (n = 61) follow-up. Only one implant was lost, resulting in a success rate of 99% at both intervals.

In another study, early loading of SLA implants was studied by Nordin and coworkers in a prospective three-arm trial.[15] Posterior partially edentulous mandibles and maxillae were included in one group. A total of 41 implants were placed in mandibular posterior sites and restored with fixed dental prostheses (FDPs), with a mean loading interval of 9 days (range 4 to 22 days). In this paper a 100% survival rate was seen after 1 year.

In one RCT that fulfilled the inclusion criteria for this review, Salvi and collaborators compared SLA implants inserted in the posterior mandible and restored with single crowns in occlusal contact after 2 or 6 weeks. A total of 67 implants were inserted in the two groups, with a 100% survival rate after 1 year of loading. No statistically significant difference could be found between the two groups.[16]

In two separate papers, Vanden Bogaerde and coworkers reported the 18-month outcome of early loaded, splinted implants either with a machined or oxidized titanium surface in the maxilla and posterior mandible.[17,18] In the group with an oxidized titanium surface, 42 implants were inserted, then loaded an average of 9 days after surgery. The authors reported a 100% implant survival rate after 18 months. For implants with a machined surface, 31 consecutive patients with 56 implants in the posterior mandible were included in the study. One implant failed before loading, which was performed earlier than 20 days after insertion (average 11 days). The overall survival rate for this group (including the early failure) was 99%.

Five-year results after early loading in the posterior mandible were reported in two different studies involving two different types of implants.[19,20] In a prospective study performed by Bornstein and coworkers in 51 patients,[19] 104 SLA implants were inserted, 89 of which were in the posterior mandible. Implants were loaded after 6 weeks with either single crowns or FDPs. One early failure occurred, and a 99% survival rate resulted after 5 years. The mean marginal bone resorption was 0.15 mm. In a second prospective multicenter study, Sullivan et al evaluated 262 implants with a microtextured acid-etched surface that were inserted in the posterior mandible with a transmucosal technique and loaded 2 months after insertion.[20] Five early failures were reported, and three further failures occurred after loading, resulting in a 97% implant survival rate. In both studies implants were restored either with single crowns or FDPs.

In a prospective study comparing early and immediate loading, Achilli et al evaluated 32 oxidized titanium tapered implants that were inserted in mandibular molar and premolar sites and loaded after 6 weeks with FDPs. A 100% success rate was reported after 1 year.[21]

Implants with a titanium plasma-sprayed surface that were loaded at 12 weeks were compared to SLA implants loaded at 6 weeks by Roccuzzo and coworkers in an RCT with a 5-year follow-up.[22] This split-mouth study compared similar edentulous areas, and implants were loaded with either single crowns or FDPs. After 5 years of observation, a 100% survival rate was seen with both protocols.

In a recently published RCT, Ganeles and coauthors compared early and immediate loading of implants placed in posterior sites of both jaws. A total of 134 implants with a chemically modified SLA surface were placed in the posterior mandible and loaded after an interval of 28 to 34 days with either single crowns or FDPs. Four early failures and one failure after loading were reported, leading to a 96% implant survival rate.[23]

Immediate Loading

According to the inclusion criteria, 11 papers on immediate loading could be included in this review: 8 were prospective clinical studies and 3 were RCTs. Of the 3 RCTs, 2 compared machined versus oxidized titanium surfaces[27,32] and one compared early versus immediate loading.[23] From the latter study,[23] only data concerning immediate loading in the posterior mandible were included in the present section, while data concerning early loading were addressed in the

previous part regarding early loading in the posterior mandible. Data on posterior maxilla were discussed in the review paper on implant loading in the partially edentulous posterior maxilla.

In one RCT, both the methods of randomization and allocation concealment were not clearly described, but complete follow-up of patients and implants was included.[28] Two of the RCTs described an adequate method of randomization and complete follow-up, but the allocation concealment was unclear.[24,33]

In a case series study, Buchs and coworkers reported a 92.7% success rate 1 year after immediate loading of titanium oxide–blasted implants in the posterior mandible either with single crowns or FDPs.[24]

Calandriello and coworkers performed two studies on immediate loading.[25,26] One of these focused on immediate loading with single crowns and FDPs. Fifty machined, immediately restored implants with occlusal contacts in centric relation were studied in the maxilla and mandible. For the purposes of this review, only the 21 implants placed in partially edentulous posterior mandibles were considered. After a 12- to 24-month follow-up, the implant survival rate was 100%. It was not possible to determine the mean bone resorption for the mandibular implants, but the authors stated that a mean bone loss of 1.2 mm was found for all implants in the study and that no statistically significant differences were found between maxillary and mandibular implants.[25]

In a second study on immediate loading of wide-platform implants with an oxidized titanium surface, 50 implants were placed and immediately loaded in first and second molar areas. All restorations were single crowns with occlusal contacts in centric relation, but with no contacts during mandibular excursions. In 7 cases a simultaneous GBR procedure was performed. The 6-month results demonstrated a 100% survival rate and a crestal bone resorption of 0.9 mm for implants without GBR (43 implants), and 1.1 mm of crestal bone loss for the 7 implants with GBR. Only 24 implants could be examined at the 24-month follow-up. They demonstrated a 100% survival rate, 1.3 mm of bone resorption in sites without GBR, and 1.8 mm of bone resorption for the implants that received GBR.[26]

Another RCT was designed by Rocci and coworkers to compare immediate loading of oxidized titanium versus machined implants in the posterior mandible.[27] In the test group, 22 patients received 66 implants with an oxidized surface supporting 24 restorations, while 22 control group patients received 55 machined-surface implants supporting 22 restorations. Neither cantilever nor pontic units were allowed. After 12 months, there was a significant difference in survival rates: 85.5% (8 failures) in the machined-surface implant group versus 95.5% (3 failures) in the oxidized-surface implant test group. The results of this study suggested that immediate loading with rough-surfaced implants seemed to be safer than the same procedure with machined implants. A more detailed analysis showed that the main differences were found when implants were placed in soft bone (type 4). In such cases, the success rate for machined implants was 56% versus 92% for rough-surfaced implants. Thus it may be speculated that the use of a modified surface becomes more important in jaw locations with "soft" bone.

Cornellini et al published two studies on immediate loading in posterior sites.[28,30] In both papers an implant stability quotient (ISQ) value of 62 or more was required as an inclusion criterion for immediate loading. In the first study the authors analyzed the performance of 30 SLA implants placed in first molar areas and immediately restored in occlusion with the opposing dentition. At the 12-month reevaluation, only 1 implant was lost, giving a survival rate of 97%. A mean bone loss of 0.2 mm was recorded.[28]

In the second paper, the authors evaluated 40 SLA implants that were immediately functionally loaded with 20 three-unit FDPs in mandibular premolar and molar areas. Only one implant was lost, resulting in a survival rate of 97.5%. A mean crestal bone resorption of 0.1 mm mesially and 0.5 mm distally was measured.[30] Thus, the authors concluded that immediate loading of SLA implants supporting single crowns or fixed partial dentures showed encouraging results, provided that good primary stability could be achieved during surgery.[30]

Abboud and coworkers investigated 20 immediately loaded sandblasted implants for single-tooth replacement in premolar or first molar areas.[29] Of these, 11 were mandibular implants that showed a 100% survival rate at the 12-month follow-up and a mean crestal bone loss of 0.03 mm.

In another study, Romanos and Nentwig evaluated the same implant design and sandblasted surface immediately loaded with FDPs in mandibular molar and premolar areas.[31] In 12 patients a total of 36 implants were placed to support 12 three-unit restorations. This study was designed as a split-mouth RCT, so that 36 implants were placed on the contralateral side of the mandible with similar local conditions. These implants were restored after 12 weeks (conventional loading). A survival rate of 100% was found in both groups. Concerning bone resorption after 24 months, 19% of test implants showed minimal vertical bone loss (< 2 mm), compared to 25% of controls. Moreover, in one control implant, bone loss > 2 mm was present. Since no statistical comparison of bone loss distribution was performed, it cannot be stated that the better outcome found in the immediately loaded group is sta-

tistically significant. However, the authors concluded that the 2-year prognosis of immediately restored implants in partially edentulous mandibular areas was similar to the prognosis with conventional loading.[31]

Achilli and coworkers conducted a study on early and immediate loading of oxidized titanium implants in the maxilla and mandible. A total of 56 implants placed in the mandible with an immediate-loading protocol could be included in the present review. The immediately loaded implants supporting FDPs in contact with the opposing dentition showed a survival rate of 100% after 12 months.[21]

A recent split-mouth RCT compared immediate loading of oxidized titanium versus machined implants in posterior mandibular sites.[32] Ten patients were included in the study and bilaterally treated, with 20 implants in the test group and 22 in the control group. All implants had to exhibit good primary stability (insertion torque > 20 Ncm and ISQ > 60) at the time of surgery and were loaded within 24 hours with light occlusal contacts in centric occlusion. The results showed no implant loss among the oxidized titanium implants (100% survival rate) and two implant losses for the machined group (91% survival rate). The mean bone loss recorded was 1.06 mm in the test group and 0.92 mm in the control group. The authors' conclusion was that when implant primary stability was achieved, immediate loading seems to be a safe procedure, especially with rough surfaces.

A recent RCT compared early and immediate loading of SLA implants with chemically modified–surface implants.[24] There were 134 implants randomized to the early loading group in the posterior mandible and 127 implants immediately loaded in the same region. All implants supported single crowns or fixed partial dentures. After a 12-month follow-up, a 98% survival rate was recorded for immediately loaded implants. Fifteen implants were placed in type 4 bone (8 in the early loading group and 7 in the immediate loading group), but none of these failed. This study, providing a large sample compared with previous papers, confirms the positive outcome of immediately loaded implants in the posterior mandible.

DISCUSSION

Early Loading

In this review, "early loading" included various loading intervals and surgical protocols. More aggressive protocols consisted of loading at a time earlier than 3 weeks after implant placement with either FDPs or single crowns.[15–18] It should be noted that only 170 implants could be followed for at least 1 year after loading with this protocol. However, the results seem encouraging, since no failures after loading were registered and only one early failure of a machined-surface implant was found.

The results of loading between 3 and 6 weeks after surgery were studied in a greater number of implants (n = 522). Six early failures and one failure after loading were reported. Implants in the posterior mandible loaded at the 2-month interval were studied in one prospective study including a large number of implants (n = 262), and the 3- and 5-year results were reported in two different publications. Five early failures and three failures after loading were reported, demonstrating a survival rate of 98.8% for loaded implants and 96.9% for inserted implants.

Five-year results were also reported for a 6-week healing interval in one multicenter study and one prospective study. A total of 122 implants loaded with either single crowns or FDPs demonstrated a survival rate of 99% to 100%.[19,20]

More recently, a multicenter RCT including implants with a chemically modified surface[23] demonstrated that loading between 4 and 5 weeks after implant placement leads to an acceptable survival rate regardless of the available type of bone.

In the earlier studies, great emphasis was placed on the necessity of having excellent primary stability in order to apply early loading.[14] In these studies great care was taken to include only implants placed in type 1, 2, or 3 bone, or sites that demonstrated high values of insertion torque. More recently, authors have applied the early loading protocol to all implants regardless of type of bone, and similar results were achieved (see Table 1).

A recent review discussed conventional, early, and immediate loading in partially edentulous patients.[43] It was clearly stated that the evolution of implant surfaces (from machined to microrough to chemically active) has allowed the healing periods to be reduced. The author differentiated between single-tooth-gap and multiple-tooth-gap situations in anterior and posterior areas of both jaws. It was suggested that single-tooth situations are more demanding when compared with cross-arch stabilization of implants because the unsplinted implant may be less protected against deleterious micromovements generated by functional forces. Thus, the necessity to achieve good primary stability has been stressed. In the same paper it was argued that single implants can share the loading forces with the rest of the adjacent teeth, while this is less likely to happen in multiple-tooth gaps in the posterior areas. In such cases the masticatory forces may be concentrated on the implant-supported restorations, thus creating an even more demanding situation.

Two of the papers selected for the present review involved single-tooth gaps, five involved multiple-tooth gaps, and three did not differentiate between the two situations. No differences could be identified on the basis of this parameter. The studies included in this review, with approximately 1,000 implants followed for periods varying from 1 to 5 years, demonstrated a minimal survival rate of 96% for inserted implants (including early failures) and 99% for loaded implants. Therefore, on the basis of the evidence available to date, early loading of implants with rough surfaces in posterior mandibular sites may be considered a routine procedure, regardless of the type of restoration used (single crown or FDP).

It must also be noted that whereas earlier studies mostly compared early loading and conventional loading, more recently early-loading protocols have been compared with immediate loading, which is considered the most demanding procedure from a biomechanical point of view. This suggests that, at least in the hands of experienced clinicians, early loading may be considered the "benchmark" to which more aggressive loading protocols are to be compared. Another consideration is that in the context of early or immediate loading, the submerged surgical placement of implants is rarely indicated.

Immediate Loading

The articles selected for the present review provided data on a total of 580 implants that were placed and immediately loaded in partially edentulous areas of the posterior mandible. Almost all authors consider immediate loading to be a more demanding procedure than early or conventional loading. It presents additional risks, and added precautions are usually taken to obtain survival rates comparable to those of the more conservative loading protocols. Some studies documented that the implant surface is critical to maximize the survival rate, especially in soft bone.[28,31]

The necessity of obtaining satisfactory primary stability has also been stressed by several authors. Many studies used the attainment of satisfactory primary stability as an inclusion criteria, either verified by hand or by measuring the ISQ, or by recording the insertion torque.[20,23,25–29,31] Since almost all studies considered only implants with good primary stability, the resulting equivalence of survival rates of immediately and conventionally loaded implants cannot be extended to all the cases. Thus, even if the results are quite promising, it is recommended to limit the immediate-loading procedure to selected cases that demonstrate satisfactory implant stability at the moment of placement. When this is not the case, the immediate-loading procedure should be aborted and implants should be left unloaded during healing.

The reviewed studies reported information on single-tooth replacement and on FDPs placed in the partially edentulous posterior mandible. Six papers considered only implant-supported FDPs, three studied only single crown indications (with only 65 implants included), and two included both single crowns and FDPs (see Table 2). The results did not show significant differences between prosthetic designs. Almost all papers described the type of occlusion provided to the immediately delivered restoration. Some authors preferred to leave the implants without functional load, while others chose to design restorations with light contacts in maximum intercuspation (see Table 2). Almost all authors emphasized the necessity of avoiding any occlusal contact during excursive movements.

Finally, some consideration should be given to the follow-up periods in the selected studies. Since immediate loading in posterior areas has only rarely been documented in the past, its use has been limited to rehabilitation of edentulous patients with several implants splinted together via a full-arch prosthesis, or to restorations of small edentulous gaps in the esthetic area with limited functional needs. Studies on immediate loading for partial edentulism in the posterior arches have been conducted only in recent years. Thus, only papers with short follow-up periods are available. Among the 10 studies that were selected for this review, 8 articles reported on 12-month follow-ups, and only 2 had observational periods of up to 24 months. It is evident that further studies with longer follow-up are required.

Moreover, there is some concern regarding the immediate loading of implants in the posterior jaws. In particular, the pretreatment analysis should evaluate whether the patient will indeed benefit from this faster procedure. While it is clear that immediate loading in the esthetic area can substantially add to patients' comfort and satisfaction, it is not clear in posterior zones with limited esthetic involvement if this is of equal benefit to the patient.[43]

A recent systematic review concluded that a high degree of primary stability at implant insertion is a key prerequisite for a successful immediate or early loading procedure.[12] A recent RCT[23] suggested that the use of modern implant surfaces may permit the achievement of high survival rates even when bone of poor quality is present. This assumption has to be confirmed by other studies.

In the present review only the results related to the partially edentulous posterior mandible have been analyzed. Thus, the information presented in this review paper may be used when planning a rehabilitation in similar clinical situations.

The use of different methods to assess bone density has not yet been related to the treatment outcome, even in situations that the clinician would consider highly demanding from a clinical point of view.

Since many of the reviewed studies applied restrictive inclusion criteria, the results reported with this technique involve multiple confounding factors, including bone quality and quantity, primary stability, and implant dimension. There is no consistency in the literature regarding the threshold values related to these confounding factors.

CONCLUSIONS

The existing literature supports loading of microroughened dental implants in the partial edentulous posterior mandible at 6 to 8 weeks in the absence of modifying factors such as fresh extraction sockets, GBR, and short implants. Therefore, loading within this time frame should be considered routine for the majority of clinical situations in the posterior mandible, either with single crowns or FDPs. Immediate loading of microroughened dental implants in the partially edentulous posterior mandible is a viable treatment alternative.

Caution is recommended in interpreting published outcomes for the immediate-loading group, as the inclusion and exclusion criteria are inconsistent and many subjective confounding factors are evident. Additional studies and longer follow-ups are needed to consolidate the data for immediate loading.

Well-designed RCTs are needed, and priority should be given to trials testing immediate loading.

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Implant Loading Protocols for the Partially Edentulous Esthetic Zone

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Purpose: *The scientific evidence related to different or novel implant loading (primary objective) and directly associated implant placement (secondary objective) protocols developed for the anterior maxillae of partially edentulous patients was reviewed.* **Materials and Methods:** *A comprehensive search of electronic databases and a hand search of six relevant journals was performed. The principal outcome variables were implant survival, implant success, and esthetic appearance. Concerning esthetic treatment outcomes, articles were specifically screened for the presence of objective evaluation parameters and patient satisfaction assessment.* **Results:** *The analysis of the literature on immediately restored or conventionally loaded implants in the esthetic zone revealed an initial survival rate of 97.3% after 1 year (10 prospective cohort studies and one case series). For periods of 1 to 5 years, the survival rate was 96.7%. These survival rates are consistent with previous reports on more traditional loading modalities. However, for immediately placed implants with immediate restoration and occlusal loading, the survival rate dropped by approximately 10% (four studies). Success criteria such as stable crestal bone levels, soft tissue recession, and probing depth could not be evaluated on the basis of the available literature.* **Conclusion:** *There is a paucity of prospective cohort studies addressing patient-centered outcomes. No parameters specific to immediate loading protocols were available for evaluation. In order to validate or reject such implant protocols for use in the esthetically sensitive anterior maxilla, long-term clinical trials should routinely include objective esthetic criteria that comprehensively embrace the pertinent elements of "pink and white esthetics" in the form of readily used indices.* Int J Oral Maxillofac Implants 2009;24(suppl):169–179

Key words: *anterior mandible, anterior maxilla, dental implants, esthetics, fixed dental prostheses, loading protocol, partial edentulism, single crown, systematic review*

In implant placement and implant loading protocols, there has been an increasing trend in recent years toward reducing both the time between tooth extraction and implant insertion, and the delay between implant placement and implant restoration. In fact, the traditional, more conservative guidelines established in the 1980s, suggesting a healing period of approximately 3 months after tooth removal and an osseointegration period of 3 to 6 months after implant placement, although leading to highly predictable outcomes, are currently more and more challenged. Furthermore, according to numerous authors, patients appear to be increasingly interested in reduced treatment time between tooth removal and delivery of the final implant-supported prosthesis, provided the level of predictability established during the previous two decades is maintained.

In the extreme, this involves insertion of an implant immediately after tooth extraction, potentially using simplified procedures such as flapless surgery, and subsequent restoration of the implant in the same session. Ultimately, this combination may not only lead to a reduction in the overall treatment time, but may also substantially decrease the associated costs. Furthermore, it has been claimed that the described approach is clearly associated with reduced surgical procedures and may more efficiently preserve the existing bone and soft tissues at the site of implantation.[1–7]

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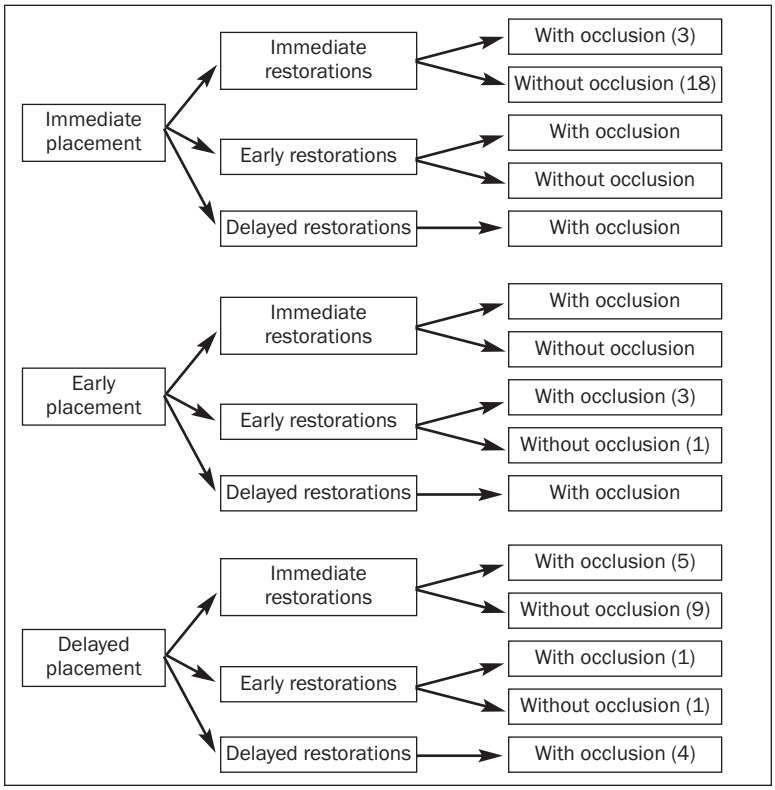

Fig 1 Diagram depicting the 15 theoretically possible options associated with the treatment variables *timing of placement*, *timing of restoration* and *with or without occlusion*. The respective number of studies corresponding to a particular placement-loading combination is shown in parentheses. Note that the majority of the 29 studies analyzed in this review—ie, 18 out of 29—refer to the combination of *immediate implant placement–immediate restoration (without occlusion).*

To date, several articles have provided evidence that the results associated with shortened treatment times after tooth extraction,[8] termed *immediate* or *early implant placement,* and/or after implant placement,[9] termed *immediate* or *early implant restoration*, may under well-defined conditions be similar to those reported for conventional protocols.[8–11] In a consensus report based on eight case series studies encompassing a total of 197 implants, Ganeles and Wismeijer stated that immediate implant restorations in extraction sockets appear to have longitudinal bone loss and soft tissue stability similar to those observed for traditionally loaded implants.[12]

Currently, the number of scientific mid- and long-term reports on combining immediate implant restoration with immediate implant placement is still limited. This is particularly true for information related to fixed implant restorations in the partially edentulous anterior maxilla that specifically comprises treatment outcome data based on objective esthetic criteria.

The aim of this review was to screen the recent literature for scientific evidence related to different or novel implant loading (primary objective) and directly associated implant placement (secondary objective) protocols developed for the anterior maxillae of partially edentulous patients. In this context, the following questions were addressed:

- How does immediate/early implant loading/restoration compare to traditional delayed/late loading in terms of implant survival, implant success, and long-term esthetic treatment outcome?
- Does the combination of immediate/early implant placement and immediate/early implant restoration affect (positively or negatively) implant survival, implant success, and long-term esthetic treatment outcome?

As a consequence, two distinct working hypotheses were tested:

- There is no correlation between implant loading/restoration protocols (immediate/early/late) and long-term implant success and esthetic outcome of anterior maxillary fixed implant restorations.
- There is no correlation between the combination of various implant placement/implant restoration protocols (immediate/early/late) and long-term implant success and esthetic outcome of anterior maxillary fixed implant restorations.

A diagram depicting the 15 theoretically possible treatment modalities based on the combination of the 3 main variables *timing of placement*, *timing of restoration,* and *presence or absence of direct occlusal contacts* is presented in Fig 1.

MATERIALS AND METHODS

Definitions

For the timing of implant placement after tooth removal and the timing of implant restoration, the following definitions established in the context of the Third ITI Consensus Conference[12] were used in this review:

Timing After Tooth Extraction:

- *Immediate implants:* Placement on the day of extraction
- *Early implants:* Placement 6 to 8 weeks after tooth extraction
- *Delayed/late/conventional implants:* Placement after 3 months or later

Timing of Loading/Restoration:

- *Immediate loading/restoration:* Within 48 hours after implant placement
- *Early loading/restoration:* > 48 hours and < 12 weeks
- *Delayed (conventional) loading:* 3 months or more after implant placement

Literature Survey

As traditional, delayed implant loading and delayed implant placement are well documented in the relevant literature, this review focused exclusively on recent studies reporting data that were associated with immediate and early implant restoration/loading protocols.

A computer search of multiple electronic databases, covering a time period from 2000 to May 2008, was performed. This time span was chosen due to the fact that the earlier literature had already been screened and analyzed in the process of the Third ITI Consensus Conference, which took place in 2003.

The following databases were consulted:

- Ovid MEDLINE, using the following key words: *dental implants, dental implantation, osseointegration, dental implants/single-tooth, dental prosthesis/implant-supported*
- The COCHRANE library—COCHRANE reviews, using the following key words: *dental implants, dental implants/single-tooth, immediate loading, dental prosthesis/implant-supported*
- PubMed search, using the following key words: *dental implants AND immediate placement, immediate loading, immediate function, early loading, early function*

Additionally, to assure optimum completeness of this literature screening, the following traditional literature search was performed:

- Hand search from 2000 to May 2008 of the content of the following six specialty journals: *Clinical Oral Implants Research, International Journal of Oral & Maxillofacial Implants, Journal of Implant Dentistry, Journal of Implant Dentistry and Related Research, International Journal of Periodontics & Restorative Dentistry,* and *Journal of Periodontology*
- Screening of the bibliographies of the following three topic-related review articles: Ganeles and Wismeijer 2004,[12] Ioannidou and Doufexi 2005,[13] and Esposito et al 2009[1]

In the first stage, all clinical studies corresponding to one of the following levels of the hierarchy of scientific evidence—ie, systematic reviews, randomized controlled trials, cohort studies, case-control studies, case series, or cross-sectional surveys—were evaluated. Case reports and expert opinions, as well as animal studies and presentations of clinical concepts and procedures, were not taken into consideration. However, only clinical studies reporting outcome data based on at least 12 months of follow-up were included for analysis. Furthermore, the respective implant survival rates had to be either directly reported or readily calculable. Finally, only studies implementing prosthetic rehabilitation protocols either within 48 hours after implant placement (*immediate loading/restoration*) or 3 to 8 weeks after implant insertion (*early loading/restoration*) were accepted.

Of 107 originally screened articles from the period 2000 to 2008, 29 publications satisfied the aforementioned inclusion criteria.[2–6,10,11,14–35] Those 29 articles reported on a total of 1,922 implants from 10 different implant manufacturers: Dentsply Friadent (Ankylos, XiVe, Frialit-2 Synchro), Nobel Biocare (Brånemark II, III, IV, Replace Select, Nobel Perfect, Sterioss, Alpha Bio), IMZ (Twin Plus), Straumann (SS, TE, BLI), Astra Tech (ST TiOblast, OsseoSpeed), Stabledent 1 piece, Southern Implant, Premium Implant, Biocom, and Biomet 3i (Osseotite) (Table 1).

Of the previously mentioned 29 articles, 20 studies fulfilled particular additional criteria in terms of containing data well-suited for statistical analysis[2–5,10,11,14–18,21,22,24–29,31] due to inclusion of results permitting direct comparisons between implants inserted in fresh extraction sites (test group) and implants placed in healed sites (control group). These studies are presented in Table 2.

Table 1 Studies Reporting Immediate, Early, and Delayed Loading Protocols of Anterior Implants

	Study	Study design	Implant system/ surface	Total no. of implants	Time of placement			Immediate restoration (patients/ implants)		Early restoration (patients/ implants)		Delay period	Delayed restoration (patients/ implants)	
					Immed	E	L	Occl	No occl	Occl	No occl		Occl	No occl
1	Malo et al (2000)[32]	Retrosp	Brånemark Mk II	94	27		67		49/94					
2	Ericsson et al (2000)[4]	Pilot	Brånemark Mk II	22			22	14/14					8/8	
3	Hui et al (2001)[27]	Preliminary report	Brånemark Mk III/IV	24	13		11		24/24					
4	Chaushu et al (2001)[16]	Clinical report	21 Sterio-Oss, 7 Alpha Bio HA	28	19		9	28/28*						
5	Andersen et al (2002)[14]	Prosp pilot	Straumann TPS	8			8				8/8	1 wk		
6	Lorenzoni et al (2003)[31]	Preliminary 1-year	Frialit-2 Synchro	12	8	4			8/8		1/4	8 wk		
7	Groisman et al (2003)[24]	Prosp	Nobel, Replace tapered	92	92				92/92					
8	Degidi and Piattelli (2003)[19]	Retrosp	Various	224	58				58/58					
8	Degidi and Piattelli (2003)[19]	Retrosp	Various	224	32				12/32					
8	Degidi and Piattelli (2003)[19]	Retrosp	Various	224	42				15/42					
9	Kan et al (2003)[28]	Prosp	Nobel, Replace	35	35				35/35					
10	Malo et al (2003)[33]	Prosp multicenter	Brånemark Mk II, III, IV	116	22		94		76/116					
11	Glauser et al (2003)[6]	Prosp	Brånemark IV TiUnite	102	23		79	102						
12	Drago and Lazzara (2004)[23]	Clinical report	Osseotite 3i	77	15		62		77/77					
13	Norton (2004)[35]	Prosp	Astra Tech ST TiOblast	28	16		12		25/28					
14	Locante (2004)[30]	Preliminary report	Stabledent 1-piece	86	46		40	86/86						
15	Degidi and Piattelli (2005)[20]	Prosp	Friadent XiVE	135	22				22/22					
15	Degidi and Piattelli (2005)[20]	Prosp	Friadent XiVE	135	14				6/14					
15	Degidi and Piattelli (2005)[20]	Prosp	Friadent XiVE	314			72						72/72	
15	Degidi and Piattelli (2005)[20]	Prosp	Friadent XiVE	314			19						6/19	
16	Cornelini et al (2005)[3]	Prosp	Straumann TE	22	22				22/22					
17	Ferrara et al (2006)[5]	Consecutive case series	Friadent Frialit-2 Synchro	33	33				33/33					
18	Degidi et al (2006)[21]	Prosp	Different: Frialit, IMZ, XiVE, Ankylos, Restore, Maestro, Brånemark	111	67		44		111/111					
19	De Kok et al (2006)[22]	Retrosp	Astra Tech ST TiOblast	43	43				25/39					
20	Lindeboom et al (2006)[29]	RCT	BioComp	50			50	25/25	25/25					
21	Barone et al (2006)[2]	Case series	Premium Impl	18	18				18/18					

Prosp = prospective; Retrosp = restrospective; RCT = randomized controlled trial; ant = anterior; max = maxilla; CI = central incisor; LI = lateral incisor; CA = canine;

Delay period	Placement zone	Single tooth	Adjacent implants	Follow-up time (mo)	Survival rate (%)	Success rate (%)	Esthetic index (yes/no)	Screw-retained/ cemented	Comments
	Ant max: 48 (CI, LI, CA) + 9 PM; ant mand: 29 (CI, LI, CA) + 8 PM	31		6–48	95.7 (4 lost)			Cemented	
12 wk	Ant max: 11 CI, 6 LI,1 CA; ant mand: 2 LI, 2 CA	22		18	Immed: 86 (2 lost); Late: 100		No	Cemented	
	Ant max: 20 CI, 3 LI, 1 CA	24		12–15	100 @ 1 y			Cemented	
	19 immediate: 2 max LI, 3 max CA, 9 max PM, 1 mand CA, 4 mand PM; 9 late: 2 max CI, 1 max LI, 1 max CA, 3 max PM, 2 mand PM	28		Immed: mean 13; Late: mean 16	Immed: 82.4 (3 lost); Late: 100		No	Screw-retained	*Central contact minimized
	Ant max: 7 CI, 1 LI	8		60	100			Screw-retained	
	5 CI, 7 LI	8	4 adjacent	Mean 13	100			Cemented	Occl guard for 8 wk
	Maxillary incisors	92		24	93.5 (6 lost)		Papilla index Jemt	Cemented	
	All over	58		Up to 54	96.6 (2 lost)	98.5 prosthetic		Both	
	Ant max not specific	NA	NA	Up to 54	100	100 prosthetic		Both	
	Ant mand not specific	NA	NA	Up to 54	100	100 prosthetic		Both	
	Ant max: 26 CA, 8 LI, 1 CA	35		12	100	100	Individual Papilla index	Cemented	
	74 Max: 15–25 42 Mand: 35–45	63	53	12	95.7 (5 lost); 93.7 single tooth, 98.1 splinted			Both	
		20		12	97.1	97.1 (3 lost)	No		Mixed group
	Max/mand nonspecific	77		18	97.4 (2 lost)		No	Cemented	
	Ant max: 16 CI, 8 LI, 1 CA + 3 PM	24	4 adjacent	8–27	96.4	96.4 (1 lost)		Bonded to coping	
	Ant max: 21 CI, 39 LI, 16 CA + 8 PM, 2 mand CA	86		36	98.8	98.8 (1 lost)		Cemented	
	All over	22		Up to 24	95.4	95.4 (1 lost)		Both	
	Ant max	NA	NA	Up to 24	100	100		Both	
12 wk	All over control group	72		Up to 24	100	100		Both	
12 wk	Ant max control group	NA	NA	Up to 24	100	100		Both	
	19 max + 3 mand/6 CI, 3 LI and 13 PM	22		12	100		Papilla index Jemt	Screw-retained	
	Ant max: 13 CI, 9 LI, 4 CA + 7 PM	33		48	93.9 (2 lost)		VAS @ 4 y = 9.3	Cemented	
	Ant max: 23 CI, 40 LI, 22 CA + 26 PM	111		60	95.5 (5 lost); immed: 92.5; late: 100	97.2	Papilla index Jemt	Both	
	Ant max: 12 CI, 9 LI, 5 CA + 13 PM	NA	NA		90.7 (4 lost)			Cemented	
	Load: 14 ant max + 11 PM; Nonload: 16 ant max + 9 PM	46	4 adjacent (2 x incisors)	12	Occl 23/25 (92%); no occl 22/25 (88%)		Papilla index Jemt	Screw-retained	
	5 max CI, 8 max PM, 2 mand CA, 3 mand PM	18		12	94.5 (1 lost)			Cemented	

PM = premolar; mand = mandible; immed = immediate; NA = not applicable; occl = occlusal; no occl = not occlusal; E = early; L = late.

Table 1 continued Studies Reporting Immediate, Early, and Delayed Loading Protocols of Anterior Implants

	Study	Study design	Implant system/ surface	Total no. of implants	Time of placement			Immediate restoration (patients/ implants)		Early restoration (patients/ implants)		Delay period	Delayed restoration (patients/ implants)	
					Immed	E	L	Occl	No occl	Occl	No occl		Occl	No occl
22	Noelken et al (2007)[34]	Prosp	Nobel Perfect	31	21		10		20/31					
23	Cooper et al (2007)[17]	Prosp cohort	Astra Tech ST TiOblast	54			54			48/54		3 wk		
24	Harvey (2007)[26]	Case series	Astra Tech OsseoSpeed	36	36					36/36				
25	Hall et al (2007)[25]	RCT	Southern rough/ tapered	28			28			14/14			14/14	
26 27	Buser et al (2008)[10]/ Belser et al (2009)[15]	Cross-sectional retrosp	Straumann SLA	45		45			45			8 wk		
28	Buser et al (2009)[11]	Prosp case series	Straumann BL SLactive	20		20			20			8 wk		
29	Cornelini et al (2008)[18]	RCT	Straumann SLA	34	34				34					
Totals				1,922	758	69	681	255	1,005	119	12		113	

Prosp = prospective; Retrosp = restrospective; RCT = randomized controlled trial; ant = anterior; max = maxilla; CI = central incisor; LI = lateral incisor; CA = canine;

Data Extraction

Subsequently, the following data were extracted from each study:

- Study design (according to the respective definitions of evidence-based dental medicine)
- Implant manufacturer, implant type, implant surface
- Total number of implants per study
- Time of implant placement (immediate/early/late)
- Time of implant restoration (immediate/early/late)
- Loading type (restoration with or without occlusion)
- Location of implants
- Type of therapy: single-tooth or adjacent implants
- Follow-up time
- Survival rate
- Success rate
- Esthetic outcome assessment (yes/no)
- Type of restoration: screw-retained or cemented

In the process of data analysis, the principal outcome variables *implant survival, implant success,* and *esthetic appearance* were addressed. Concerning esthetic treatment outcomes, the study results were specifically screened for presence of objective evaluation parameters, such as the *papilla index* described by Jemt,[36] the *pink and white esthetic score* (*PES/WES*) *index*,[11,15,37] and patient satisfaction assessment based on *visual analog scale* (*VAS*) analysis.[5,15,38]

RESULTS

In terms of the implemented treatment modalities investigated in the 29 studies, the large majority—ie, 18 studies—addressed the combination *immediate implant placement, immediate restoration, absence of direct occlusal load*; 3 studies evaluated *immediate implant placement, immediate restoration, presence of direct occlusal load*; 3 studies focused on *early implant placement, early restoration, presence of direct occlusal load*; and 1 study analyzed *delayed implant placement, early restoration, presence of direct occlusal load* (see Fig 1).

Of the 1,922 total implants encompassed by the 29 publications, 1,120 represented anterior single-tooth replacements. After an observation time of 12 to 60 months, independent of the treatment modality, an overall implant survival rate of 96.6% was calculated (Table 1). It should be noted that none of the studies made a distinction between implant survival and prosthesis survival.

Implant Survival

The 21 studies that reported on 758 implants inserted in fresh extraction sites, and which were subsequently immediately restored either with or without direct occlusal contacts, revealed an overall survival rate of 96.6% for an observation period of up to 60 months.

Delay period	Placement zone	Single tooth	Adjacent implants	Follow-up time (mo)	Survival rate (%)	Success rate (%)	Esthetic index (yes/no)	Screw-retained/ cemented	Comments
	Ant max 24 (CI + CA + PM) + 7 mand CI	14	17	Up to 27	96.8	96.8 (1 lost)	PES	Cemented	
	Ant max @ 3y 15 CI, 21 LI, 7 CA	43		36	94.4 (3 lost)		Papilla index Jemt	Cemented	8 withdrawals
	Ant max not specific	36		18	100			Screw-retained	
26 wk	Ant max: 15 to 25	28		12	96.4 (1 lost)		Papilla index Jemt	Screw-retained	
	Ant max: 26 CI, 11 LI, 3 CA, 5 PM	45		24–48	100	100	PES/WES	Screw-retained	
	Ant max: 14 CI, 3 LI, 1 CA, 2 PM	20		12	100	100	PES/WES	Screw-retained	
	Ant max: 13 CI, 21 PM	34			100		Papilla index Jemt	Screw-retained	
		1,120			96.6				

PM = premolar; mand = mandible; immed = immediate; na = not applicable; occl = occlusal.

More specifically, the mean implant survival rate calculated for the immediate restoration/without occlusion group (based on 18 studies; N = 1,005 implants; mean observation time approximately 23.6 months; range 12 to 60 months) was 97.1%, and the rate calculated for the immediate restoration/with occlusion group (based on 3 studies; N = 216 implants; mean observation time 20.3 months; range 12 to 36 months) was 92.8%.

For early restoration/loading (five publications; 131 implants), the overall survival rate, independent of the timing of implant placement, amounted to 98.9%. A prospective cohort study involving 54 implants that had been inserted in healed sites reported survival rates of 96.2% after 12 months and 94.4% after 36 months.[7,17] If one looks, still in the context of early loading, separately at the two studies based on implants inserted according to the concept of early implant placement, an implant survival rate of 100% was published after follow-up periods of 12 months[10] and 24 to 48 months.[11]

Finally, all three studies reporting on delayed implant loading in the context of controlled prospective trials published 100% survival rates.[4,20,25] It should be noted that all of the included implants had been inserted in healed extraction sites.

Implant Success

Ten of the 29 studies also presented success rates when reporting treatment outcomes, with the mean implant success rate being 98.6%. Only 1 retrospective study specifically mentioned a prosthetic success rate, which corresponded to 98.5%.[19]

Esthetic Evaluation

In 12 studies the authors mentioned the use of a structured esthetic evaluation protocol, with 7 of these using a papilla index analysis, as proposed by Jemt.[36] In 1 study the level of subjective patient satisfaction was evaluated by means of questionnaires based on a VAS. Finally, 1 retrospective[11] and 1 prospective[15] case series study implemented the so-called "pink and white esthetic score" (PES/WES) index, a further development of the pink esthetic score originally published by Fürhauser and coworkers in 2005.[37]

Miscellaneous

In 9 of the 29 studies the anterior implant restorations were exclusively of the screw-retained type, while in 13 investigations cemented suprastructures were consistently utilized. Two groups of authors published data based on both respective restorative options.[19–21,33]

Table 2 Studies Reporting Immediate, Early, and Delayed Loading Protocols of Anterior Implants Fulfilling All Inclusion Criteria

	Study	Study design	Implant system/ surface	Total no. of implants	Time of placement			Immediate restoration (patients/ implants)		Early restoration (patients/ implants)		Delay period	Delayed restoration (patients/ implants)	
					Immed	E	L	Occl	No occl	Occl	No occl		Occl	No occl
1	Ericsson et al (2000)[4]	Pilot	Brånemark Mk II	22			22						8/8	
1	Ericsson et al (2000)[4]	Pilot	Brånemark Mk II	22			22	14/14						
2	Hui et al (2001)[27]	Preliminary report	Brånemark Mk III/IV	13	13				13/13					
2	Hui et al (2001)[27]	Preliminary report	Brånemark Mk III/IV	11			11		11/11					
3	Chaushu et al (2001)[16]	Clinical report	21 Sterio-Oss, 7 Alpha Bio HA	19	19			19/19						
3	Chaushu et al (2001)[16]	Clinical report	21 Sterio-Oss, 7 Alpha Bio HA	9			9	9/9						
4	Andersen et al (2002)[14]	Prosp pilot	Straumann TPS	8			8				8/8	1 wk		
5	Lorenzoni et al (2003)[31]	Preliminary 1-year	Frialit-2 Synchro	12	8	4			8/8		1/4	8 wk		
6	Groisman et al (2003)[24]	Prosp	Nobel, Replace tapered	92	92				92/92					
7	Kan et al (2003)[28]	Prosp	Nobel, Replace	35	35				35/35					
8	Cornelini et al (2005)[3]	Prosp	Straumann TE	22	22				22/22					
9	Ferrara et al (2006)[5]	Consecutive case series	Frialit-2 Synchro, Friadent	33	33				33/33					
10	Degidi et al (2006)[21]	Prosp	Different: Frialit, IMZ, XiVE, Ankylos, Restore, Maestro, Brånemark	67	67				67/67					
10	Degidi et al (2006)[21]	Prosp	Different: Frialit, IMZ, XiVE, Ankylos, Restore, Maestro, Brånemark	44			44		44/44					
11	De Kok et al (2006)[22]	Retrosp	Astra Tech ST TiOblast	43	43				25/39					
12	Lindeboom et al (2006)[29]	RCT	BioComp	50			50	25/25	25/25					
13	Barone et al (2006)[2]	Case series	Premium Impl	18	18				18/18					
14	Cooper et al (2007)[17]	Prosp cohort	Astra Tech ST TiOblast	54			54			48/54		3 wk		
15	Harvey (2007)[26]	Case series	Astra Tech OsseoSpeed	36	36				36/36					
16	Hall et al (2007)[25]	RCT	Southern rough/ tapered	28			28		14/14				14/14	
17,18	Buser et al (2008)[10]/ Belser et al (2009)[15]	Cross-sectional retrosp	Straumann SLA	45		45							45	
19	Buser et al (2009)[11]	Prosp case series	Straumann BL SLactive	20		20							20	
20	Cornelini et al (2008)[18]	RCT	Straumann SLA	34	34				34					
Totals				715	420	69	226	67	495					

The studies highlighted with a darker background identify those comprising two distinctly different cohorts (test/control).
Prosp = prospective; Retrosp = restrospective; RCT = randomized controlled trial; ant = anterior; max = maxilla; mand = mandible; CI = central incisor; LI = lateral incisor; CA = canine;

DISCUSSION

Based on the analysis of 29 clinical studies, all reporting outcome data on implant therapy performed in the anterior segments of the jaws of partially edentulous patients and consistently applying either immediate or early implant restoration/loading protocols, an overall implant survival rate of 96.6% for an observation period of up to 5 years clearly underlines the high level of predictability of these specific treatment modalities. This includes protocols combining both immediate implant placement and immediate implant restoration, provided there is an absence of direct occlusal contact during the osseointegration phase.

Furthermore, it has been demonstrated in particular that anterior maxillary single-tooth implant replacement, with implants inserted and restored according to the concept of early implant placement and early implant restoration, is a successful and highly predictable treatment modality in general, and from an

Delay period	Placement zone	Single tooth	Adjacent implants	Follow-up time (mo)	Survival rate (%)	Success rate (%)	Esthetic index (yes/no)	Screw-retained/ cemented	Comments
12 wk	4 CI, 3 LI, 1 mand CA	8		18	100		No	Cemented	
	7 CI, 3 LI, 1 CA, 2 mand LI, 1 mand CA	14		18	86 (2 lost)		No	Cemented	
	Ant max: 20 CI, 3 LI, 1 CA	13		12–15	100 @ 1 y			Cemented	
	Ant max: 20 CI, 3 LI, 1 CA	11		12–15	100 @ 1 y			Cemented	
	2 max LI, 3 max CA, 9 max PM, 1 mand CA, 4 mand PM	19		13	82.4 (3 lost)		No	Screw-retained	*Central contact minimized
	2 max CI, 1 max LI, 1 max CA, 3 max PM, 2 mand PM	9		16	100		No	Screw-retained	*Central contact minimized
	Ant max: 7 CI, 1 LI	8		60	100			Screw-retained	
	Ant max: 5 CI, 7 LI	12	4 adjacent	13	100			Cemented	Occl guard for 8 wk
	Maxillary incisors	92		24	93.5 (6 lost)		Papilla index Jemt	Cemented	
	Ant max: 26 CI, 8 LI, 1 CA	35		12	100	100	Individual Papilla index	Cemented	
	19 max + 3 mand / 6 CI, 3 LI and 13 PM	22		12	100		Papilla index Jemt	Screw-retained	
	Ant max: 13 CI, 9 LI, 4 CA + 7 PM	33		48	93.9 (2 lost)		VAS @ 4 y = 9.3	Cemented	
	Ant max: 23 CI, 40 LI, 22 CA + 26 PM	67		60	92.5	97.2	Papilla index Jemt	Both	
	Ant max: 23 CI, 40 LI, 22 CA + 26 PM	44		60	100	97.2	Papilla index Jemt	Both	
	Ant max: 12 CI, 9 LI, 5 CA + 13 PM	39	NA		90.7 (4 lost)			Cemented	
	Load 14 ant max + 11 PM; Nonload 16 ant max + 9 PM	46	4 adjacent (2 x incisors)	12	Load 23/25 (92%) / Nonload 22/25 (88%)		Papilla index Jemt	Screw-retained	
	5 max CI, 8 max PM, 2 mand CA, 3 mand PM	18			12	94.5 (1 lost)			Cemented
	Ant max at 3 y 15 CI, 21 LI, 7 CA	43		36	94.4 (3 lost)		Papilla index Jemt	Cemented	8 withdrawals
	Ant max not specific	36		18	100			Screw-retained	
26 wk	Ant max: 15 to 25	28		12	96.4 (1 lost)		Papilla index Jemt	Screw-retained	
8–12 wk	Ant max: 26 CI, 11 LI, 3 CA, 5 PM	45		24–48	100	100	PES/WES	Screw-retained	
8–12 wk	Ant max: 14 CI, 3 LI, 1 CA, 2 PM	20		12	100	100	PES/WES	Screw-retained	
	Ant max: 13 CI, 21 PM	34			100		Papilla index Jemt	Screw-retained	
		696			95.85				

PM = premolar; NA = not applicable; occl = occlusal; No occl = No occlusal; Immed = immediate; E = early; L = late.

esthetic point of view in particular.[10,11,15] In this context, the pertinence of evaluation tools such as the PES/WES index for the objective outcome assessment of the esthetic dimension of anterior single-tooth implants has been confirmed.

Implant dentistry has constantly evolved toward simplification of clinical procedures and shortened treatment times, with such developments as flapless surgery and immediate implant placement.[39–41] Studies that have applied these protocols mostly report short- and mid-term implant survival and success rates similar to those of more traditional treatment approaches. However, when it comes to their routine implementation in the anterior maxilla, these protocols may lead to less favorable results from an esthetic point of view, as for example recessions of the facial peri-implant mucosa. In fact, the recently published evidence suggests that immediately placed but not yet restored implants in the esthetic zone yield a significant number of sites with soft tis-

sue recession (approximately 40%).[39–41] For immediately placed and immediately loaded implants, such data do not exist.

In order to validate or reject such implant protocols for use in the esthetically sensitive anterior maxilla, respective clinical long-term trials should routinely include objective esthetic criteria when assessing outcomes. These criteria should comprehensively embrace the pertinent elements of the so-called "pink and white esthetics," preferably in the form of an easy-to-use index.

In an attempt to define decision-making criteria for the choice between immediate and early implant restoration, the following recommendations may be proposed.

Immediate Implant Restoration and Loading

- Immediate restoration and loading can be used when the implant is of adequate length (≥ 8 mm) and diameter (≥ 4 mm) and the implant achieves "good" primary stability.
- The restoration should be taken out of any functional occlusal contacts both in centric occlusion and during excursive mandibular movements.
- The restoration should not be removed during the healing period of approximately 6 weeks. The patient should be instructed in how to function during the healing period and how to perform adequate oral hygiene.
- Screw-retained provisional restorations are recommended.
- Patients with parafunctional occlusal habits should be fitted with a habit appliance.
- Immediate restoration and loading can be used when the bone volume at the site is close to ideal, ie, when either minimal or no simultaneous guided bone regeneration procedures are required.

Early Loading

- Early loading is defined as 1 week to 2 months. This involves a more conservative approach and minimal augmentation procedures. Since current surface technologies show adequate bone contact at 3 weeks, it might be considered favorable to wait until the third week or later for an early loading protocol. Abutment and provisional placement could be accomplished at the determined time. A final impression is considered depending on soft tissue maturity. Final restoration and torque to 35 Ncm occur at 6 to 8 weeks.
- Patients with parafunctional habits should wear a habit appliance.

CONCLUSIONS

The analysis of the literature on immediately restored or conventionally loaded implants in the esthetic zone revealed an initial survival rate of 97.3% after 1 year. This is based on 10 prospective cohort studies and 1 case series. With an observation period of more than 1 year, but not more than 5 years, the respective survival rate was 96.7%, indicating an additional implant loss of 0.5% between years 2 and 5.

The survival rates, therefore, are consistent with previously reported survival rates of other modalities of implant restoration. However, when the implant is placed immediately after the extraction, with an immediate restoration and occlusal load, the survival rate drops by approximately 10% (4 studies).

One randomized controlled trial involving 50 implants placed in healed sites of the esthetic zone, however, indicated a lower survival rate (88%) for conventionally loaded implants when compared to immediately loaded (92%) implants after 1 year. It should be noted that this difference was due to a single implant lost.

Success criteria such as bone levels, soft tissue recession, and probing depth cannot be evaluated on the basis of the available literature.

There is a paucity of prospective cohort studies addressing patient-centered outcomes. No parameters specific to immediate loading protocols were available for evaluation.

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Consensus Statements and Recommended Clinical Procedures Regarding Loading Protocols

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INTRODUCTORY REMARKS

Treatment with dental implants has proven to be a predictable modality for replacing missing or failing teeth with various types of fixed or removable dental prostheses. A large body of scientific evidence of varying quality has demonstrated that successful outcomes can be achieved with different clinical treatment protocols for a wide range of indications. While it was traditionally thought that healing periods of 3 to 6 months combined with submersion of implants under the oral mucosa was critical for predictable osseointegration of dental implants, modified surgical and loading protocols have demonstrated similar outcomes over time.

Loading protocols for dental implants have been a central focus of discussion in the field since the origin of osseointegration. Several consensus conferences have been held on the topic, and recommendations have been published based on the evidence available at the time.

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Multiple factors have been found to influence and/or alter the quality and predictability of various loading protocols for completely and partially edentulous arches. These factors include the health of the patient; oral conditions such as periodontal status, occlusion, and function/parafunction; characteristics of the proposed implant site; implant size and shape; implant material and surface properties; and timing and methodology of implant placement, including primary implant stability, loading procedures, and long-term maintenance. These factors remain relevant, and because implants as well as associated materials and procedures have evolved, continued evaluation remains important. The predictable optimization of treatment outcomes through more efficient treatment methods based on sound science remains a valid goal for both clinician and patient.

This group was asked to critically discuss and evaluate the current evidence relating to loading protocols for dental implants. Four position papers had been prepared by group members to facilitate the deliberations. These individuals had been invited by the Consensus Conference Committee well ahead of the conference to prepare their reviews. The papers were distributed to all group members for individual study and preparation prior to the meeting. The reviewers were asked to present a summation of the quality and quantity of existing literature relating to loading protocols for dental implants in edentulous arches, the posterior maxilla, the posterior mandible, and the anterior maxilla (esthetic zone). Further, each reviewer presented conclusions, from which group discussion could be initiated. At the conference, each position paper was openly discussed and critically evaluated.

At the outset of the first session, the group revisited the conclusions and consensus statements from the previous ITI Consensus Conference, held in Gstaad, Switzerland, in 2003, and published by Cochran and coworkers,[1] as well as the various definitions for loading protocols from other organizations.[2–4]

Disclosure

All the group members were asked to reveal any conflicts of interest potentially influencing the outcomes of the consensus work. No such conflicts were identified.

Definitions of Loading Protocols

Loading protocols were considered during a consensus meeting held at a congress in Barcelona, Spain, in 2002. The following definitions for implant loading were agreed upon by Aparicio and coworkers[2]:

- *Immediate loading:* The prosthesis is attached to the implants on the same day the implants are placed.
- *Early loading:* The prosthesis is attached in a second procedure, earlier than the conventional healing period of 3 to 6 months. The time of loading should be stated in days/weeks.
- *Conventional loading:* The prosthesis is attached to the implants in a second procedure 3 to 6 months after the implants are placed.
- *Delayed loading:* The prosthesis is attached in a second procedure later than the conventional healing period of 3 to 6 months.

The Third ITI Consensus Conference, held in 2003 in Gstaad, Switzerland, modified the definitions as follows (Cochran et al, 2004)[1]:

- *Immediate loading:* A restoration is placed in occlusion with the opposing dentition within 48 hours of implant placement.
- *Early loading:* A restoration in contact with the opposing dentition and placed at least 48 hours after implant placement but not later than 3 months afterward.
- *Conventional loading:* The prosthesis is attached in a second procedure after a healing period of 3 to 6 months.
- *Delayed loading:* The prosthesis is attached in a second procedure that takes place some time later than the conventional healing period of 3 to 6 months.
- *Immediate restoration:* A restoration inserted within 48 hours of implant placement but not in occlusion with the opposing dentition.

For a Consensus Conference of the European Association for Osseointegration (EAO), held in Zurich, Switzerland, in 2006, a review was presented by Nkenke and Fenner.[3] The group accepted the following definitions:

- *Immediate loading:* A situation in which the superstructure is attached to the implants in occlusion with the opposing dentition within 72 hours.
- *Conventional loading:* A situation in which the prosthesis is attached to the implants after an unloaded healing period of at least 3 months in the mandible and 6 months in the maxilla.
- *Nonfunctional immediate loading* and *immediate restoration* are used when a prosthesis is fixed to the implants within 72 hours without achieving full occlusal contact with the opposing dentition.

Cochrane reviews are recognized as a gold standard in evidence-based health care. Recently, Esposito and coworkers published an updated version of their systematic review regarding different times for loading dental implants, and based it on the following definitions[4]:

- *Immediate loading* was defined as implants in function within 1 week after their placement. No distinction was made between occlusal and nonocclusal loading.
- *Early loading* was defined as putting implants in function between 1 week and 2 months after placement.
- *Conventional loading* was defined as putting implants in function after 2 months.

For the purpose of the literature reviews, conclusions, and consensus statements for the 2008 ITI Consensus Conference, our group agreed to use the definitions of the 2003 ITI Consensus (Cochran and coworkers, 2004).[1]

Following agreement on the definitions to adopt, the group then assessed if each review paper adequately addressed the respective topic of interest and whether the supporting literature selected by the reviewers was complete. Where missing, additional publications were made available for inclusion. The group then divided into smaller working units for detailed consideration of each treatment indication. A focus of discussion within the working units, and then within the group as a whole, related to the quality or level of evidence found for each indication, and what constituted adequate support for the group to make consensus statements and clinical recommendations.

The group's consensus statements and recommendations were presented to the plenary sessions, where they were considered and discussed by all participants attending the conference. Subsequent to these discussions, final consensus statements and clinical recommendations were prepared. The final consensus statements and clinical recommendations follow.

CONSENSUS STATEMENTS AND CLINICAL RECOMMENDATIONS

The group found consensus in making the following general and indication-specific (edentulous patients;

partially edentulous patients) consensus statements and clinical recommendations:

General Statements

1. The literature base associated with loading protocols for dental implants remains limited, particularly with regard to studies of high scientific quality, such as randomized controlled trials (RCTs) or systematic reviews.
2. While placing a priority on publications considered to represent a higher level of evidence, the group acknowledged the potential value of other studies (cohort studies, etc) identified in the searches.
3. In agreement with the 2007 Cochrane Report,[4] the group recommends that for future evaluations the ITI definitions for dental implant loading be modified from the 2004 ITI Consensus Report[1] to state that:

   - Conventional loading of dental implants is defined as being greater than 2 months subsequent to implant placement.
   - Early loading of dental implants is defined as being between 1 week and 2 months subsequent to implant placement.
   - Immediate loading of dental implants is defined as being earlier than 1 week subsequent to implant placement.
   - A separate definition for delayed loading is no longer required.

Edentulous Patients

Mandible and Maxilla. For the edentulous mandible and maxilla, existing literature supports loading of microroughened implants between 6 and 8 weeks subsequent to implant placement with fixed or removable prostheses in the mandible, and fixed prostheses in the maxilla. Therefore, for the majority of patients, loading of dental implants for these indications and within this time frame should be considered routine.

- A lower level of evidence exists to support loading of dental implants with maxillary overdentures for this time frame (6 to 8 weeks).
- There is no evidence available at this time to support loading of dental implants in the edentulous arches between 2 and 6 weeks after implant placement.
- For the edentulous mandible, the literature supports immediate loading of microroughened implants with fixed prostheses or overdentures.
- This consensus statement is made with the understanding that the treatment is complex.
- Treatment within this time frame, for the above indications, can be considered a valid treatment option for clinicians with the appropriate education, experience, and skill.

Conventional loading (greater than 2 months subsequent to placement) is recommended under specific conditions in the edentulous maxilla and mandible. These conditions include, but are not limited to, alveolar ridge augmentation, sinus floor elevation, and the presence of parafunction, maxillary overdentures, and compromised host status.

Maxilla. For the edentulous maxilla, the literature supports immediate loading of microroughened implants with fixed prostheses. This consensus statement is made with the understanding that the treatment is complex and can be considered a valid treatment option for clinicians with the appropriate education, experience, and skill.

Insufficient data exist to support immediate loading of dental implants with overdenture prostheses in the edentulous maxilla.

Partially Edentulous Patients

Posterior Mandible and Maxilla. For the partially edentulous posterior mandible and maxilla, in the absence of modifying factors such as fresh extraction sockets, augmentation, and short implants, existing literature supports loading of microroughened implants between 6 and 8 weeks subsequent to implant placement. Therefore, for the majority of patients, loading of dental implants for these indications and within this time frame should be considered routine.

Conventional loading (greater than 2 months subsequent to implant placement) should be the procedure of choice for partially edentulous posterior sites (maxilla and mandible) when:

- Stability is considered inadequate for early or immediate loading
- Specific clinical conditions exist, such as compromised host and/or implant site, presence of parafunction or other dental complications, need for extensive or concurrent augmentation procedures, sinus floor elevation

Posterior Mandible. For the partially edentulous posterior mandible, immediate loading of microroughened implants can be considered a viable treatment option. Caution is recommended in interpreting published outcomes for this indication, as inclusion and exclusion criteria are inconsistent, and many confounding factors are evident. Treatment within this time frame, for this indication, is complex and can be

considered a valid treatment option for clinicians with the appropriate education, experience, and skill.

Insufficient evidence exists to support immediate loading of dental implants in the partially edentulous posterior maxilla.

Esthetic Zone. While implant survival in partially edentulous sites in the esthetic zone does not appear to be affected by loading protocols, success criteria and patient-centered outcomes may be. As no data exist evaluating these aspects, clinical trials are recommended. For partially edentulous sites in the esthetic zone, loading of microroughened implants between 6 and 8 weeks after implant placement can be considered routine.

Immediate loading of microroughened dental implants can be considered a viable treatment option for partially edentulous sites in the esthetic zone. Treatment within this time frame, however, is complex and can be considered a valid treatment option for clinicians with the appropriate education, experience, and skill.

Conventional loading (greater than 2 months subsequent to implant placement) remains the procedure of choice for partially edentulous sites in the esthetic zone when:

- Stability is considered inadequate for early or immediate loading
- Specific clinical conditions exist, such as compromised host and/or implant site, presence of parafunction or other dental complications, need for extensive or concurrent augmentation procedures, sinus floor elevation

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GROUP 4

Surgical Techniques in Implant Therapy

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Review Papers Submitted for Discussion:

Clinical and Esthetic Outcomes of Implants Placed in Postextraction Sites
Stephen T. Chen/Daniel Buser

Bone Augmentation Procedures in Localized Defects in the Alveolar Ridge: Clinical Results with Different Bone Grafts and Bone-Substitute Materials
Simon Storgård Jensen/Hendrik Terheyden

Bone Augmentation Procedures in Implant Dentistry
Matteo Chiapasco/Paolo Casentini/Marco Zaniboni

Ridge Preservation Techniques for Implant Therapy
Ivan Darby/Stephen T. Chen/Daniel Buser

Clinical and Esthetic Outcomes of Implants Placed in Postextraction Sites

Stephen T. Chen, BDS, MDSc, PhD[1]/Daniel Buser, DMD, Prof Dr Med Dent[2]

Purpose: *The aim of this review was to evaluate the clinical outcomes for the different time points of implant placement following tooth extraction.* ***Materials and Methods:*** *A PubMed search and a hand search of selected journals were performed to identify clinical studies published in English that reported on outcomes of implants in postextraction sites. Only studies that included 10 or more patients were accepted. For implant success/survival outcomes, only studies with a mean follow-up period of at least 12 months from the time of implant placement were included. The following outcomes were identified: (1) change in peri-implant defect dimension, (2) implant survival and success, and (3) esthetic outcomes.* ***Results and Conclusions:*** *Of 1,107 abstracts and 170 full-text articles considered, 91 studies met the inclusion criteria for this review. Bone augmentation procedures are effective in promoting bone fill and defect resolution at implants in postextraction sites, and are more successful with immediate (type 1) and early placement (type 2 and type 3) than with late placement (type 4). The majority of studies reported survival rates of over 95%. Similar survival rates were observed for immediate (type 1) and early (type 2) placement. Recession of the facial mucosal margin is common with immediate (type 1) placement. Risk indicators included a thin tissue biotype, a facial malposition of the implant, and a thin or damaged facial bone wall. Early implant placement (type 2 and type 3) is associated with a lower frequency of mucosal recession compared to immediate placement (type 1).* Int J Oral Maxillofac Implants 2009;24(suppl):186–217

Key words: *bone grafts, early implant placement, esthetics, immediate implant, implant survival*

Advances in biomaterials and clinical techniques have facilitated significant expansion in the indications for dental implant therapy. In the beginning, the replacement of already missing teeth, eg, in edentulous patients, dominated daily practice. Today, many patients present for treatment to replace teeth that first need to be extracted before implants can be placed. This provides clinicians with the opportunity to decide on the timing of implant placement after tooth extraction.[1,2] This decision is critical, since it has a significant influence on treatment outcome.[2] A recent systematic review of randomized controlled trials (RCTs) identified only two studies of immediate implants that fulfilled the inclusion criteria.[3] Although this review concluded that implants placed into fresh or healing sockets was a viable treatment option, more research was required.

The aim of this paper was to review the literature pertaining to implants placed in postextraction sites, and to identify the level of evidence and clinical outcomes for the different time points of implant placement following extraction.

MATERIALS AND METHODS

An electronic search of the dental literature using PubMed was undertaken to identify papers published in English between January 1990 and May 2008, using the following search terms: *dental implant, extraction, socket, immediate implant, immediate placement, delayed implant, delayed placement,* and *late placement.* A hand search of the following journals was undertaken: *Clinical Oral Implants Research, International Journal of Oral & Maxillofacial Implants, International Journal of Periodontics & Restorative Dentistry, Journal of Periodontology, Journal of Clinical Periodontology* and *Clinical Oral Implants*

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and Related Research. In addition, the reference lists of recent review papers were searched for additional citations.[1,2,4–8] Papers accepted for publication were also included.

Selection of Studies

All clinical studies of implants in postextraction sites that included 10 or more treated patients were evaluated. For studies reporting on success and survival outcomes, only studies with a mean follow-up period of at least 12 months from the time of implant placement were included. Where a follow-up publication of a previous study was identified, the most recent study was included.

Studies were excluded if the mean follow-up period was not stated. In studies that reported on cases with different implant placement times after tooth extraction, studies were excluded if the data did not permit a differentiation of the placement time in subjects and sites.

Evaluation of Treatment Outcome

The following treatment outcomes were recorded:

- *Change in peri-implant defect dimension*, either as a reduction in defect area (mm^2 or %), defect height, width, and/or depth (mm or %), or as the change in the number of exposed implant threads. The following parameters were recorded: study design, implant surface, number of patients and implant sites, timing of implant placement after tooth extraction, implant sites, augmentation method, healing protocol (whether submerged or transmucosal), concomitant use of systemic antibiotics, healing time from implant placement to surgical reentry, and postoperative complications.
- *Implant survival*, recorded either as an overall survival rate or cumulative survival rate. Loading protocol and complications during the follow-up period were also recorded, in addition to the parameters listed above.
- *Esthetic outcomes*. The following parameters were recorded: descriptive soft tissue outcomes, esthetic indices, recession of the mucosa and papillae (in mm or % change), changes in probing depths or attachment levels, radiographic changes of the proximal bone, loading protocol, patient-evaluated esthetic outcomes, and complications during the follow-up period.

Definitions

In the literature, a number of descriptive terms have been used to describe when implants are placed after tooth extraction. The terms *immediate*, *recent*, *delayed*, and *mature* were introduced to describe the timing of placement in relation to soft tissue healing and the predictability of guided bone regeneration.[9] The term *late* was used to describe time intervals of 6 months or more after extraction.[10] More recently, the term *early* has been used to describe implant placement after initial soft and hard tissue healing but before complete healing of the socket has occurred.[5,11,12]

Table 1 Classification and Descriptive Terms for Timing of Implant Placement After Tooth Extraction (from Chen and Buser[2])

Classification	Descriptive terminology	Desired clinical outcome
Type 1	Immediate placement	An extraction socket with no healing of bone or soft tissues
Type 2	Early placement-with soft tissue healing (typically 4 to 8 wk of healing)	A postextraction site with healed soft tissues but without significant bone healing
Type 3	Early placement-with partial bone healing (typically 12 to 16 wk of healing)	A postextraction site with healed soft tissues and with significant bone healing
Type 4	Late placement (more than 6 mo of healing)	A fully healed socket

The imprecise nature of these descriptive terms in the dental literature was discussed at the Third ITI Consensus Conference in 2003, and a new classification system for timing of implant placement after tooth extraction was proposed.[13] A slight modification to the classification was made in a 2008 ITI publication, the ITI Treatment Guide, Vol 3 (Table 1).[2] This classification system was based on the desired clinical outcome of the wound-healing process, rather than on descriptive terms or rigid time frames following extraction. Type 1 placement refers to placement of an implant on the same day as tooth extraction and as part of the same surgical procedure. Type 2 placement occurs when the implant is placed after soft tissue healing, but before any clinically significant bone fill occurs within the socket. In contrast, type 3 placement is defined as placement of an implant following significant clinical and/or radiographic bone filling of the socket. In type 4 placement, the implant is placed into a fully healed site. This classification was validated in a recent review paper.[1] The authors of the paper felt that the classification was an appropriate means for describing the timing of implant placement in postextraction sites, as it accounted for variations in the healing capacity of individuals.

Although this classification system has clarified the terminology for implant placement in postextraction sites, various descriptive terms remain in wide use in the dental implant literature. Therefore, to

avoid ambiguity with respect to the timing of implant placement after extraction, the descriptive terms and classification adopted in the Third ITI Treatment Guide, Vol 3, were used simultaneously in this review.[2] The term *postextraction sites* was used to describe collectively fresh and healing extraction sites that permit implants to be placed immediately (type 1), early after soft tissue healing (type 2), and early after partial bone healing (type 3).

RESULTS

A total of 1,107 abstracts and 170 full-text articles were evaluated. Of these, 91 studies met the inclusion criteria for this review. Data were extracted from the studies and tabulated.

Regenerative Outcomes of Postextraction Implants

There were 28 studies reporting on healing of peri-implant defects in postextraction sites (Table 2). Eleven comparative studies were identified, of which 7 were RCTs.[14–20] Four were prospective and retrospective studies.[21–24] The remaining 17 studies were prospective and retrospective case series, the majority of which investigated immediate placement (type 1).[25–38] Three studies reported on treatment outcomes with early placement (type 2).[39–41]

How Effective Are Bone Augmentation Procedures? The majority of studies used combinations of bone grafts and/or barrier membranes to promote bone regeneration in peri-implant defects. The most commonly used augmentation material was deproteinized bovine bone mineral (DBBM), either alone[31,33] or in conjunction with expanded polytetrafluoroethylene (e-PTFE) membranes[15] or collagen membranes.[21,22,24,30,32,40,41] Other augmentation materials included autogenous bone alone,[17,26] e-PTFE barrier membrane alone,[27,29] freeze-dried demineralized laminar cortical bone membrane,[34] composite graft of polymethyl methacrylate and calcium hydroxide,[36] and hydroxyapatite alone.[16] Despite the heterogeneity of the evaluated bone-augmentation techniques and variations in methods for quantifying defect fill, all studies reported significant fill of the peri-implant defects, resulting in clinically acceptable resolution of the defects.

Five RCTs have provided data to compare different augmentation techniques (Table 3).[14–16,19,20] In a study comparing defect height changes with immediate placement (type 1), defect reduction was significantly greater when an e-PTFE membrane was combined with demineralized freeze-dried bone allograft (DFDBA) than for an e-PTFE membrane alone after 6 months of submerged healing (5.68 ± 1.4 mm vs 3.18 ± 2.8 mm; $P < .04$).[14] In a study of 83 patients comparing a hydroxyapatite graft and a resorbable polymer membrane with immediate placement (type 1) and submerged healing, no significant differences were observed in defect height resolution. Residual defect height for both groups was between 0.70 and 0.80 mm ($P = .772$).[16] In a study comparing four different augmentation techniques (e-PTFE membrane alone, e-PTFE membrane and autogenous bone, resorbable polymer membrane and autogenous bone, and autogenous bone alone) with a nonaugmented control group, no significant differences were observed with respect to reduction in defect height and orofacial defect depth after 6 months of healing with immediate placement (type 1).[19] However, sites treated with the addition of a membrane (e-PTFE or resorbable polymer) showed greater reduction in the mesiodistal width of the peri-implant defect. A study of immediate placement (type 1) with transmucosal healing reported no significant differences in defect height and depth reduction when comparing two augmentation methods (DBBM and collagen membrane, and DBBM alone) to a nonaugmented control group.[20]

The results of these controlled clinical studies are supported by retrospective and prospective cases series studies with immediate (type 1) and early (type 2) implant placement. Without exception, these studies showed statistically and clinically significant resolution of the peri-implant defects. There is strong evidence to suggest that bone augmentation procedures are effective in promoting bone fill and defect resolution in peri-implant defects with both surgical approaches—immediate (type 1) and early (type 2) placement.

Are Bone Augmentation Procedures Necessary? Recently, several studies reported on healing outcomes without the use of barrier membranes and bone grafts within the peri-implant defects in postextraction sites.[19,20,23,35,37–39] In two separate studies, Chen et al reported that various combinations of barrier membranes and/or bone grafts and substitutes achieved similar defect resolution when compared to nonaugmented control sites that were allowed to heal with a blood clot alone.[19,20] Defect height reductions between 68% and 83% were reported. Nir-Hadar et al reported that after 3 to 6 months of submerged healing, the residual vertical defect was less than 0.5 mm with early placement (type 2), irrespective of whether an initial orofacial defect was present or not.[39] Complete defect resolution was observed with immediate placement in a prospective study in 10 patients.[35] In this study, the peri-implant defects were less than 2 mm in the orofacial dimension. The same authors compared the outcomes of

Table 2 Clinical Studies Reporting on Healing of Peri-implant Defects Associated with Implants in Postextraction Sites

Study	Study design	Implant surface	No. of patients (No. of implants)	Placement time after extraction	Augmentation method	Healing protocol	Defect changes
Gelb (1993)[25]	Prosp CS	Turned	35 (50)	Type 1	e-PTFE membrane, DFDBA graft or e-PTFE membrane + DFDBA graft	Submerged	100% thread coverage for all techniques except in one case of a no-wall defect treated with DFDBA graft only, 76% coverage
Becker et al (1994)[26]	Prosp CS	Turned	30 (54)	Type 1	Autogenous bone chips	Submerged	Mean initial defect height 5.5 ± 3.0 mm reduced to 0.5 ± 1.0 mm at reentry* Mean initial orofacial defect width 3.7 ± 2.1 mm reduced to 0.2 ± 0.8 mm*
Lang et al (1994)[27]	Prosp CS	TPS	16 (21)	Type 1	e-PTFE membrane only	Transmucosal	20/21 sites with complete bone regeneration
Becker et al (1994)[28]	Multicenter Prosp CoS	Turned	40 (49)	Type 1	e-PTFE membrane only	Submerged	At sites with no early membrane removal (N = 29): mean initial defect height of 4.9 ± 2.5 mm reduced to 0.1 ± 0.4 mm at reentry† At sites with early membrane removal (N = 20): mean initial defect height of 6.4 ± 4.3 mm reduced to 2.4 ± 3.3 mm†
Nir-Hadar et al (1998)[39]	Prosp CS	Turned	14 (21)	Type 2 (6 to 8 weeks)	No augmentation	Submerged	Mean initial vertical defect 2.5 ± 0.37 mm reduced to 0.36 ± 0.64 mm when a horizontal (orofacial) defect was present* Mean initial vertical defect 3.86 ± 0.58 mm reduced to 0.48 ± 0.25 mm when a horizontal (orofacial) defect was absent* Mean initial horizontal (orofacial) defect 1.6 ± 1.73 mm reduced to 0.02 ± 0.02 mm*
Hämmerle et al (1998)[29]	Prosp CS	TPS	10 (11)	Type 1	e-PTFE membrane only	Transmucosal	Mean initial vertical defect 4.7 ± 1.3 mm reduced to 2.1 ± 0.8 mm at reentry† 94% defect volume fill†
Nemcovsky et al (1999)[30]	Prosp CS	TPS and HA	29 (33)	Type 1	DBBM only in small (size of defects not specified) defects DBBM and resorbable collagen membrane in dehiscence defects > 4 mm	Submerged	No membrane sites: Mean initial defect height 1.9 ± 1.16 mm reduced to 0.3 ± 0.46 mm at reentry† Membrane sites: Mean initial defect height 4.6 ± 1.18 mm reduced to 0.7 ± 0.7 mm at reentry†
Nemcovsky et al (2000)[31]	Prosp CS	SBE and TPS	24 (26)	Type 1	DBBM only; intact bone walls	Submerged	Mean initial defect height 2.6 ± 1.72 mm reduced to 0.6 ± 0.70 mm†
Nemcovsky et al (2000)[40]	Prosp CS	SBE and TPS	21 (28)	Type 2 (5 to 7 weeks)	DBBM and resorbable collagen membrane; dehiscence defects were all > 4 mm or had > 25% of the implant surface exposed	Submerged	For single implants: Mean initial defect height 6.7 ± 2.23 mm reduced to 0.6 ± 0.69 mm at reentry Mean initial defect area 23.7 ± 11.49 mm^2 reduced to 0.7 ± 0.99 mm^2 at reentry For adjacent implants: Mean initial defect height 6.4 ± 1.03 mm reduced to 0.8 ± 0.27 mm at reentry Mean initial defect area 20.67 ± 4.4 mm^2 reduced to 0.6 ± 0.40 mm^2 at reentry
Nemcovsky et al (2000)[32]	Prosp CS	Various (microtextured, TPS and HA)	61 (61)	Type 1	DBBM and resorbable collagen membrane (membrane not used when all bone walls were intact)	Submerged	Vertical gain in bone between 1.5 and 3.6 mm
Van Steenberghe et al (2000)[33]	Prosp CS	Turned	15 (21)	Type 1	DBBM with no membrane	Submerged	Mean initial defect height 3.8 ± 0.6 mm reduced to 1.1 ± 0.3 mm at reentry

Table 2 continued Clinical Studies Reporting on Healing of Peri-implant Defects Associated with Implants in Postextraction Sites

Study	Study design	Implant surface	No. of patients (No. of implants)	Placement time after extraction	Augmentation method	Healing protocol	Defect changes
Rosenquist and Ahmed (2000)[34]	Prosp CS	Turned	25 (34)	Type 1	Freeze-dried demineralized human laminar cortical bone used as a barrier membrane	Membrane left exposed	Mean initial defect height of 8.5 mm reduced to 0.3 mm at reentry
Hämmerle and Lang (2001)[41]	Prosp CS	TPS	10 (10)	Type 2 (8 to 14 weeks)	DBBM and resorbable collagen membrane	Transmucosal	Mean initial vertical defect height reduced from 7.8 ± 1.9 mm to 2.5 ± 0.6 mm† Defect area reduction of 86 ± 33%; 8/10 sites had 100% defect area reduction
Covani et al (2003)[35]	Prosp CS	SBE and TPS	10 (15)	Type 1	No augmentation; marginal defects between socket wall and implant were no more than 2 mm	Submerged	No residual bone defects observed; distance between facial and lingual bone walls reduced from 10.5 ± 1.5 mm to 6.8 ± 1.3 mm (35% change)
Yukna et al (2003)[36]	Prosp CS	HA	23 (30)	Type 1	Composite of polymethyl methacrylate and calcium hydroxide	Submerged	Orofacial internal socket dimension reduced from 6.9 to 0 mm External ridge width decreased from 9.1 ± 2.4 mm to 8.4 ± 1.9 mm (P = .08)
Botticelli et al (2004)[37]	Prosp CS	SLA	18 (21)	Type 1	No augmentation	Semisubmerged	Defect height reduction: mesial 1.6 ± 3.8 mm; facial 5.5 ± 2.3 mm; distal 0.4 ± 2.3 mm; lingual 3.5 ± 2.7 mm Defect width reduction: mesial 0.3 ± 0.8 mm; facial 1.5 ± 0.7 mm; distal 0.1 ± 0.8 mm; lingual 1.1 ± 0.8 mm
Covani et al (2007)[38]	Prosp CS	TPS	20 (20)	Type 1	No augmentation	Submerged	Mean reduction in crestal bone height was 0.8 mm (0 mm in 38% of sites, > 0 to 1 mm in 47% of sites, > 1 to 2 mm in 15% of sites)

Study design: Prosp = prospective; CoS = cohort study; CS = case series.
Implant surface: turned = equivalent to machined surface; TPS = titanium plasma-sprayed; HA = hydroxyapatite-coated; SLA = surface sandblasted with large-grit and acid-etched; SBE = sandblasted and acid-etched.
Placement time after extraction: Type 1 = immediate placement at the time of extraction; Type 2 = early placement after initial soft tissue healing; Type 3 = early placement after substantial bone healing; Type 4 = late placement after complete healing of the ridge.
Augmentation method: e-PTFE = expanded polytetrafluoroethylene membrane; DBBM = demineralized bovine bone mineral; DFDBA = demineralized freeze-dried bone allograft.
*Significant within-group change from baseline (P < .05).
†Significant within-group change from baseline (P < .01).

Table 3 Controlled Clinical Studies Comparing Different Augmentation Methods Used with Implants Placed into Postextration Sites

Study	Implant surface	Placement protocol/ healing protocol/ clinical indications	Study aim/ outcome variables	Experimental groups and augmentation methods	No. of patients	No. of implants	Reentry period following placement	Results
Gher et al (1994)[14]	TPS and HA	Type 1/Submerged/ Maxillary anterior and premolar sites; mandibular canine, premolar and molar sites	RCT/To compare two bone augmentation methods at two implant surfaces/Change in defect height and crestal bone levels	Group 1: TPS surface and e-PTFE membrane only Group 2: TPS surface and e-PTFE plus DFDBA Group 3: HA surface and e-PTFE membrane only Group 4: HA surface and e-PTFE plus DFDBA	Group 1 = 10 Group 2 = 10 Group 3 = 10 Group 4 = 10	Group 1 = 11 Group 2 = 12 Group 3 = 10 Group 4 = 10	6 mo	No differences between implant surfaces Mean defect height reduction: Non-DFDBA grafted = 3.18 ± 2.83 mm; DFDBA grafted = 5.68 ± 3.45 mm ($P < .04$) Mean crestal bone loss from most coronal bone crest: Non-DFDBA grafted = 1.59 ± 1.66 mm; DFDBA grafted = 1.53 ± 1.38 (NS) Mean crestal bone loss from most apical part of crest: Non-DFDBA grafted = 0.11 ± 2.76 mm; DFDBA grafted = −1.39 ± 2.76 (ie, gain in crestal bone height) ($P < .02$)
Zitzmann et al (1997)[15]	Turned	Type 1, 2, 3, 4/Submerged/Maxillary and mandibular sites-all locations	RCT/To compare bone augmentation using a resorbable collagen membrane with a nonresorbable e-PTFE membrane in a split-mouth randomized study/Change in defect area	Each patient required at least two immediate implants; one site randomly received a resorbable collagen membrane and the other site a nonresorbable e-PTFE membrane (provided there was 14 mm of space between the two sites; if less than 14 mm the same membrane was used for both sites). DBBM was grafted at both sites	25	84 Type 1 = 27 Type 2, 3, 4 (between 6 wk and 6 mo after tooth extraction) = 17 Healed site (more than 6 mo after extraction) = 40	4 mo in the mandible and 6 mo in the maxilla	Mean defect area reduction: e-PTFE membrane: 78 ± 50.2% Collagen membrane: 92 ± 19.3% ($P < .0001$) Mean defect area reduction in the presence of a wound dehiscence: For collagen membrane No dehiscence (n = 39): 94 ± 19.0%; Dehiscence (n = 4): 87 ± 18.9% (NS) For e-PTFE membrane No dehiscence (n = 23): 98 ± 9.8% Dehiscence (n = 18): 65 ± 68.4% ($P = .01$)
Prosper et al (2003)[16]	Sand-blasted	Type 1/ Submerged/ Maxillary and mandibular molar sites	RCT/To compare two bone augmentation methods in conjunction with a wide-diameter implant (5.9 mm)/ Primary outcome variable-change in defect height	Group 1: HA graft only Group 2: Resorbable polymer membrane only	83 patients total No. of patients in each group not stated; all patients belonged to the same treatment group/ Some patients received more than 1 implant	Group 1 = 56 Group 2 = 55	4 y from placement; all patients completed the 4-y follow-up	Residual vertical defect height: Group 1: range 0.70 to 0.80 mm Group 2: range 0.73 to 0.80 mm ($P = .772$)

Table 3 continued Controlled Clinical Studies Comparing Different Augmentation Methods Used with Implants Placed into Postextration Sites

Study	Implant surface	Placement protocol/ healing protocol/ clinical indications	Study aim/ outcome variables	Experimental groups and augmentation methods	No. of patients	No. of implants	Reentry period following placement	Results
Cornelini et al (2004)[18]	SLA	Type 1/Transmucosal/Maxillary and mandibular canines and premolars	RCT/To compare the effect of demineralized bovine bone as an adjunct to resorbable collagen for bone augmentation at immediate implants	Test group: DBBM and resorbable collagen membrane Control group: Resorbable collagen membrane only	Test group = 10 Control group = 10	Test group = 10 Control group = 10	6 mo	Mean radiographic crestal bone location from implant shoulder, baseline to 6 mo: Test group: 1.7 mm vs 1.8 mm Control group: 2.2 mm vs 2.1 mm Mean proximal mucosal margin levels coronal to the shoulder at 6 mo: Buccal Test group: 2.6 mm Control group: 2.3 mm ($P < .01$) Lingual Test group: 1.3 mm Control group: 1.1 mm ($P < .01$) Mean buccal mucosal margin levels coronal to the shoulder at 6 mo: Test group: 2.1 mm Control group: 0.9 mm ($P < .05$)
Chen et al (2005)[19]	Turned	Type 1/Submerged/Single-tooth implants in the maxillary anterior and premolar regions	RCT/To compare the effect of various bone augmentation procedures on healing of the peri-implant marginal defect/Primary outcome variables-defect height, width, and depth changes and resorption of the facial bone wall	Group 1: e-PTFE membrane only Group 2: Resorbable polymer membrane only Group 3: Resorbable polymer membrane and autogenous bone Group 4: Autogenous bone only Group 5: No augmentation; control	Group 1 = 12 Group 2 = 11 Group 3 = 12 Group 4 = 14 Group 5 = 12 Total = 62	Group 1 = 12 Group 2 = 11 Group 3 = 12 Group 4 = 14 Group 5 = 12 Total = 62	2 y after loading	Defect height reduction (%): Group 1: 74.9 ± 27.8*; Group 2: 69.1 ± 27.6; Group 3: 83.1 ± 23.8; Group 4: 75.3 ± 20.9; Group 5: 73.6 ± 24.1 (NS) Defect depth (orofacial) reduction (%): Group 1: 73.6 ± 30.3; Group 2: 75.8 ± 34.3; Group 3: 89.7 ± 19.9; Group 4: 75.6 ± 26.0; Group 5: 69.7 ± 44.2 (NS) Defect width (mesiodistal) reduction (%): Group 1: 67.3 ± 23.6; Group 2: 60.6 ± 35.9; Group 3: 71.2 ± 29.2; Group 4: 34.1 ± 28.3; Group 5: 73.6 ± 24.1 ($P < .01$ between groups; Group 1 different from Groups 4 and 5, Group 2 different from Group 4, Group 3 different from Groups 4 and 5)
Chen et al (2007)[20]	SLA	Type 1/Transmucosal/Single-tooth implants in maxillary anterior and premolar sites	RCT/To compare the effect of various bone augmentation procedures on healing of the peri-implant marginal defect/Primary outcome variables-change in defect height, width, and depth, and facial crestal bone	Maxillary anterior and premolar sites Group 1 (n = 10): DBBM Group 2 (n = 10): DBBM and resorbable collagen membrane Group 3 (n=10): No augmentation; control	Group 1 = 10 Group 2 = 10 Group 3 = 10	Group 1 = 10 Group 2 = 10 Group 3 = 10	6 mo	Mean change in vertical defect height: Group 1: 81.2 ± 5.0%; Group 2: 70.5 ± 17.4%; Group 3: 68.2 ± 16.6% (NS) Mean change in defect depth (orofacial): Group 1: 71.7 ± 34.3%; Group 2: 81.7 ± 33.7%; Group 3: 55.0 ± 28.4% (NS) At sites with intact bone walls, mean change in facial crestal bone height: Group 1: 1.1 ± 1.2 mm; Group 2: 1.0 ± 0.6 mm; Group 3: 1.3 ± 0.9 mm (NS) At sites with intact bone walls, mean horizontal resorption of the facial bone: Group 1: 13.9 ± 16.7%; Group 2: 23.8 ± 23.4%; Group 3: 48.3 ± 9.5% ($P = .015$; Group 3 significantly greater than Groups 1 and 2)

Implant surface: Turned = equivalent to machined surface; TPS = titanium plasma-sprayed; HA = hydroxyapatite-coated, SLA = surface sandblasted with large-grit and acid-etched.
Placement protocol (placement time after extraction): Type 1 = immediate placement at the time of extraction; Type 2 = early placement after initial soft tissue healing; Type 3 = early placement after substantial bone healing; Type 4 = late placement after complete healing of the ridge. Study design: RCT = randomized controlled trial; CCS = controlled clinical study; CoS = cohort study; CS = case series. Augmentation method: e-PTFE = expanded polytetrafluoroethylene membrane; DBBM = demineralized bovine bone mineral; DFDBA = demineralized freeze-dried bone allograft; TCP = beta tricalcium phosphate.
*The authors reported standard error; standard deviation was derived from data presented in the paper.

type 1 and type 2 placement, and concluded that both approaches resulted in complete defect fill.[23] A human histologic study confirmed that spontaneous bone regeneration occurred in experimental peri-implant defects that were less than 2 mm in width, and that the newly regenerated bone became integrated with the previously exposed implant surface.[42]

Covani and coworkers observed that complete defect fill occurred in the peri-implant gaps following type 1 and type 2 implant placement.[23,35] The initial peri-implant gaps were 2 mm or less, and all sites had intact bone walls. These observations are corroborated by human histologic studies that have shown spontaneous bone regeneration and osseointegration when peri-implant defects were less than 2 mm in a horizontal dimension.[42–44] In contrast, two studies examining healing outcomes when the initial peri-implant gaps were more than 2 mm reported that not all sites healed with complete bone fill. Botticelli et al demonstrated that 25% of sites with initial orofacial gaps of 2 to 3 mm healed completely, compared to 78% of sites with initial gaps of less than 2 mm.[37] Schropp et al observed that only 52% of sites with an initial orofacial defect depth of 4 to 5 mm healed spontaneously in the presence of intact bone walls.[17]

Summarizing these studies, there is evidence to show that peri-implant defects with gaps of less than 2 mm following type 1 and type 2 implant placement may heal with spontaneous bone regeneration and defect resolution. However, gaps of 2 mm or more in the orofacial dimension show clearly reduced predictability for spontaneous bone regeneration.

Do Implants Prevent Resorption of the Ridge in Postextraction Sites? Recent clinical and experimental studies have demonstrated that healing in postextraction sites is characterized by bone regeneration within the socket and external dimensional changes due to bone resorption and bone modeling.[45–47] A series of well-designed experimental studies in a canine model have demonstrated that implants placed into extraction sockets of mandibular premolar teeth did not prevent these resorptive and modeling changes from taking place.[48,49] The result is a reduction in the orofacial dimension of the ridge and a loss of crestal bone height, predominantly at the facial aspect of the ridge.

Several studies have provided clinical data on the dimensional changes that occur adjacent to implants in postextraction sockets when no augmentation was performed.[35,37,38] In a prospective study, the distance between the facial and lingual bone walls changed from 10.5 ± 1.5 mm to 6.8 ± 1.3 mm (35% reduction in initial orofacial width) after 6 months of submerged healing.[35] In this study, implants were placed into extraction sockets (type 1 implant placement) in maxillary and mandibular anterior and premolar sites. A further prospective study reported on type 1 placement of 21 implants in 18 patients.[37] Implant sites were confined to maxillary and mandibular anterior and premolar sites. After 4 months of submerged healing, the implant sites were reentered and changes in the dimensions of the ridges were recorded. External bone resorption and modeling resulted in a reduction in the orofacial crest width of 56% on the facial aspect and 30% on the lingual aspect. The height of the crestal bone was reduced by 0.2 to 0.6 mm. In a similar prospective study, Covani and coworkers reported a mean loss in facial crestal bone height of 0.8 mm after 6 months of submerged healing following type 1 placement in 20 patients.[38] Implant sites included maxillary and mandibular anterior and premolar sites. Although 38% of the sites showed no change, 47% had between 0 mm and 1 mm of loss, and 15% had between 1 and 2 mm of loss.

These studies provide strong evidence that type 1 placement per se does not prevent vertical or horizontal resorption of the ridges in postextraction sites.

Does Bone Augmentation Prevent Ridge Resorption with Postextraction Implants? Three RCTs[14,19,20] and one prospective clinical case series[36] reported on the effect of bone augmentation on external dimensional changes with postextraction implant placement.

In a study of 40 patients, vertical resorption of the facial crestal bone was similar for sites treated with an e-PTFE membrane alone or an e-PTFE membrane and DFDBA (1.59 ± 1.7 mm vs 1.53 ± 1.4 mm) for type 1 placement after 6 months of submerged healing.[14] Similar changes in facial crestal bone height were observed in a study of 30 patients who received 30 immediate implants and transmucosal healing.[20] After a healing time of 6 months, vertical resorption of the facial bone was 1.1 ± 1.2 mm for peri-implant defects grafted with DBBM, 1.0 ± 0.6 mm for sites augmented with DBBM and collagen membrane, and 1.3 ± 0.9 mm for nonaugmented control sites. There were no significant differences between groups. The results of these two studies are similar to results from studies of nongrafted postextraction implant sites with respect to vertical crestal bone resorption.[37,38]

A study of various augmentation techniques with type 1 placement showed that although defect fill was similar, dehiscence defects showed significantly greater horizontal resorption than sites with intact bone walls.[19] In another study by the same authors, significantly less horizontal resorption of the facial bone occurred when the peri-implant defects were grafted with DBBM (13.9% to 23.8%) compared to the nonaugmented control group (48.3%).[20] Similarly, Yukna and Castellon reported that following type 1 placement and grafting of the peri-implant defects

with a composite of polymethyl methacrylate and calcium hydroxide, the external dimensions of the sockets changed only slightly, from 9.1 ± 2.4 mm to 8.4 ± 1.9 mm (an 8% reduction in orofacial ridge width) after 6 months.[36] Both these studies used bone fillers with a low substitution rate.

These studies provide strong evidence that bone augmentation following type 1 placement reduces horizontal resorption of the facial bone. However, these augmentation procedures appear not to influence vertical resorption of the facial bone.

Does Damage to or Loss of the Facial Bone Affect Regenerative Outcomes? In postextraction sites, loss of one or more of the socket walls is a common observation. In a retrospective study of 75 patients, only 10 out of 31 extraction sites (32%) had intact bone walls.[21] The majority of extraction sites presented with damage to the socket walls, with two-wall (52% of sites) or no-wall/one-wall (16% of sites) defects. The authors also reported that the proportion of two- and three-wall defects diminished as the time after tooth extraction increased. In an RCT, 60 out of 92 type 3 and type 4 implant placement sites had peri-implant defects. Of these, 48 were three-wall defects and 12 were dehiscence or two-wall defects.[17]

Several studies were identified that reported on treatment outcomes in postextraction sites in the presence of dehiscences of the socket walls.[17,19,20,25,30,40] In two RCTs of type 1 placement using various augmentation techniques, sites with dehiscence defects achieved similar defect fill compared to intact sites.[19,20] However, greater horizontal resorption of the facial bone occurred in the presence of a dehiscence, despite bone augmentation.[19] In a prospective study of type 1 placement in 35 patients, 100% implant thread coverage was achieved in all sites except one site with a no-wall defect morphology, which achieved only 76% coverage.[25] In this study, DFDBA was used alone or in combination with an e-PTFE membrane. A study of type 1 implant placement in 29 patients receiving 33 implants showed significant gain in crestal bone height at dehiscence sites using DBBM and collagen membrane.[30] The resultant ridge height was similar to that observed in sites that initially had intact bone walls. In a study of type 2 implant placement in which all 28 implant sites in 21 patients presented with dehiscence defects, a defect area reduction of 97% was reported using DBBM and collagen membrane.[40] A gain in crestal bone height of 6 to 7 mm was recorded.

In contrast to these studies, Schropp et al reported that a trend toward greater bone fill was observed at sites with intact bone walls compared to sites with dehiscence defects.[17]

These studies provide strong evidence that bone augmentation following type 1 and type 2 placement is effective in reconstructing the damaged facial bone. However, with type 1 placement, greater resorption of the facial bone was shown to occur in one RCT. This may have significant implications for esthetic outcomes. A recent study reported a high incidence of recession of the facial mucosa in the presence of defects of the facial bone with type 1 placement, despite bone augmentation using DBBM and collagen membranes.[50]

Does Timing of Implant Placement Affect the Regenerative Outcome? There were six studies that provided comparative data on the effect of timing of implant placement on regenerative outcomes (Table 4).[15,17,21–24]

Three studies compared immediate (type 1), early (type 2 or 3), and late (type 4) implant placement. In a split-mouth randomized study of dehiscence defects augmented with DBBM, Zitzmann et al reported less defect area reduction with healed sites (80% for e-PTFE membrane and 90% for collagen membrane) compared to immediate and healing sites (85% to 94% for e-PTFE membrane and 95% to 97% for collagen membrane) in 25 patients.[15] Similarly, in a retrospective study of 75 patients by the same authors, defect area reduction was significantly better with type 1 and types 2 and 3 implant placement (92% ± 20.8% and 92% ± 20.7%, respectively) compared to type 4 (80% ± 34.1%).[21] The authors suggested that the difference was attributable to the greater proportion of one-wall/no-wall defects found with type 4 placement compared to immediate and early placements, which had a greater proportion of two-wall and three-wall defects. In another retrospective study, the use of DBBM and collagen membrane resulted in less defect area reduction with type 4 placement (87.6% ± 11.5%) compared to type 1 (90.2% ± 9.1%) and type 2 (95.6% ± 8.7%) placement.[24] Type 2 placement achieved the best regenerative outcome in this study.

Two studies compared types 1 and 2 implant placement. In a prospective study using DBBM and collagen membrane to manage dehiscence defects, significantly greater defect area reduction was observed with type 2 placement (91.2% ± 9.1%) compared to immediate placement (type 1; 77.4% ± 17.0%) in maxillary molar sites.[22] Covani et al reported that both type 1 and type 2 placement in sites with intact bone walls achieved complete defect fill in the absence of simultaneous bone augmentation procedures.[23]

One RCT compared early placement in 46 patients who received single-tooth implants in maxillary and mandibular anterior and premolar sites.[17] Implants were placed a mean of 10 days after extraction (range 3 to 35 days) in the test sites (23 implants in 23 patients). In control sites (23 implants in 23 patients),

Table 4 Clinical Studies Comparing Different Times After Extraction and Their Effect on Healing of Peri-Implant Defects

Study	Study design	Implant surface	No. of patients (No. of implants) by placement time after tooth extraction: Type 1	Types 2 and 3	Type 4	Augmentation method (healing protocol)	Observation period	Results for placement times after tooth extractionmethod: Type 1	Types 2 and 3	Type 4
Zitzmann et al (1997)[15]	RCT	Turned	25* (27)	25* (17)	25* (40)	DBBM and either non-resorbable e-PTFE or resorbable collagen membrane (randomly allocated)	4 to 6 mo	Defect area reduction 85% for e-PTFE; 95% for collagen membrane	Defect area reduction 94% for e-PTFE; 97% for collagen membrane	Defect area reduction 80% for e-PTFE; 90% for collagen membrane
Zitzmann et al (1999)[21]	Retro CS	Turned	75* (31)	75* (23) (placement time after extraction from 6 wk to 6 mo)	75* (48) (placement time after extraction > 6 mo)	DBBM and resorbable collagen membrane (submerged)	4 to 6 mo	Defect area reduction 92% ± 20.8% Defect morphology: no-wall/1-wall defect: 16% 2-wall defect: 52% 3-wall defect: 32%	Defect area reduction 92% ± 20.7% Defect morphology: no-wall/1-wall defect: 39% 2-wall defect: 55% 3-wall defect: 6%	Defect area reduction 80% ± 34.1% Defect morphology: no-wall/1-wall defect: 92% Trend toward less successful outcome of type 4 compared to types 2/3 and type 1 placements combined (P = .05)
Nemcovsky and Artzi (2002)[22]	Retro CS	Microrough, HA and TPS	19 (23)	24 (31) (4 to 6 wk)	–	DBBM and resorbable collagen membrane (submerged)	6 to 8 mo	Defect height reduction 77.4% ± 17.0%§ Defect area reduction 90.2% ± 9.1%§ (All sites presented initially with dehiscence defects)	Defect height reduction 91.2 % ± 9.1%§ Defect area reduction 97.2% ± 3.9%§ (All sites presented initially with dehiscence defects)	–
Covani et al (2004)[23]	Prosp CS	NR	33 (20)	33 (20) (6 to 8 wk)	–	No augmentation (submerged)	4 mo mandible, 6 mo maxilla	Facial to lingual ridge width change from 10.0 ± 1.5 mm to 8.1 ± 1.3 mm† Complete defect fill	Facial to lingual ridge width change from 8.9 ± 2.4 mm to 5.8 ± 1.3 mm† Complete defect fill	–
Nemcovsky et al (2002)[24]	Retro CS	HA and TPS	19/23	25/39 (4 to 6 wk)	22/40	DBBM and resorbable collagen membrane (submerged)	6 to 8 mo	Defect height reduction 77.4% ± 16.9%§ Defect area reduction 90.2% ± 9.1%§	Defect height reduction 88.8% ± 15.3%§ Defect area reduction 95.6% ± 8.7%§ Significantly greater defect area and height reduction recorded for early placement (type 2) compared to the other 2 treatment groups	Defect height reduction 75.2% ± 18.0%§ Defect area reduction 87.6% ± 11.5%§

Table 4 continued Clinical Studies Comparing Different Times After Extraction and Their Effect on Healing of Peri-Implant Defects

Study	Study design	Implant surface	No. of patients (No. of implants) by placement time after tooth extraction: Type 1	Types 2 and 3	Type 4	Augmentation method (healing protocol)	Observation period	Results for placement times after tooth extraction: Type 1	Types 2 and 3	Type 4
Schropp et al (2003)[17]	RCT	Acid-etched	–	Group 1: 23 (23) early placement (mean 10 d; range 3 to 15 d after tooth extraction) Group 2: 23 (23) early placement (type 3 - mean 14.1 wk; range 65 to 138 d after tooth extraction)	–	Autogenous bone in dehiscence sites (submerged)	3 mo	–	Defect height reduction: Group 1: 48% Group 2: 34% (no significant differences between groups) Defect width (mesiodistal) reduction: Group 1: 48% Group 2: 39% (no significant differences between groups) Defect depth (orofacial) reduction (for sites with intact facial bone, ie, 3-wall defects only): Group 1: 59% Group 2: 77% (no significant differences between groups)	–

Study design: Retro = retrospective; Prosp = prospective; RCT = randomized controlled trial; CS = case series.
Implant surface: Turned = equivalent to machined surface; TPS = titanium plasma-sprayed; HA = hydroxyapatite-coated; SLA = surface sandblasted with large grit and acid-etched.
Placement time after extraction: Type 1 = immediate placement at the time of extraction; Type 2 = early placement after initial soft tissue healing; Type 3 = early placement after substantial bone healing; Type 4 = late placement after complete healing of the ridge.
Augmentation method: e-PTFE = expanded polytetrafluoroethylene membrane; DBBM = demineralized bovine bone mineral; DFDBA = demineralized freeze-dried bone allograft; TCP = beta tricalcium phosphate.
– = Due to the study design, there were no data for this parameter.
NR = not reported.
* Indicates total number of patients in the study.
† Significant within-group differences ($P < .05$).
‡ Significant within-group change from baseline ($P < .01$).
§ Significant between-group difference ($P < .05$).

implants were placed a mean of 14.1 weeks following extraction (range 9.3 to 19.7 weeks). Most sites did not receive bone grafts or membranes; three control sites received autogenous bone chips to cover dehiscences of the facial bone. The authors reported no statistically significant differences in defect height, width, and depth reduction between the two groups.

These studies provide strong evidence that augmentation procedures are more successful with immediate (type 1) and early (types 2 and 3) implant placement than with late placement (type 4). There is some evidence to show that regenerative outcomes are better with type 2 placement compared to type 1 placement in the presence of dehiscence defects of the bone. However, with intact bone walls, type 1 and type 2 placement achieve similar results with respect to fill of the peri-implant defect.

Does the Healing Protocol (Submerged Versus Transmucosal Healing) Affect Treatment Outcome? Most studies used a submerged healing protocol following implant placement. In five studies that used a transmucosal healing protocol,[18,20,27,29,41] the healing outcomes appeared to be similar to reports from studies using a submerged approach. No studies were identified that directly compared submerged with transmucosal healing for postextraction implants.

Evidence is lacking to demonstrate the superiority of one healing protocol over the other with respect to healing of peri-implant defects with postextraction implants.

What Are the Postoperative Complications with Postextraction Implants? The majority of studies with postextraction implants reported the occurrence of postoperative complications. Although not common, the most clinically significant complication with type 1 placement was postoperative infection or abscess formation leading to implant loss.[19,51–56]

The most common complication reported was dehiscence of the wound and exposure of e-PTFE membranes when submerged healing was used with immediate implants.[15,19,25,28,30,31,33–35,52,57–60] Three studies reported on the rate of complications with e-PTFE membranes,[58,59,61] which ranged from 4.3% to 48% of sites. Studies with reentry defect data showed that this complication was associated with impaired healing and reduced bone fill in the peri-implant defects.[15,28] Premature membrane exposure and infections in 15% to 20% of sites were reported in studies of type 1 placement using transmucosal healing when e-PTFE membranes were used.[27,29] In studies using collagen membranes combined with bone grafts and bone substitutes, wound dehiscences were also reported.[30–35,62,63] These studies reported complication rates ranging from 4.2% to 36.7%.

Since 1998, there has been a clear trend in study designs to use resorbable collagen membranes rather than e-PTFE membranes for bone augmentation. In the event of wound dehiscences, collagen membranes have been associated with less adverse healing outcomes. A split-mouth study which compared e-PTFE membranes with collagen membranes demonstrated that when wound dehiscences occurred, bone fill was significantly better in sites with collagen membranes than in sites with e-PTFE membranes.[15] Furthermore, the healing outcomes were similar in sites with collagen membranes, whether or not a wound dehiscence occurred.

Other complications reported with type 1 placement included postoperative pain,[38,52,64] sloughing of the flaps,[30,31] postoperative bleeding,[31] and temporary paresthesia.[65,66] Absence of complications with type 1 implants was reported in only seven studies.[26,38,67–71]

Only two studies reported on complications with type 2 placement. These included postoperative infection and necrosis of the flap in 2 out of 10 patients (20%)[41] and postoperative bleeding.[31] No complications were reported in two studies with type 2 placement and submerged healing.[39,72]

Two studies provided comparative data on postoperative complications with postextraction implants placed with submerged healing. In a split-mouth study comparing type 1 and type 4 placement, premature implant exposure occurred in 7 out of 14 sites (50%) with type 1 placement compared to 4 out of 14 sites (28.8%) with type 4 placement. Bone augmentation with particulate hydroxyapatite was undertaken.[73] In a retrospective study in which autogenous bone chips were grafted into peri-implant defects, premature implant exposure occurred in 10.2% of sites with type 1 placement compared to 11.8% of sites with type 4 placement.[74]

There were no studies that compared the rate of postoperative complications between type 1 and type 2 or 3 implant placements.

The evidence is clear that postoperative complications are common with immediate placement. The most common complication is dehiscence of the wound when either collagen or e-PTFE membranes are used in conjunction with submerged healing. There is strong evidence to show that in the presence of a wound dehiscence, collagen membranes result in better bone regeneration and defect fill compared to e-PTFE membranes. There were no comparative data for complication rates between type 1 and type 2 or 3 implant placements.

Do Systemic Antibiotics Enhance the Treatment Outcome? The majority of studies included systemic antibiotics that were prescribed perioperatively and/or postoperatively. Amoxicillin was the most

commonly prescribed antibiotic. There were no studies that reported on the influence of systemic antibiotics on the outcome of bone augmentation procedures, or on the occurrence of postoperative complications.

Survival Outcomes of Postextraction Implants

A total of 54 papers reporting on survival outcomes of postextraction implants were identified (Table 5). There were 24 prospective and 11 retrospective studies; of these, the majority reported on survival outcomes with type 1 implant placement.[25,27,50–52,54–56,58,59,61,63,64,67–71,75–85] Four studies provided data on type 2 placement.[11,39,72,86]

There were 19 studies that provided data comparing different placement times after extraction (Table 6). Of these, only two were RCTs[87,88] and two were controlled clinical studies.[73,89] The remaining studies were prospective and retrospective case series studies.[53,57,65,66,74,90-99]

What Are the Survival Outcomes of Postextraction Implants? The data on survival outcomes of postextraction implants were predominantly derived from studies with type 1 implant placement. Most studies (35 studies) were short term, with mean observation periods of 1 to 3 years. Survival rates ranged from 65% to 100% (median 99%), with 25 studies reporting survival rates of 95% or higher. Ten studies had mean follow-up periods of 3 to 5 years. Survival rates over this period ranged from 90% to 100% (median 95.5%). Only 3 studies were published with follow-up periods of greater than 5 years; survival rates for these studies ranged from 92% to 97% (median 95%).

Seven studies reported on survival after early implant placement (type 2), six of which were short-term studies of 1 to 3 years. One study provided comparative data between type 1 and type 2 placement over 4 years. The survival rates for type 2 placement ranged from 91% to 100% (median 100%).

There were only two studies that reported data on early implant placement with partial bone healing (type 3). The survival rates were 96% and 100%.

Due to the heterogeneity of the studies with respect to implant surfaces, loading protocols, and the relatively short-term observation period for the majority of studies, the data should be interpreted cautiously. However, it appears that survival rates for postextraction implants are high, with the majority of studies reporting survival rates of over 95%.

Does Timing of Implant Placement Influence Survival Outcomes? Of the 19 studies with comparative data, most compared type 1 and type 4 implant placement (11 studies). Three studies compared type 1 and type 2 implant placement. Two studies compared type 2 and type 3 implant placement, and one study compared type 1 and type 3 implant placement (two of these studies were RCTs).[87,88] One study had comparative data on type 1, type 2, and type 4 placement. The majority were short-term studies. Four studies reported follow-up periods of 3 to 5 years, whereas only one study had a follow-up time of over 5 years. In one retrospective study with comparative data, it was unclear when implants were placed after tooth extraction.[94]

Type 1 Versus Type 4 Implant Placement. All studies comparing type 1 to type 4 implant placement were either retrospective or prospective cohort or case series studies. In seven studies with conventional or delayed loading, survival rates of type 1 implants ranged from 90% to 100% (median 99%) compared to 60% to 100% (median 94%) for implants with type 4 placement.[64,73,90,91,96–98] In six studies of immediate restoration of single-tooth, short-span, and full-arch replacements, the survival rates of immediate implants (type 1 placement) was 65% to 100% (median 91%) compared to 94% to 100% (median 95%) for implants with type 4 placement.[53,66,92,96,98,99] In one retrospective study providing data on three placement protocols, type 1 and type 2 implant placement had higher survival rates (99% and 100%, respectively) than type 4 implant placement (81.8%).[57]

There is evidence to show that postextraction implants have survival rates similar to implants in healed sites. With immediate loading, type 1 implants may have lower survival rates than implants placed into healed sites.

Type 1 Versus Type 2 Implant Placement. Two short-term retrospective studies[57,95] and one prospective cohort study with a 5-year follow-up[65] provided comparative data on type 1 and type 2 placement. Survival rates for type 1 implant placement ranged from 90% to 99% (median 90%) compared to a range of 90% to 100% (median 94%) for type 2 placement. Thus, implants placed with an immediate or early (type 2) protocol appear to have a similar survival outcome. In two studies, increased failure rates were noted in patients with a history of periodontitis.[65,94]

Type 1 Versus Type 3 Implant Placement. Comparative data for type 1 and type 3 implant placement were examined in only one study, which was an RCT.[88] A total of 50 patients were selected, each with a single tooth site with radiographic evidence of chronic apical periodontitis. The patients were randomly allocated to receive either immediate placement or placement 12 weeks after extraction (type 3). A submerged healing protocol was used and patients were followed up for 12 months. The survival rates of implants placed immediately were 92% and 100% for type 1 and type 3 placement, respectively.

Table 5 Clinical Studies Reporting on Survival Outcomes with Postextraction Implants

Study	Study design/ Placement time after tooth extraction	Implant surface	No. of patients (No. of implants)	Implant sites	Augmentation method/ Healing protocol	Loading protocol/ Restoration type	Observation period	Survival rate (%)
Gelb (1993)[25]	Prosp CS/ Type 1	Turned	35 (50)	Maxillary and mandibular anterior teeth and premolars, and mandibular molars	e-PTFE membrane alone, or DFDBA graft alone, or e-PTFE membrane combined with DFDBA graft/ Submerged	Conventional/Single-tooth restorations	Mean 17 mo (range 8 to 44 mo)	98
Lang et al (1994)[27]	Prosp CS/ Type 1	TPS	16 (21)	Maxillary incisors, canines, premolars, and mandibular premolars	e-PTFE membrane alone/ Transmucosal	Delayed/Single-tooth, short-span prostheses, short-span tooth-implant prostheses	Mean 30.3 mo (range 21 to 42 mo)	100
Rosenquist and Grenthe (1996)[51]	Retro CS/ Type 1	Turned	51 (109)	NR	No augmentation in most cases; e-PTFE membrane in 5 patients/ Submerged	Conventional in the mandible; delayed in the maxilla/Restoration type NR	Mean 30.5 mo (range 1 to 67 mo)	93.6
Pecora et al (1996)[52]	Retro CS/ Type 1	TPS	31 (32)	Maxillary and mandibular incisor, canine, premolar, and molar sites	e-PTFE membrane in 10 sites/ Submerged	NR/Single-tooth restorations	Mean 16.3 mo after loading	96.9
Cosci and Cosci (1997)[58]	Retro CS/ Type 1	HA	353 (423)	NR	e-PTFE membrane for sites with intact bone walls; hydroxyapatite or DFDBA graft and collagen membrane for socket wall defects or apical fenestration/ Submerged	NR/Restoration type NR	Range 1 to 7 y	99.5
Schwartz-Arad and Chaushu (1997)[62]	Retro CS/ Type 1	Turned and HA	49 (85)	Maxillary and mandibular anterior, premolar, and molar sites	Autogenous bone chips/ Submerged	NR/Restoration type NR	Range 4 to 7 y	95 after 5 y
Nir-Hadar et al (1998)[39]	Prosp CS / Type 2 (4 to 8 wk after extraction)	Turned	14 (21)	All areas	No augmentation/ Submerged	Delayed/NR	12 mo	95.2
Becker et al (1999)[59]*	Prosp multicenter CoS/Type 1	Turned	40 (49)	All areas Single-tooth replacement	e-PTFE membrane alone/ Submerged	NP/Single-tooth replacements	5 y	93.9
Grunder (2000)[86]	Prosp CS/ Type 2 (8 wk after extraction)	Turned	10 (10)	Maxillary central and lateral incisors	e-PTFE membrane and DBBM/ Submerged	Delayed/Single-tooth replacements	1 y after loading	100
Schwartz-Arad et al (2000)[63]	Retro CS/ Type 1	Turned and HA	43 (56)	Maxillary and mandibular molar sites only	Autogenous bone when required; e-PTFE (2 sites) and collagen membranes (6 sites) /Submerged	Delayed/Single-tooth and short spans	Mean 15 mo (range 4 to 60 mo)	89.3
Huys (2001)[67]	Retro CS/ Type 1	TPS	147 (556)	NR	Composite polymer graft/ Submerged	Conventional/Ball-retained overdentures, short-span prostheses, implant-tooth prostheses, single crowns	Range 7 to 10 y	96.6

Table 5 continued Clinical Studies Reporting on Survival Outcomes with Postextraction Implants

Study	Study design/ Placement time after tooth extraction	Implant surface	No. of patients (No. of implants)	Implant sites	Augmentation method/ Healing protocol	Loading protocol/ Restoration type	Observation period	Survival rate (%)
Gomez-Roman et al (2001)[61†]	Prosp CS/ Type 1	Grit blasted and acid-etched	104 (124)	All sites	Autogenous bone (9 sites), HA (24 sites), e-PTFE membrane (17 sites)/Transmucosal	NR/Single-tooth, partial, and full arches	Mean 2.6 y (up to 6.3 y)	97
Goldstein et al (2002)[68]	Prosp CS/ Type 1	Turned	38 (47)	Maxillary sites	DFDBA and resorbable polymer barrier membrane/Submerged	NR/Single-tooth replacements	Mean 39.4 mo (range 1 to 5 y)	100
Artzi et al (2003)[69]	Prosp CS/ Type 1	TCP blasted	10 (12)	Maxillary molar sites only	DBBM or TCP/Submerged	NR/Single-tooth and extended spans	2 y	100
Kan et al (2003)[76]	Prosp CS/ Type 1	HA	35 (35)	Maxillary incisor and canine sites	No augmentation/Transmucosal	Immediate restoration/Single-tooth replacements	1 y	100
Covani et al (2004)[54]	Prosp CS/ Type 1	TPS	95 (164)	Maxillary and mandibular incisor, canine, and premolar sites	No augmentation at 58 sites with intact bone walls; autogenous bone chips and resorbable membranes in 105 sites with dehiscence and fenestration defects/Transmucosal	Immediate restoration/ Single-tooth replacements	4 y	97
Bianchi and Sanfilippo (2004)[106]	Retro CS/ Type 1	TPS	116 (116)	All sites	NR/Submerged	Delayed/Single-tooth replacements	1 to 9 y	100
Cangini and Cornelini (2005)[77]	Prosp CCS/ Type 1	SLA	32 (32)	Maxillary and mandibular incisor, canine, and premolar sites; all teeth had periodontal defects	Enamel matrix derivative (18 sites); resorbable collagen membrane (14 sites)/Transmucosal	Delayed/Single-tooth replacements	12 mo	100
Cornelini et al (2005)[70]	Prosp CS/ Type 1	SLA	22 (22)	Maxillary and mandibular incisor, canine, and premolar sites	Resorbable collagen membrane/ Transmucosal	Immediate restoration/ Single-tooth replacements	12 mo	100
Vanden Bogaerde et al (2005)[55]	Prosp CS/ Type 1	Titanium oxide coated	19 (50)	Maxillary anterior and premolar sites, and mandibular premolar and molar sites	Autogenous bone in 3-wall defects; autogenous bone and resorbable polymer membrane for 1- and 2-wall defects/Transmucosal	Immediate and early loading/Short-span to full-arch restorations	18 mo	100
Barone et al (2006)[56]	Prosp CS/ Type 1	TPS	18 (18)	Maxillary and mandibular incisor, canine, and premolar sites	No augmentation (all sites with intact bone walls and marginal gaps < 2 mm)/Transmucosal	Immediate restoration/ Single-tooth restorations	12 mo	94.5
Ferrara et al (2006)[78]	Prosp CS/ Type 1	Grit-blasted/ acid-etched	33 (33)	Maxillary and mandibular incisor, canine, and premolar sites	Osseous coagulum if a marginal gap was present/Transmucosal	Immediate restoration/ Single-tooth restorations	4 y	94.0
Fugazzotto (2006)[79]	Prosp CS/ Type 1	SLA	83 (83)	Maxillary first and second molars	Osseous coagulum or demineralized bone matrix paste with resorbable or titanium-reinforced e-PTFE membrane/Submerged	Delayed/Single restorations	Mean 12.4 mo in function	100

Table 5 continued Clinical Studies Reporting on Survival Outcomes with Postextraction Implants

Study	Study design/ Placement time after tooth extraction	Implant surface	No. of patients (No. of implants)	Implant sites	Augmentation method/ Healing protocol	Loading protocol/ Restoration type	Observation period	Survival rate (%)
De Kok et al (2006)[80]	Retro CS/ Type 1	Titanium-oxide grit-blasted	28 (43)	Maxillary anterior and premolar sites	NR/Transmucosal	Immediate restoration/ Single-tooth restorations	12 to 30 mo (no mean)	90.7
Wagenberg and Froum (2006)[81†]	Retro CS/ Type 1	Turned and unspecified rough-surfaced implants	591 (1,091)	Maxillary and mandibular incisor, canine, and premolar sites	Mineralized FDBA and resorbable polymer membrane/Submerged	Delayed/ Restoration type NR	35% for 1 y 46% for 2 to 5 y 19% for 5 to 11 y	95
Covani et al (2007)[82]	Prosp CS/ Type 1	Sandblasted and acid-etched	10 (10)	Maxillary and mandibular incisor, canine, and premolar sites	NR/Submerged	Delayed/ Single restorations	12 mo	100
Juodzbalys and Wang (2007)[83]	Prosp CS/ Type 1	NR	12 (14)	Maxillary central and lateral incisors	DBBM and resorbable collagen membrane/Submerged	Delayed/ Single restorations	12 mo after loading	100
Sammartino et al (2007)[71]	Retro CS/ Type 1	SLA (53 implants) and grit-blasted/ acid-etched (34 implants)	55 (83)	Maxillary and mandibular incisor, canine, and premolar sites	No augmentation (all marginal gaps were ≤ 2 mm)/ Transmucosal	Early/Single- and multiple-tooth replacements	2 y	96.6
Kan et al (2007)[50]	Prosp CS/ Type 1	Titanium oxide coated	23 (23)	Maxillary central and lateral incisors, and canines	Autogenous bone or DBBM and resorbable collagen membrane/ Transmucosal	Immediate restoration/ Single-tooth restorations	12 mo	100
Schwartz-Arad et al (2007)[64]	Retro CS/ Type 1	NR	87 (210)	Maxillary and mandibular anterior teeth and premolars, and maxillary molars	DBBM and autogenous bone mixture/ Transmucosal	Immediate restoration/ Single-tooth and short-span restorations	Mean 15.6 ± 12.6 mo (range 6 to 52 mo)	97.6
Crespi et al (2007)[123]	Prosp CS/ Type 1	TPS	27 (150)	All sites	Autogenous bone chips/ Transmucosal	Immediate loading/ Full-arch maxillary and mandibular restorations	18 mo	100
Villa and Rangert (2007)[84]	Prosp CS/ Type 1	Titanium oxide coated	33 (100)	Maxillary incisors, canines, and premolars	Autogenous bone and DBBM/ Transmucosal	Immediate and early loading/Single-tooth, partial, and full-arch restorations	12 mo	97.4§
Cafiero et al (2008)[100]	Prosp CoS/ Type 1	SLA	82 (82)	Maxillary and mandibular molars	DBBM and resorbable collagen membrane when marginal gaps > 1 mm/ Transmucosal	Early/Single-tooth restorations	12 mo	100
Fugazzotto (2008)[60]	Retro CS/ Type 1	SLA	386 (391)	Maxillary first and second molars	DBBM or demineralized bone putty, and titanium reinforced e-PTFE membrane/Submerged	NR/Single (387 implants) and splinted restorations (4 implants)	Mean 40.3 mo	99.5
Fugazzotto (2008)[101]	Retro CS/ Type 1	SLA	335 (341)	Mandibular first and second molars	DBBM or demineralized bone putty, and titanium-reinforced e-PTFE membrane at sites with marginal gaps > 3 mm/Submerged	NR/Single-tooth and splinted restorations	Mean 30.8 mo	99.1

Table 5 continued Clinical Studies Reporting on Survival Outcomes with Postextraction Implants

Study	Study design/ Placement time after tooth extraction	Implant surface	No. of patients (No. of implants)	Implant sites	Augmentation method/ Healing protocol	Loading protocol/ Restoration type	Observation period	Survival rate (%)
Buser et al (2008)[11]	Retro CS / Type 2 (4 to 8 wk after extraction)	SLA	45 (45)	Maxillary anterior and premolar teeth	DBBM and collagen membrane; graft applied to marginal defects and external surface of the facial bone/Submerged	Early/Single-tooth restorations	23 patients for 2 y 16 patients for 3 y 6 patients for 4 y	100
Barone et al (2008)[85]	Prosp CS/ Type 1	TPS	12 (12)	Maxillary premolar sites; all sites required simultaneous sinus floor elevation using osteotomes	Cortico-cancellous porcine bone and collagen gel, and resorbable membrane/Transmucosal	Delayed/Single-tooth restorations and multiple implant prostheses	18 mo	91.7
Buser et al (2009)[72]	Prosp CS / Type 2 (4 to 8 wk after extraction)	SLA	20 (20)	Maxillary anterior and premolar teeth	DBBM and collagen membrane; graft applied to marginal defects and external surface of the facial bone/Submerged	Early/Single-tooth restorations	12 mo	100

Study design: Prosp = prospective; Retro = retrospective; RCT = randomized controlled trial; CCS = controlled clinical study; CoS = cohort study; CS = case series.
Implant surface: Turned = equivalent to machined surface; TPS = titanium plasma-sprayed; HA = hydroxyapatite-coated; SLA = surface sandblasted with large-grit and acid-etched.
Placement time after extraction: Type 1 = immediate implant placement; Type 2 = early implant placement with soft tissue healing; Type 3 = early implant placement with partial bone healing; Type 4 = late placement in a fully healed site.
Augmentation method: e-PTFE = expanded polytetrafluoroethylene membrane; DBBM = demineralized bovine bone mineral; DFDBA = demineralized freeze-dried bone allograft; FDBA = freeze-dried bone allograft; TCP = beta tricalcium phosphate.
Loading protocol: according to the ITI Consensus Conference (2003).[124] NR = not reported.
* This study represents the 5-year follow-up; 1-year results were published in Becker et al (1994).[28]
†This study includes data from a previous report by the same authors: Wagenberg and Ginsberg (2001).[126]
§Survival rate is for a subset of 76 out of 100 implants in 33 patients, that were placed in infected extraction sockets.

Table 6 Clinical Studies with Comparative Data on Survival Outcomes with Different Implant Placement Times After Extraction

Study	Study design	Implant surface	No. of patients (No. of implants)			Augmentation method (healing protocol)	Loading protocol/ restoration type	Observation period	Survival rate (%)		
			Type 1	Types 2 and 3	Type 4				Type 1	Types 2 and 3	Type 4
Yukna (1991)[73]	Prosp CCS	HA	14 (14)	–	14 (14)	HA/Submerged	Delayed/Splinted bridges	Mean 16 mo (range 8 to 24 mo)	100	–	100
Cranin et al (1993)[90]	Prosp CCS	Polycrystalline Alumina Ceramic	30* (25)	–	30* (5)	No augmentation/ Transmucosal	Delayed/Restoration type NR	Mean 85 mo (range not stated)	92.0	–	60.0
Watzek et al (1995)[57]	Retro CS	HA and turned	20* (97)	20* (26) (6 to 8 wk after extraction)	20* (11)	e-PTFE membrane with DBBM or hydroxyapatite grafts/Submerged	Delayed in the maxilla; conventional in the mandible/ Full-arch fixed restorations	Mean 27.1 mo (range 4 to 83 mo)	98.9	100	81.8
Polizzi et al (2000)[65†]	Prosp CoS	Turned	143* (146)	143* (34) (3 to 5 wk after extraction)	–	Combinations of e-PTFE and collagen membranes, autogenous bone and DFDBA/Submerged	Delayed in the maxilla; Conventional in the mandible/ Single-tooth, partial and full-arch restorations	60 mo after functional loading	90.4	93.6	–
Schwartz-Arad et al (2000)[74]	Retro	Turned and HA	43* (117)	–	43* (263)	Autogenous bone/ Submerged	Conventional loading in the mandible; delayed in the maxilla/Full-arch restorations	5 y	96	–	89.4
Jo et al (2001)[91]	Retro CS	NR	75* (81)	–	75* (205)	No augmentation/ Transmucosal	Immediate and delayed loading protocols used/ Restoration type NR	Mean 40 mo	98.9	–	93.9
Chaushu et al (2001)[53]	Retro	HA	20* (19)	–	20* (9)	Autogenous bone/ Transmucosal	Immediate restoration/ Single-tooth restorations; sites NR	Mean 13 mo (range 6 to 24 mo)	82.4	–	100
Malo et al (2003)[66]	Prosp CS	Turned	76* (22)	–	76* (94)	NR/Transmucosal	Immediate restoration in 73 patients/Single-tooth and short spans	1 y	100	–	94.7
Norton (2004)[92]	Prosp CS	Titanium oxide grit-blasted	25* (16)	–	25* (12)	NR/Transmucosal	Immediate restoration/ Single-tooth restorations	Mean 20.3 mo (range 13 to 30 mo) In function for 15.7 mo (range 8 to 27 mo)	97.6	–	95.2
Gotfredsen (2004)[93]	Prosp CS	Titanium oxide grit-blasted	–	Group A: 10 (10) 4 wk after extraction Group B: 10 (10) 12 wk after extraction	–	e-PTFE membrane only/ Submerged	Delayed/Single-tooth restorations	5 y	–	100	–
Evian et al (2004)[94]	Retro CS	HA and turned	100 (100)	49 (49) (placement time after extraction NR)	–	NR/Submerged	Conventional/ Restoration type NR	Mean 2.6 y	85	85.7	–
Perry and Lenchewski (2004)[95]	Retro CS	NR	442* (322)	442* (777) (8 to 12 wk after extraction)	–	NR/Submerged	Conventional/ Restoration type NR	34.5 mo (range 5.8 to 67.4 mo)	90	90	–

Table 6 continued Clinical Studies with Comparative Data on Survival Outcomes with Different Implant Placement Times After Extraction

Study	Study design	Implant surface	No. of patients (No. of implants)			Augmentation method (healing protocol)	Loading protocol/ restoration type	Observation period	Survival rate (%)		
			Type 1	Types 2 and 3	Type 4				Type 1	Types 2 and 3	Type 4
Schropp et al (2005)[87]	RCT	Acid-etched	23 (23) Mean 10 d after extraction (range 3–15 d)	23 (23) (3 mo after extraction)	–	Type 1—no augmentation; Type 3— autogenous bone particles if defects present/Submerged	Conventional/Single-tooth restorations	2 y	91	96	–
Degidi et al (2006)[96]	Prosp CS	Mixed: turned, TPS and acid-etched	67 (67)	–	44 (44)	NR/Transmucosal	Immediate restoration/ Single-tooth restorations	5 y	92.5	–	100 $P < .05$
Lindeboom et al (2006)[88]	RCT	SBE	25 (25)	25 (25) (12 wk after extraction)	–	Particulate autogenous cancellous bone and resorbable collagen membrane/Submerged	Delayed/Single-tooth restorations	12 mo	92	100	–
Fugazzotto et al (2007)[97]	Retro CS	SLA	22 (39)	–	39 (130) All patients on bisphosphonate therapy	Demineralized bone matrix blocks with type 1 placement, and resorbable or e-PTFE membranes	NR	12 to 24 mo	100	–	100
Degidi et al (2007)[98]	Retro CS	Various surfaces	1,064* (416)	–	1,064* (658)	NR/Transmucosal	Immediate restoration/ Restoration type NR	Mean 3 y	90.2	–	93.9
Siegenthaler et al (2007)[89]	Prosp CCT	SLA	34 (34)	–	–	DBBM and resorbable collagen membrane	Conventional/ Single-tooth restorations	12 mo	100	–	–
Horwitz et al (2007)[99]		Sandblasted and acid-etched	19* (41)	–	19* (33)	NR/Transmucosal	Immediate loading/ Single-tooth, partial and full-arch restorations	12 mo	65	–	94

Study design: Prosp = prospective; Retro = retrospective; RCT = randomized controlled trial; CCS = controlled clinical study; CoS = cohort study; CS = case series.
Implant surface: Turned = equivalent to machined surface; TPS = titanium plasma-sprayed; HA = hydroxyapatite-coated; SLA = sandblasted with large-sized grit and acid-etched surface; SBE = sandblasted and acid-etched.
Placement time after extraction: Type 1 = immediate placement at the time of extraction; Type 2 = early placement after initial soft tissue healing; Type 3 = early placement after substantial bone healing; Type 4 = late placement after complete healing of the ridge.
Augmentation method: e-PTFE = expanded polytetrafluoroethylene membrane; DBBM = deproteinized bovine bone mineral; DFDBA = demineralized freeze-dried bone allograft; HA = hydroxyapatite.
Loading protocols according to the ITI Consensus Conference (2003).[124]
– = due to the study design, there were no data for this parameter.
NR = not reported.
*Indicates total number of patients in the study.
†This study represents the 5-year follow-up; 3-year results were published in Grunder et al (1999).[127]

Type 2 Versus Type 3 Implant Placement. One study compared the outcomes of 10 implants placed 4 weeks after extraction in 10 patients, with 10 implants placed 12 weeks after extraction in another group of 10 individuals.[93] The survival rate was 100% for both groups after 5 years of function. One RCT compared the outcomes of different early placement times over a 2-year observation period.[87] A total of 46 subjects each received a single implant, either 3 to 15 days (mean 10 days) or 3 months after extraction (type 3 placement). The survival rates were 91% for type 2 and 96% for type 3. It should be noted that implant placement between 3 and 15 days after extraction is unlikely to have been accompanied by complete soft tissue healing, and therefore does not fulfill the definition of early placement with soft tissue healing (type 2) adopted in this review.

Does Implant Surface Affect Implant Survival? A variety of implant surfaces were used in the studies reviewed, with many studies reporting the use of mixed implant systems and surfaces. Implants with a machined surface were widely used prior to the year 2000; subsequently, the majority of studies utilized roughened surfaces. Survival rates for machined implant surfaces ranged from 93.6% to 100% (median 95%).[25,39,51,59,65,66,68,86] Survival rates for hydroxyapatite (HA)-coated implants were 82.4% to 100% (median 99.5%).[53,58,73,76] Survival rates reported in studies that used implants with a titanium plasma-sprayed surface (TPS) ranged from 94.5% to 100% (median 97%).[27,52,56,67] In studies using implants with a sandblasted and acid-etched surface (SLA), survival rates of 99.1% to 100% (median 100%) were reported.[23,60,70,77,79,89,97,100,101]

Due to differences in study design and follow-up periods, no direct conclusions can be drawn from the data. However, there was a trend toward slightly lower survival rates for implants with a machined surface (median survival rate 95%) and highest survival rates for implants with an SLA surface (median survival rate 100%). No studies were designed to compare the survival of implants with different surfaces in postextraction sites. One retrospective study reported no differences in survival outcomes between implants with machined and roughened surfaces.[81]

Does Systemic Antibiotic Therapy Improve Survival Outcomes? The majority of studies reported that systemic antibiotics were prescribed. However, the antibiotic regimen varied considerably between studies. Penicillin was the most common antibiotic prescribed. There were no studies that evaluated survival outcomes with and without systemic antibiotic therapy. In one retrospective study, implant survival was significantly influenced by choice of antibiotics.[81] Failure rates were higher in patients who were allergic to penicillin and were prescribed alternative antibiotics.

What Are the Potential Risk Indicators for Survival of Postextraction Implants? Several factors have been considered as potential risk indicators for failure of postextraction implants.

Chronic Periodontitis. In a retrospective study of 1,091 implants in 591 patients who were observed for a period of 1 to 11 years, an overall survival rate of 95% was reported.[81] The authors reported that there were significantly more failures in men than in women, in those who were prescribed alternative antibiotics to penicillin, in implants in mandibular anterior sites, and in tooth sites with chronic periodontitis. Three other studies identified chronic periodontitis as a risk indicator.[51,65,94] A higher failure rate was also noted in periodontitis sites irrespective of the timing of placement after extraction.[65,94] In a study of implants placed into 76 extraction sites with infection (55 chronic periodontitis, 15 endodontic pathology, and 6 root fractures) in 33 patients, two implants failed during the 12-month follow-up. The failed implants were in sites affected by chronic periodontitis.[84]

Periapical Pathology. The data for survival of implants in sites with apical pathology are contradictory. Two controlled studies have been published comparing sites with periapical pathology. In the RCT of Lindeboom et al described previously, the authors reported that the survival rate was lower for type 1 compared to type 3 implant placement.[88] In a controlled clinical study, type 1 implant placement was compared in 17 tooth sites with apical pathology and 17 sites without apical pathology in 32 subjects.[89] After 12 months, the survival rates for both groups were 100%. It should be noted that 5 sites (4 with apical pathology and 1 without apical pathology) were withdrawn due to lack of initial implant stability.

Immediate Loading. The data on survival of immediately loaded implants placed into postextraction sites are unclear. Although high survival rates ranging from 91% to 100% (median 100%) were reported in a number of prospective case series studies of immediate restoration of single-tooth, short-span, and full-arch cases,[55,56,64,70,76,78,80,102] comparative studies have reported lower survival rates of 65% to 100% (median 91%) for type 1 implants compared to 94% to 100% (median 95%) for implants with type 4 placement for similar clinical indications.[53,66,92,96,98,99] In a study in which implants were placed into extraction sockets of teeth with chronic periodontitis, a much lower survival rate was observed with type 1 placement (65%) compared to implants placed into healed (type 4) placement sites (94%).[99]

Implant Sites. The majority of reports with type 1 placement were confined to single-root extraction

sites in the maxillary and mandibular anterior and premolar regions. Several studies provided data on implants placed into multiroot extraction sites.[60,63,69,79,100,101] The survival rates of 89% to 100% (median 99.5%) were similar to the results for implants in single-root extraction sites.

Systemic Risk Factors. One study reporting on the effect of systemic conditions on postextraction implant survival was identified.[97] In this retrospective study comparing type 1 and type 4 implant placement, no postoperative complications or implant failures were observed in 61 patients who were on oral bisphosphonate therapy.

Esthetic Outcomes of Postextraction Implants

Esthetic outcomes of postextraction implants were reported in 17 prospective[20,50,56,66,70,72,76–78,82,83,86,88,93,103–105] and 7 retrospective studies.[11,80,106–110] (Table 7).

Esthetic outcomes were reported as changes in the position of the midfacial mucosa and papillae, width of keratinized mucosa, radiographic location of the proximal bone, esthetic indices, and patient- and clinician-rated esthetic results. The majority of studies reported on outcomes with single-tooth implant restorations, predominantly in the maxillary anterior and premolar regions.

The majority of studies were short term, with follow-up periods of 12 to 24 months. Three studies reported on esthetic outcomes after mean observation periods of 4 to 5 years.[20,78,93] One study provided data on a subset of patients who were followed for 6 to 9 years.[106]

What Tissue Alterations Occur with Postextraction Implants? Changes in the level of the midfacial mucosa and height of the papillae have been reported in studies using different placement protocols.

Midfacial Mucosa. Three studies reported that mean recession of the midfacial mucosa ranging from 0.5 to 0.9 mm (median 0.75 mm) occurred with type 1 implant placement.[70,76,107] One of these studies used an immediate restoration protocol in which implants were placed without elevation of surgical flaps.[76] In a retrospective study of type 1 implant placement without flap elevation in 85 single maxillary central and lateral incisor sites in 85 patients, mean recession of 4.6% of the length of the adjacent maxillary central incisor was reported.[110] With type 2 placement, one study reported 0.6 mm of recession of the facial mucosa.[86] In a study comparing type 2 and type 3 placement, mean recession of 0.6 mm and 0.7 mm was reported, respectively. Over 5 years, further recession of 0.3 mm occurred in the type 2 placement group, whereas a reduction in recession of 0.3 mm was observed in the type 3 placement group.[93] These dimensional changes are similar to those found in reports of single-tooth implants in healed sites (type 4 implant placement).[111–113]

In addition to mean values, which express the magnitude of change, frequency analyses provide a useful way to examine the trends in soft tissue recession.[107] Frequency of recession with type 1 placement was reported in eight studies.[20,50,83,88,103,104,107,110] Recession was reported in a high proportion of sites, ranging from 8.7% to 45.2% (median 39%). Five studies reported that recession of 1 mm or greater was observed in 8% to 40.5% (median 21.4%) of sites.[50,83,88,103,107] In one study in which type 1 implants were placed without elevation of surgical flaps and restored 3 months later, recession of more than 10% of the length of the adjacent reference maxillary central incisor occurred in 18% of sites.[110]

One retrospective case series study with 45 single-tooth implants using early placement (type 2) showed a low incidence of recession after 2 to 4 years of follow-up.[11] This low incidence of recession was confirmed in a prospective study of type 2 placement by the same authors.[72] Only one out of 20 sites (5%) exhibited recession, and this was between 0.5 and 1.0 mm. In contrast, a prospective pilot study comparing type 2 and type 3 placement reported a much higher frequency of recession in both treatment groups. The authors observed that the clinical crowns of the implant restorations were longer than the contralateral natural teeth in 9 of 10 and 8 of 10 sites, respectively. The difference in frequency of recession reported in these studies may be due to the different approaches to bone augmentation used by the authors. Gotfredsen used e-PTFE membranes when defects of the facial bone were present, but with no adjunctive bone grafts.[93] In addition, the utilization of e-PTFE membranes required a second open flap procedure for membrane removal, causing additional morbidity and local bone resorption. In contrast, Buser and coworkers grafted the peri-implant defects and external surfaces of the facial bone with DBBM and covered the graft with a resorbable collagen membrane, which did not require a second open-flap procedure.[12,72] DBBM is a xenograft reported to have a low substitution rate[114] and therefore exhibits low dimensional change over time.

There were three studies of type 1 placement with immediate restoration that reported on changes to the midfacial mucosa. Kan et al reported that mean recession of 0.5 ± 0.53 mm occurred after 12 months.[76] Wohrle observed that recession of 1 mm to 1.5 mm occurred in 2 out of 14 (14.3%) sites.[103] In a prospective study in which type 1 implants with defects of the facial aspect were immediately restored, recession of greater than 1.5 mm was

Table 7 Clinical Studies Reporting on Esthetic Parameters with Postextraction Implants

Study	Study design	Placement protocol	Healing protocol/ loading protocol	No. of patients (No. of implants)	Follow-up period	Change in midfacial mucosa		Change in papillae height	Esthetic outcomes
						Frequency	Mean		
Wohrle (1998)[103]	Prosp CS	Type 1	Transmucosal/ Immediate restoration	14 (14)	1 to 3 y	14.3%; recession 1 to 1.5 mm	NR	NR	NR
Grunder (2000)[86]	Prosp CS	Type 1	Submerged/ Delayed	10 (10)	12 mo	NR	0.6 mm (median 0.5 mm; range 0 to 1.5 mm)	Mean recession of papilla 0.4 mm (median 0.5 mm; range 0 to 1 mm)	NR
Kan et al (2003)[76]	Prosp CS	Type 1	Transmucosal/ Immediate restoration	35 (35)	12 mo	NR	0.5 ± 0.53 mm	Mean recession of papilla 0.53 ± 0. 4 mm (mesial); 0.39 ± 0.4 mm (distal)	Patient evaluation of esthetic outcome (Rating 0 to 10; 0 = totally unsatisfied, 10 = totally satisfied): 33/35 patients were totally satisfied with the esthetic outcome (rated 10) 2/35 patients rated the outcome as 9 Mean patient-rated esthetic outcome 9.9
Malo et al (2003)[66]	Prosp CS	Type 1	Transmucosal/ Immediate restoration	67 (85)	12 mo	Mucosal recession observed in 1 patient	NR	NR	Dentist evaluation at 1 y: Excellent 18/67 patients Good 41/67 Acceptable 6/67 Unacceptable 2/67 Patient evaluation at 1 y: All patients were satisfied with the esthetic outcome
Bianchi and Sanfilippo (2004)[106]	Retro CS	Type 1	Submerged/ Delayed	22 (22) test sites (connective tissue grafts at the time of implant placement) 20 (20) control sites	6 to 9 y	6- to 9-year follow-up: Recession > 1 mm in 5% of test and 20% of control sites	NR	NR	NR
Gotfredsen (2004)[93]	Prosp CS	Type 2 (4 wk after extraction) and Type 3 (12 wk after extraction)	Submerged/ Delayed	Type 2: 10 (10) Type 3: 10 (10)	5 y	Recession at baseline: Type 2: 9/10 crowns longer than control tooth Type 3: 8/10 crowns longer than control teeth	Type 2: 0.6 ± 1.2 mm increased by 0.3 ± 0.5 mm after 5 y Type 3: 0.7 ± 1.4 mm reduced by 0.3 ± 0.6 mm after 5 y	Gain in papilla height of 0.3 ± 0.4 mm for type 2; gain of 1.0 ± 0.7 mm for type 3 between baseline and 5 y	Patient evaluation based on a Visual Analog Scale (VAS): Type 2: 9.8 (range 9.1-10.0) Type 3: 8.8 (range 5.1-10.0) Dentist evaluation using the same VAS: Type 2: 5.9 (range 2.9-9.5) Type 3: 8.4 (range 6.1-9.7)

Table 7 continued Clinical Studies Reporting on Esthetic Parameters with Postextraction Implants

Study	Study design	Placement protocol	Healing protocol/ loading protocol	No. of patients (No. of implants)	Follow-up period	Change in midfacial mucosa		Change in papillae height	Esthetic outcomes
						Frequency	Mean		
Cangini and Cornelini (2005)[77]	Prosp CCS	Type 1	Transmucosal/ Delayed	32 (32)	12 mo	NR	0.2 ± 1.5 mm at sites treated with enamel matrix derivative and 0.9 ± 1.3 mm at sites with collagen membrane	NR	NR
Cornelini et al (2005)[70]	Prosp CS	Type 1	Transmucosal/ Immediate restoration	22 (22)	12 mo	NR	Mean recession 0.75 mm	Jemt Papilla Index*: Score 2: 61% of papillae Score 3: 39% of papillae No scores of 0, 1, and 4	NR
Schropp et al (2005)[104]	RCT	Mean 10 d postextraction Type 3	Submerged/ Conventional	Mean 10 d postextraction 23 (23) Type 3: 23 (23)	2 y	8.7% exposure of metal margin	NR	Jemt Papilla Index*: Score 2: 33% of papillae Score 3: 8% of papillae	All patients were highly satisfied with the esthetic outcome
Barone et al (2006)[56]	Prosp CS	Type 1	Transmucosal/ Immediate restoration	18 (18)	12 mo	Width of keratinized mucosa 3.3 ± 0.5 mm; no significant change from baseline	NR	NR	All patents were satisfied with the esthetic outcome
Lindeboom et al (2006)[88]	RCT	Type 1 and Type 3	Submerged/ Delayed	Type 1: 25 (25) Type 3: 25 (25)	Mean 12.4 mo	26% sites with recession No recession in 56% of type 1 placements and 84% of type 3 Recession 0 to 1 mm in 28% of type 1 placements and 16% of type 3 Recession 1 to 2 mm in 8% of type 1 placements (none for type 3)	NR	Jemt Papilla Index*: Score 2 in 22% of type 1 and 28% of type 3 implant placement sites Score 3 in 78% of type 1 and 72% of type 3 implant placement sites	NR
De Kok et al (2006)[80]	Retro CS	Type 1	Transmucosal/ Immediate restoration	20 (25)	6 to 30 mo	NR	NR	Jemt Papilla Index*: Score 1: 64% of papillae Score 2: 32% of papillae Score 3: 4% of papillae	NR
Ferrara et al (2006)[78]	Prosp CS	Type 1	Transmucosal/ Immediate restoration	33 (33)	4 y	NR	NR	Papillae when initially present were never lost	Patient-rated esthetic outcome; Score of 9.3 ± 0.65 (using a 10-point scale, with 0 = completely unsatisfactory and 10 = completely satisfactory)
Chen et al (2007)[20]	RCT	Type 1	Submerged/ Conventional	19 (19)	4 y	33.3% of sites with recession	NR	NR	NR
Juodzbalys and Wang (2007)[83]	Prosp CS	Type 1	Submerged/ Delayed	12 (14)	12 mo	21.4% with recession of 1 to 2 mm	NR	Jemt Papilla Index*: Score 2: 64% of papillae Score 3: 36% of papillae	Pink Esthetic Score (PES)† of 11.1 64.3% of cases with incomplete mesial and distal papillae 42.9% of cases with alveolar process deficiency

Table 7 continued Clinical Studies Reporting on Esthetic Parameters with Postextraction Implants

Study	Study design	Placement protocol	Healing protocol/ loading protocol	No. of patients (No. of implants)	Follow-up period	Change in midfacial mucosa		Change in papillae height	Esthetic outcomes
						Frequency	Mean		
Covani et al (2008)[82]	Prosp CS	Type 1	Submerged/ Delayed	10 (10)	12 mo	Mean 4.1 mm width of keratinized mucosa on the facial aspect	NR	NR	NR
Kan et al (2007)[50]	Prosp CS	Type 1	Transmucosal/ Immediate restoration	23 (23)	12 mo	34.8% recession ≥ 1.5 mm; 8.3% of sites with V-shaped defects of the facial bone[†] 42.8% of sites with U-shaped defects of the facial bone; 100% of sites with UU-shaped defects of the facial bone	NR	NR	NR
Steigmann et al (2007)[105]	Prosp CS	Type 1	Transmucosal/ Immediate restoration	10 (10)	24 mo	NR	NR	9/10 sites with slight blunting of the papillae	All patients extremely satisfied with the esthetic outcome
Evans and Chen (2008)[107]	Retro CS	Type 1	NR/Conventional	42 (42)	Mean 19 mo	45.2% recession 0.5 mm 21.4% recession 1.0 mm 19.1% recession ≥ 1.5 mm	Mean recession 0.9 ± 0.78 mm	Mean recession of papilla 0.5 ± 0. 52 mm (mesial); 0.5 ± 1.0 mm (distal)	Subjective Esthetic Score (SES)[§] 82% satisfactory (scores I and II) 18% unsatisfactory (scores III and IV)
Degidi et al (2008)[108]	Retro CS	Type 1/ Type 4	Transmucosal/ Immediate restoration	45 (52)	2 to 6 y	NR	NR	Jemt Papilla Index for type 1 and type 4 implant placement combined: Score 1: 14.5% of papillae Score 2: 50% of papillae Score 3: 35.5% of papillae	NR
Degidi et al (2008)[109]	Retro CS	Type 1	Transmucosal/ Immediate restoration	49 (152)	24 mo	NR	NR	Combined Jemt Papilla Index scores 2 and 3 decreased when two implants were placed ≥ 4 mm apart when the bone crest to contact point between to implant crowns was > 6 mm	Multiple adjacent implants
Buser et al (2008)[11]	Retro CS	Type 2	Submerged/Early	45 (45)	2 to 4 y	NR	NR	NR	No recession of the midfacial mucosa was observed
Buser et al (2009)[72]	Prosp CS	Type 2	Submerged/Early	20 (20)	12 mo	NR	Mean difference between test and contralateral natural teeth 0.18 mm One site with recession of 0.5 to 1.0 mm	NR	Mean modified PES[‖] of 8.1 (out of 10) Mean WES[¶] of 8.65 (out of 10)

Table 7 continued Clinical Studies Reporting on Esthetic Parameters with Postextraction Implants

Study	Study design	Placement protocol	Healing protocol/ loading protocol	No. of patients (No. of implants)	Follow-up period	Change in midfacial mucosa		Change in papillae height	Esthetic outcomes
						Frequency	Mean		
Chen et al (2009)[110]	Retro CS	Type 1	Transmucosal/ Early	85 (85)	26 mo	At 44 sites with initial gingival margins level with adjacent maxillary central incisor: 20.5% recession 5 to 10%; 18% recession of > 10%	Mean recession of 4.6 ± 6.6%#	Mean recession of papillae 6.2% ± 6.8% (mesial)#; 7.4% ± 7.5% (distal)#	Subjective Esthetic Score (SES)§ 42.4% good (score I) 38.8% acceptable (score II) 9.4% unsatisfactory (scores III and IV) Mean PES† of 10.95 (out of 14) 21.2% optimum (scores 13 and 14) 56.5% good (scores 10 to 12) 22.3% suboptimal (score 8 or 9)

Study design: Prosp = prospective; Retro = retrospective; RCT = randomized controlled trial; CCS = controlled clinical study; CS = case series.
Placement time after extraction: Type 1 = immediate placement at the time of extraction; Type 2 = early placement after initial soft tissue healing; Type 3 = early placement after substantial bone healing; Type 4 = late placement after complete healing of the ridge.
Augmentation method: e-PTFE = expanded polytetrafluoroethylene membrane; DBBM = deproteinized bovine bone mineral; DFDBA = demineralized freeze-dried bone allograft; HA = hydroxyapatite.
Loading protocols according to the ITI Consensus Conference (2003).[124]
NR = not reported.
*Papilla Index Score as described by Jemt (1997).[118]
†PES = Pink Esthetic Score of Furhauser et al (2005): Seven variables assessed in relation to reference tooth and assigned scores of 0, 1, or 2 out of a total possible score of 14, for i, shape of mesial papilla; ii, shape of distal papilla; iii, level of soft tissue margin; iv, soft tissue contour; v, alveolar process deficiency; vi, soft tissue color; vii, soft tissue texture.[121]
‡Dehiscence defect on facial aspect of the implant classified as: V-shaped, narrow defect isolated to facial surface of implant only; U-shaped, wide defect extending proximally into the mesial or distal aspects of the tooth to be extracted; UU defect, wide defect extending to and including the mesial or distal surfaces of the adjacent teeth.[102]
§ Subjective Esthetic Score (SES):[107] I = vertical facial change was 0.5 mm or less and labial tissue fullness was in harmony with the adjacent teeth; II = vertical facial change was between 0.5 and 1.0 mm and the facial tissue fullness was in harmony; III = vertical facial change was between 1.0 and 1.5 mm or the facial tissue appears deficient in contour; IV = vertical facial change was greater than 1.5 mm and a deficiency in facial tissue contour was noted.
‖Modified Pink Esthetic Score (modPES) of Furhauser et al (2005)[121]: Five variables assessed in relation to reference tooth and assigned scores of 0 , 1, or 2 out of a total possible score of 10, for i, shape of mesial and distal papillae; ii, level of soft tissue margin; iii, soft tissue contour; iv, alveolar process; v, soft tissue color and texture.
¶ White Esthetic Score (WES): Scores of 0, 1, and 2 assigned out of a total possible score of 10, for I, tooth form; ii, tooth volume/outline; iii, color; iv, surface texture; and v, translucency.[72]
#Tissue level change expressed as a percentage of the length of the adjacent maxillary central incisor which served as the reference.

observed in 34.8% of sites.[50] Chen et al observed that mucosal recession occurred soon after restoration of the implants, and then remained stable between the 1-year and 3-year recall periods.[20]

One RCT compared type 1 and type 3 placement in sites with radiographic evidence of chronic periapical periodontitis.[88] Absence of recession was noted in only 56% of immediate implant (type 1) sites, compared to 84% for early placement (type 3). Recession of 1 to 2 mm was observed in 8% of type 1 implant sites. In contrast, there were no sites with recession of 1 to 2 mm in the type 3 placement group.

In an RCT comparing implant placement soon after tooth extraction (mean 10 days) with early placement after partial bone healing (type 3), recession of the mucosal margin resulting in exposure of the metal margin of the implants was observed in 8.7% of implants in each of the two groups after 2 years.[104] The height of the implant crowns was subjectively determined to be too long in 17% of the 10-day postextraction sites and 20% of type 3 implant placement sites, and too short in 30% of type 3 implant placement sites. The crowns were of an appropriate height in 83% of the 10-day postextraction sites and only 50% of type 3 implant sites.

Data on long-term outcomes are limited. However, one study provided data on a subset of patients who were followed for 6 to 9 years, with implants placed in both anterior and posterior sites.[106] Twenty-two patients received 22 single-tooth type 1 implants that were submerged at the time of surgery using connective tissue grafts. Twenty patients with 20 immediate implants that were placed without the use of connective tissue (CT) grafts served as controls. Between 6 and 9 years following surgery, the proportion of sites with recession greater than 1 mm (in relation to adjacent teeth) was 5% in test sites compared to 20% in control sites. It was not possible to distinguish between anterior and posterior sites from the study.

From these studies, it can be concluded that recession of the midfacial mucosa, even when combined with grafts of bone or bone substitutes, is a common complication with type 1 placement. The recession occurs soon after restoration of the implants. Recession of 1 mm or more was observed in a high proportion (range 8% to 40.5%; median 21.4%) of sites. This dimensional change may lie within the visual threshold of detecting a difference in mucosal levels.[115] Mucosal recession would therefore be expected to have an adverse effect on esthetic outcomes, as most studies reported that implants were placed in the maxillary anterior and premolar sites. Recession was also observed with immediate restoration of implants, and implants placed without elevation of surgical flaps.

Early placement (type 2 and type 3) may also be associated with recession. However, there is evidence to suggest that early placement with soft tissue healing (type 2) is associated with a relatively low incidence of recession when implant placement is combined with GBR procedures using DBBM. There is evidence that early placement with partial bone healing (type 3) is associated with a lower frequency of recession compared to type 1 placement.

Papillae. With type 1 placement, a mean loss of papilla height of between 0.5 and 0.6 mm was reported in three studies.[76,86,107] Changes in papilla height were similar for conventional loading and immediate restoration protocols. In a prospective study of type 1 placement using the crown of the natural tooth as an immediate restoration, slight blunting of the papilla was reported in 9 out of 10 treated sites.[105] In a retrospective study of type 1 placement with immediate restoration, 64% of sites achieved a satisfactory papilla form.[80] Loss of papilla height was accompanied by a reduction in the height of the proximal crestal bone of 0.3 to 1.9 mm (median 1.2 mm).[56,66,70,76,83,105] Less than ideal papilla fill was reported for adjacent implants when the interimplant distance was less than 2 mm.[109]

Four studies used the Papilla Index of Jemt to describe the form of the papillae with immediate placement.[70,83,88,108] The results were variable. In the four studies, a score of 3 (indicating complete fill of the proximal embrasure space) was recorded in 35% to 78% (median 37%) of sites. A score of 2 (indicating that half or more of the papilla height was present, but not 100%) was recorded in 22% to 64% (median 55%) of sites. A score of 1 (indicating that less than half of the papilla height was present) was only recorded in one study, affecting 14.5% of sites[108]; three studies reported that no sites recorded a score of 1. In studies of immediate restoration of implants[70,108] there was no clear advantage over studies using conventional loading protocols[83,114] according to this index.

Two studies provided comparative data on different placement times after extraction. One RCT reported that the risk of a missing papilla or negative papilla form at the time of restoration was 7.2 times greater for type 3 compared to type 2 implant placement (33% of sites vs 8% of sites, respectively).[104] However, after 1.5 years there was no difference between the groups (8% for type 2 placement and 3% for type 3 placement). Overall, 5% of sites had a score of 0, 35% had a score of 1, and 60% had a score of 2. Another RCT comparing type 1 and type 2 implant placement showed no difference between treatment groups.[88] Studies of type 4 implant placement have reported similar variations in papilla fill.[116,117]

The main disadvantage of the Papilla Index of Jemt[118] is that scores are based on the degree of fill of the embrasure space after the crown has been attached to the implant, and not on a comparison with the pretreatment form and height of the papilla prior to tooth extraction. Implant crowns will often have an altered width and contact area to compensate for a reduction in height of the papilla.[119] This makes it difficult to compare results between studies with this index. Several studies reported that the form of the papilla improved over time with postextraction implants,[80,104] a phenomenon also reported with type 4 placement.[116–118]

The results of these studies show that type 1 placement is associated with recession of the papillae. The majority of sites achieved fill of the interproximal embrasure space of at least half of the height, but achieving complete fill was variable. There is evidence to suggest that the final form of the papillae with type 1 placement using immediate restoration and conventional loading is similar. Similar outcomes have been reported with type 4 placement. Two RCTs provide strong evidence that the final form of the papillae is independent of the timing of implant placement after tooth extraction.

Width of Keratinized Mucosa. Three studies reported on the width of the keratinized mucosa on the facial aspect following type 1 placement. The mean width was 3.3 mm and 4.1 mm in two studies.[56,82] In a third study, 92.9% of sites had a width of keratinized mucosa greater than 2 mm.[83] These dimensions are in accord with studies of type 4 implant placement.[116,119] The width of keratinized mucosa was greater when type 1 implants were submerged using connective tissue (CT) grafts, compared to sites that did not receive CT grafts.[106]

What Factors Are Associated with Recession of the Mucosa? Several factors have been associated with recession of the peri-implant mucosa.

Tissue Biotype. With type 1 placement, sites with a thin tissue biotype had a higher frequency of recession of > 1 mm than sites with a thick tissue biotype.[20,76,107]

*Facial Bone Wall***.** Kan et al reported that damage to the facial bone wall encountered at the time of type 1 placement represented a significant risk factor for mucosal recession.[50] In 23 patients, implants were placed into fresh extraction sites with a damaged facial bone wall. The defects were grafted with DBBM and covered with a resorbable membrane. The results indicate that the risk of recession increased with the width of the dehiscence of the facial bone. Only 8.3% of sites with narrow (V-shaped) defects exhibited recession of 0.5 mm or more. Recession for sites with wide (U-shaped) defects and defects that involved the adjacent teeth (UU-shaped defects) was 42.8% and 100%, respectively.

The thickness of the facial bone at the time of implant placement may be an important factor. In an RCT, Chen et al noted three residual defect types following type 1 placement.[20] Sites that healed with complete bone fill or a residual craterlike defect had an initial thickness of the facial bone of 0.7 to 0.9 mm and recorded vertical loss of crestal bone height of 0.3 to 0.9 mm at reentry. In contrast, sites that healed with a dehiscence defect initially had a facial bone thickness of 0.5 mm and recorded vertical crestal bone loss of 2.1 mm at reentry. Thus extraction sockets with thin facial bone lost more vertical height and had less bone fill than sites with thicker bone.

Orofacial Position of the Implant Shoulder. The orofacial position of the implant shoulder in the extraction socket with type 1 placement is strongly associated with mucosal recession. In three studies, implants that were placed facially within the sockets had a higher frequency and greater magnitude of recession than sites where implants were more palatally positioned.[20,107,110] At sites with recession, the implants had a significantly greater orofacial defect depth of 2.3 mm compared to 1.1 mm for sites with no recession.[20] This is consistent with the observation that a peri-implant gap with type 1 implant placement is required to minimize compression of the facial bone wall on inserting the implant, and to allow bone regeneration in the gap to establish a thicker facial bone wall.[120] These clinical observations have been corroborated in an experimental study of implants in fresh extraction sockets in a canine model.[49] Less vertical crestal bone loss was observed when the peri-implant defects were wide, compared to sites where the defects were less than 2 mm in width.

What Are the Outcomes Based on Esthetic Indices? Esthetic indices were used in four studies. Based on the Pink Esthetic Score (PES),[121] a mean score of 11.1 (out of a maximum 14) was reported in a prospective study of 14 immediate implants in 12 patients.[83] In this study, 64.3% of cases had incomplete fill of the papillae, and 42.9% had deficiencies in the alveolar process. In a retrospective study of 85 maxillary central and lateral incisors, a mean PES of 10.95 was recorded.[110] Optimum esthetic results were achieved in 21.23% of sites (PES scores of 13 and 14). Suboptimal esthetic outcomes (PES scores of 8 and 9) were seen in 22.3% of sites. Using an alternative scoring system, 82% of sites had a satisfactory esthetic outcome with type 1 placement in a retrospective study of 42 implants in 42 patients.[107] A total of 18% of sites had an unsatisfactory outcome, mainly due to recession of the midfacial mucosa. In a prospective case series study with 20 single-tooth implants using

early placement (type 2), the 12-month results exhibited a mean modified PES index of 8.1, and a mean WES index of 8.65 (both out of a maximum of 10).[72]

Studies reporting on patient-evaluated esthetic outcomes generally reported that patients were highly satisfied with the results with immediate (type 1) placement[56,66,76,105] and early placement (type 2 and type 3)[104] irrespective of the loading protocol.

Although there has been increased interest in and reporting of esthetic outcomes with postextraction implants since the Third ITI Consensus Conference in 2003, there are still relatively few studies at the current time that evaluate esthetic outcomes using objective parameters.

CONCLUSIONS

Regenerative Outcomes of Postextraction Implants

From the studies reviewed, it can be concluded that:

- Bone augmentation procedures are effective in promoting bone fill and defect resolution in peri-implant defects following immediate (type 1) and early (type 2) placement.
- Peri-implant defects associated with immediate (type 1) and early (type 2) placement may heal spontaneously when the peri-implant defect is less than 2 mm in width and the facial bone wall is intact.
- Immediate placement does not prevent vertical or horizontal resorption of the ridges.
- Bone augmentation combined with immediate placement may reduce horizontal resorption, but does not prevent vertical resorption of the facial bone.
- Bone augmentation procedures are more successful in combination with immediate (type 1) and early (type 2 and type 3) placement compared to late placement (type 4).
- Evidence is lacking to demonstrate the superiority of one placement protocol over the other with respect to healing of peri-implant defects with postextraction implants. However, there is some evidence to show that regenerative outcomes are better with early placement (type 2) compared to immediate placement (type 1) in the presence of dehiscence defects of the facial bone wall.
- Postoperative complications are common with immediate placement.
- The efficacy of concomitant antibiotic therapy with regard to healing of postextraction implants has not been demonstrated.

Survival Outcomes of Postextraction Implants

- The survival rates for postextraction implants are high, with the majority of studies reporting rates of over 95%.
- Immediate (type 1) and early (type 2) placement protocols have similar survival rates.
- There is some evidence to suggest that implants with a machined surface have a lower survival outcome than implants with a roughened surface.
- There is no evidence to show that systemic antibiotics affect the survival outcome of postextraction implants.
- A history of chronic periodontitis is a risk indicator for survival of postextraction implants. The evidence for periapical pathology and immediate restoration as risk indicators is contradictory. Evidence for systemic factors as risks for implant survival is lacking.

Esthetic Outcomes of Postextraction Implants

- Tissue alterations leading to recession of the facial mucosa and papillae are common with immediate placement.
- There is evidence that early placement (type 2 and type 3) is associated with a lower frequency of mucosal recession compared to immediate placement (type 1).
- Risk indicators for recession with immediate placement include a thin tissue biotype, a facial malposition of the implant, and a thin or damaged facial bone wall.
- There is evidence to suggest that immediate restoration and conventional loading protocols appear to have similar outcomes with respect to soft tissue alterations.
- Although patient-evaluated esthetic outcomes with postextraction implants are generally favorable, there are relatively few studies that evaluate esthetic outcomes using objective parameters.

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Bone Augmentation Procedures in Localized Defects in the Alveolar Ridge: Clinical Results with Different Bone Grafts and Bone-Substitute Materials

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Purpose: *The objective of this review was to evaluate the efficacy of different grafting protocols for the augmentation of localized alveolar ridge defects.* ***Materials and Methods:*** *A MEDLINE search and an additional hand search of selected journals were performed to identify all levels of clinical evidence except expert opinions. Any publication written in English and including 10 or more patients with at least 12 months of follow-up after loading of the implants was eligible for this review. The results were categorized according to the presenting defect type: (1) dehiscence and fenestration-type defects, (2) horizontal ridge augmentations, (3) vertical ridge augmentations, and (4) maxillary sinus floor elevations using the lateral window technique or transalveolar approach. The review focused on: (1) the outcome of the individual grafting protocols and (2) survival rates of implants placed in the augmented bone.* ***Results and Conclusion:*** *Based on 2,006 abstracts, 424 full-text articles were evaluated, of which 108 were included. Eleven studies were randomized controlled clinical trials. The majority were prospective or retrospective studies including a limited number of patients and short observation periods. The heterogeneity of the available data did not allow identifying one superior grafting protocol for any of the osseous defect types under investigation. However, a series of grafting materials can be considered well-documented for different indications based on this review. There is a high level of evidence (level A to B) to support that survival rates of implants placed in augmented bone are comparable to rates of implants placed in pristine bone.* Int J Oral Maxillofac Implants 2009;24(suppl):218–236

Key words: *bone grafting, bone-substitute material, dental implant, ridge augmentation, sinus floor elevation*

Resorption of the edentulous or partially edentulous alveolar ridge or bone loss due to periodontitis or trauma frequently compromises dental implant placement in a prosthetically ideal position. Therefore, augmentation of an insufficient bone volume is often indicated prior to or in conjunction with implant placement to attain predictable long-term functioning and an esthetic treatment outcome.[1] Autogenous bone grafts are still considered the gold standard in bone regeneration procedures.[2] However, donor site morbidity, unpredictable resorption, limited quantities available, and the need to include additional surgical sites are drawbacks related to autografts that have intensified the search for suitable alternatives. Bone-substitute materials have increased in popularity as adjuncts to or replacements for autografts in bone augmentation procedures to overcome the limitations related to the use of autografts. Bone-substitute materials can be categorized in three groups: *(1)* allogenic, from another individual within the same species; *(2)* xenogenic, from another species; or *(3)* alloplastic, synthetically produced.

The osteogenic potential of bone defects may vary considerably depending on their extent and morphology. It may be too optimistic to expect that the material characteristics of a single grafting material will be suitable for all indications. In addition, the

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osteogenic potential of the grafting material may influence the time needed for completion of the bone regeneration procedure.

This review was undertaken to evaluate the treatment outcomes following augmentation of localized bone defects, with special emphasis on comparing the clinical performance of different bone grafts and bone-substitute materials. A recent systematic review of bone augmentation procedures performed prior to or in conjunction with placement of dental implants revealed that only a limited number of studies passed the strict inclusion criteria for such a review.[3] Therefore, the inclusion criteria for the present review allowed evaluation of all levels of evidence, from case series up to the level of randomized controlled trials,[4] to gather as much clinical information as possible about clinical experience with different grafting protocols for augmentation of localized bone defects.

The hypothesis was that augmentation of localized alveolar ridge defects in the forms of dehiscence-type defects, fenestration-type defects, bone defects in the lateral and vertical dimensions, and inadequate initial bone height toward the sinus floor are predictable procedures with implant survival rates comparable to those of implants placed in pristine bone, using autogenous bone grafts, bone-substitute materials, or combinations of these. The results obtained with different grafting protocols were compared. Finally, the results with and without the use of barrier membranes were recorded for the individual clinical indications.

MATERIALS AND METHODS

Study Types

Any clinical evaluation of a bone augmentation procedure in humans associated with immediate or delayed placement of dental implants published in English and including 10 or more treated patients was evaluated.

Patient Selection

The review included patients intended for dental implant placement in the maxilla and/or mandible, presenting with localized bone defects that required bone augmentation procedures simultaneous with implant placement or to allow later implant placement.

Augmentation Procedures

Peri-implant defects in the form of dehiscence-type defects and fenestration-type defects were included if they were augmented at the time of implant placement. Two-stage augmentation procedures for localized defects in the alveolar ridge were also included. In these cases a distinction was made as to whether the alveolar ridge was augmented in the horizontal or vertical dimension. Finally, maxillary sinus floor elevation procedures, including the lateral window technique and the transalveolar approach, were included in the review.

Evaluation of Outcome

Implant survival is a straightforward outcome measure, but it shows little sensitivity to minor changes in bone volume and soft tissue levels. In this review, implant survival rate was only included if the mean observation period was 1 year or more after prosthetic loading. The implant survival rates are presented as ranges and median values. Implant success is defined in several different ways and was not included in the present review. In addition to implant survival, the following parameters were recorded for the different augmentation techniques and grafting protocols:

1. In dehiscence-type defects and fenestration-type defects, the primary parameter of evaluation was the degree of bone defect reduction. This parameter was most often presented as the relative reduction of defect area (mm^2 or %) or defect height (mm or %), or as the number of exposed implant threads pre- and postaugmentation. All results were recalculated and the defect reduction was recorded as a percentage of the original defect size. In addition, the proportion of cases that showed complete resolution of the former defect, ie, where the goal of the treatment was accomplished, was recorded. Finally, the frequency of complications was recorded.
2. In an alveolar ridge with insufficient height or width to accommodate an implant with the desired dimensions, a two-stage augmentation procedure is usually indicated. The first outcome parameter of interest in a two-stage bone augmentation procedure is the possibility of implant placement in an ideal position for the later prosthetic restoration. Gain in ridge width and height was recorded as an indirect measure of the efficiency of the different grafting protocols in providing sufficient alveolar ridge dimensions for implant placement. The percentage of cases in need of regrafting or additional grafting at the time of implant placement was also recorded as an indirect measure of the predictability of the grafting protocol. The long-term goal, for both one-stage and two-stage augmentation procedures, is the stability of the augmented bone volume, allowing unhindered masticatory function and optimal esthetics, as expressed by implant survival, bone stability, and soft tissue stability.
3. A study was categorized as a randomized controlled clinical trial (RCT), a controlled clinical trial (CCT), a prospective study (PS), or a retrospective study (RS).[4]

4. Grafting materials were categorized in one of the following groups:

- No graft (coagulum)
- Autograft block (extraoral or intraoral donor site)
- Autograft particulate
- Autograft from bone trap
- Membrane alone (nonresorbable or resorbable)
- Allograft (freeze-dried bone allograft [FDBA] or demineralized freeze-dried bone allograft [DFDBA])
- Xenograft (demineralized bovine bone mineral [DBBM], algae-derived, or coral-derived)
- Alloplast (hydroxyapatite [HA], β-tricalcium phosphate [TCP], bioglass, or calcium sulphate)
- Combinations (autograft + allograft, autograft + xenograft, autograft + alloplast, allograft + xenograft, or allograft + alloplast)

5. Whether the augmented site was covered with a resorbable membrane, a nonresorbable membrane, or no membrane was recorded. For maxillary sinus floor elevation procedures, it was only registered whether some kind of membrane was used to cover the lateral window, and if machined or rough-surfaced implants were placed in the augmented bone.

6. All healing times were recorded or calculated to be presented as mean values. For implant survival rates, ranges and median values were calculated.

7. The treatment result after augmentations in the orofacial dimension cannot be evaluated using traditional radiographs. Computed tomography (CT), conventional tomography, and digital volume tomography are only seldom used at control visits because of their high doses of radiation. Therefore, the outcome of augmentation of dehiscence-type defects, fenestration-type defects, and horizontal ridge augmentations could only be evaluated with clinical parameters. These included defect fill at reentry (%), gain in ridge width at reentry (mm), soft tissue stability (mm), and ultimate implant survival (%). Augmentations in the vertical dimension can be evaluated by traditional x-ray as marginal bone stability (mm) in vertical ridge augmentations and apical bone stability (mm) in maxillary sinus floor elevation procedures. However, since this information was only available from a very limited number of publications, the radiographic evaluation was excluded from the final evaluation.

8. Infectious complications are often related to the exposure of membranes. All membrane exposures were recorded as complications, although the consequence of exposure may differ when nonresorbable and resorbable membranes are compared. The type of membrane used was recorded; therefore, the outcome data should reveal whether exposure of nonresorbable membranes leads to a compromised healing result more often than exposure of resorbable membranes.

The background variables and outcome measures that were recorded for each defect type are listed in Table 1.

If data from different time points for the same pool of patients were presented in separate publications, the most recent paper was included for the evaluation of implant survival. However, additional clinical and radiographic data were included from all available observation times (if $n \geq 10$) to monitor healing dynamics from immediately postoperative to long-term healing results.

Exclusion Criteria

Studies were excluded if data covered:

- Grafting of bone defects caused by tumor resections, osteoradionecrosis, osteochemonecrosis, and bisphosphonate-associated osteonecrosis
- Grafting of bone defects in syndrome patients with craniofacial involvement and with congenital malformations, such as cleft patients
- Grafting of extraction sockets and intraalveolar defects simultaneously with immediate implant placements (presented in parallel reviews by Buser and Chen and Darby et al in this supplement)
- Treatment of defects caused by peri-implantitis
- Augmentations of the complete ridges in severely atrophied edentulous jaws, including the application of distraction osteogenesis (presented in a parallel review by Chiapasco et al in this supplement)
- Grafting protocols including the addition of growth factors or other bioactive molecules to the grafting materials
- Different augmentation procedures and/or grafting materials evaluated in the same paper, where the outcome measures could not be separated according to the individual protocols

Search Strategy

A search was performed in PubMed and the Cochrane library, combining the following terms: *clinical study, clinical trial, dental implant, preprosthetic surgery, bone transplantation, bone graft, autograft, allograft, xenograft, alloplast, bone substitute, bone filler, onlay bone graft, inlay bone graft, bone regeneration, bone augmentation, peri-implant defect, fenestration, dehiscence, atrophy, bone loss, guided bone regeneration, guided tissue regeneration, horizontal ridge augmentation, vertical ridge augmentation, block graft, sinus augmentation, sinus floor elevation, sinus lift*.

Table 1 Data Collected for the Individual Defect Types

Background and treatment variables	Dehiscence-type defects and fenestration-type defects	Horizontal ridge augmentation	Vertical ridge augmentation	Sinus augmentation
Study type	x	x	x	x
No. of patients	x	x	x	x
No. of augmentation procedures	x	x	x	x
No. of implants	x	x	x	x
Implant surface				x
Grafting material	x	x	x	x
Initial bone height				x
Membrane over augmented site	x	x	x	x
Staged/simultaneous implant placement		x	x	x
Healing time before implant placement, mean (mo)		x	x	x
Healing time before reentry/abutment, mean (mo)	x	x	x	x
Follow-up after augmentation, mean (mo)	x	x	x	x
Outcome measures				
Gain in ridge width (mm)		x		
Gain in ridge height (mm)			x	
Defect reduction (%)	x			
Cases with complete defect fill (%)	x	x	x	
Complication rate including membrane exposures (%)	x	x	x	x
Implant survival (%)	x	x	x	x

In addition, a manual search of the tables of contents of the following journals was performed: *British Journal of Oral & Maxillofacial Surgery; Clinical Implant Dentistry and Related Research; Clinical Oral Implants Research; Clinical Oral Investigations; Implant Dentistry; International Journal of Oral & Maxillofacial Implants; International Journal of Oral & Maxillofacial Surgery; International Journal of Periodontics & Restorative Dentistry; Journal of Clinical Periodontology; Journal of Craniofacial Surgery; Journal of Oral Implantology; Journal of Oral and Maxillofacial Surgery; Journal of Oral Rehabilitation; Journal of Periodontology; Journal of Prosthetic Dentistry;* and *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*.

Finally, reference lists of the included articles were checked for additional publications of relevance. Publications available in print or electronic form up to January 1, 2008, were considered.

RESULTS

A total of 2,006 abstracts and 424 full-text articles were evaluated. One hundred eight articles met the inclusion criteria. Data from the included studies are listed in Tables 2 to 6. Grafting protocols that are documented in three or more studies for the individual defect types are discussed in the following sections.

Dehiscence-type Defects and Fenestration-type Defects

Forty-six publications were evaluated as full text, of which 20 studies (4 RCTs, 1 CCT, 12 PS, 3 RS) were included (Table 2).[5–24] Sixteen studies described the augmentation of dehiscence-type defects,[5–10,12,14,15,17–21,23,24] four described fenestration-type defects,[7,11,16,22] and in one study the data set could not be separated for the two defect types.[13] In 627 patients, a total of 987 implants were inserted. Reentry was performed after a mean healing period of 5.8 months. A mean defect fill of 81.7% could be calculated based on 17 patient pools.[5,6,8,9,11–18,20,21,23,24] Complete defect fill was accomplished in 68.5% of the cases (data from 10 studies).[5,9,11,12,15–18,21,23] Seven studies followed the patients for 12 to 60 months after loading, reporting survival rates of 93% to 100% (median: 95.4%).[6,7,10,19,21–23]

Three different grafting protocols were documented in three or more studies. Three studies (114 patients, 155 implants) reported on the use of a nonresorbable membrane alone.[5,6,10] Membrane exposure was recorded in 13.8% of the cases, and the mean defect fill at reentry was 79.4%.[5,6] After 18 to 24 months of function, the implant survival rate was reported in two studies to be 93% and 100%, respectively.[5,6] Six studies (69 patients, 131 implants) described the use of autograft as augmentation material, which was harvested locally as chips,[9,11,12,18]

Table 2 Augmentation of Dehiscence-type Defects and Fenestration-type Defects

Study	Study type	Defect type	No. of patients	No. of augm	No. of implants	Grafting material	Membrane	Healing impl (mo)	Follow-up (mo)	Defect fill (%)	% Complete fill	Complication rate (%)	Implant survival (%)
Jovanovic et al (1992)[5]	PS	Deh	11	16	16	Membr alone	Nonres	5	-	89	69	25	-
Dahlin et al (1995)[6]	CCT	Deh	44	54	54	Membr alone	Nonres	4.5	24	77	ND	11	93
Fugazzotto (1997)[7]	RS	Deh	84	172	172	DFDBA+TCP	Nonres	7.5	24	ND	ND	ND	99
		Fen	25	77	77	DFDBA+TCP	Nonres	7.5	24	ND	ND	ND	100
Zitzmann et al (1997)[8]	RCT	Deh	25	41	41	DBBM	Nonres	5	-	78	ND	24	-
		Deh	25	43	43	DBBM	Res	5	-	92	ND	16	-
Schlegel et al (1998)[9]	RCT	Deh	11	20	20	AP	none	6	-	60	60	20	-
		Deh	11	20	20	AP	Res	6	-	95	85	35	-
Lorenzoni et al (1999)[10]	RS	Deh	59	85	85	Membr alone	Nonres	6	18	ND	ND	ND	100
Peleg et al (1999)[11]	PS	Fen	ND	17	17	AP	Res	5.6	-	87	76	0	-
von Arx and Kurt (1999)[12]	PS	Deh	11	16	16	AP	none	6.6	-	90	63	6	-
Carpio et al (2000)[13]	RCT	Deh & Fen	25	25	25	A+DBBM	Nonres	6	-	54	ND	46	-
		Deh & Fen	23	23	23	A+DBBM	Res	6	-	61	ND	48	-
Nemcovsky et al (2000)[14]	PS	Deh	21	28	28	DBBM	Res	7	-	97	ND	0	-
van Steenberghe et al (2000)[15]	PS	Deh	15	21	21	DBBM	none	6	-	71	48	19	-
Widmark and Ivanoff (2000)[16]	PS	Fen	12	12	12	ABT	none	6	-	82	58	ND	-
Hämmerle and Lang (2001)[17]	PS	Deh	10	10	10	DBBM	Res	6.5	-	86	80	20	-
Tawill et al (2001)[18]	PS	Deh	13	14	14	AP	Res	6	-	87	71	14	-
Zitzmann et al (2001)[19]	PS	Deh	75	112	112	DBBM	Res	5	59	ND	ND	ND	95.4
		Deh	25	41	41	DBBM	Nonres	5	59	ND	ND	ND	92.9
Nemcovsky et al (2002)[20]	PS	Deh	43	54	54	DBBM	Res	7	-	94	ND	9	-
De Boever and De Boever (2005)[21]	PS	Deh	13	16	16	DBBM	Nonres	4	42	97	81	6	94
Juodzbalys et al (2007)[22]	PS	Fen	17	20	20	DBBM	Res	5	60	ND	ND	5	100
Llambés et al (2007)[23]	RS	Deh	11	14	32	ABT	Res	4.4	12	83	66	27	94
Park et al (2008)[24]	RT	Deh	18	18	18	FDBA	Res	6	-	83	ND	0	-

RCT = randomized controlled trial; CCT = controlled clinical trial; PS = prospective study; RS = retrospective study; Deh = dehiscence-type defect; Fen = fenestration-type defect; No. of augm = number of augmentation procedures; ND = no data; Membr alone = membrane without grafting material; AP = autogenous particulate; A = autogenous bone; ABT = autogenous bone from bone trap; DBBM = deproteinized bovine bone mineral; DFDBA = demineralized freeze-dried bone allograft; FDBA = freeze-dried bone allograft; Res = resorbable; Nonres = nonresorbable; Healing impl = mean healing time from implant placement to loading; Follow-up = mean period of loading; Defect fill = percentage reduction of bone defect size from intraoperative condition to reentry; % Complete fill = percentage of cases with complete resolution of the bone defect at reentry; Implant survival = implant survival after at least 12 months of loading.

Table 3 Horizontal Ridge Augmentation

Study	Study type	No. of patients	No. of augm	No. of implants	Grafting material	Membrane	Healing augm (mo)	Healing impl (mo)	Follow-up (mo)	Gain width (mm)	Complication rate (%)	Implant survival (%)
Buser et al (1996)[25]	PS	40	40	66	AB IO	Nonres	8.9	3.5	–	3.5	2.5	–
Raghoebar et al (1996)[26]	RS	23	23	27	AB IO	None	3	6	31	ND	13	100
Fugazzotto (1997)[7]	RS	99	ND	183	AG+ALP	Nonres	ND	7.5	24	ND	ND	97
von Arx et al (1998)[27]	PS	18	18	27	AB IO	None	5.2	7.2	12	ND	ND	100
Parodi et al (1998)[28]	RS	16	16	27	Membr alone	Nonres	9.5	ND	-	2.5	31	–
Chiapasco et al (1999)[29]	PS	15	15	30	AP	Nonres	7	6	22	2.7	13	100
		15	15	44	AB EO	None	7	6	22	4	0	100
Bedrossian and Tawfilis (2000)[30]	RS	63	87	187	AB IO	None	4	4.5	38	ND	ND	100
Kirkland et al (2000)[31]	RS	12	12	ND	AG+ALP	Res	12	ND	–	3.2	ND	–
Sethi and Kaus (2001)[32]	PS	60	ND	118	AB IO	ND	4.5	6	22	ND	0	98
Cordaro et al (2002)[33]	PS	15	18	40	AB IO	None	6	6	12	5	0	100
Friedmann et al (2002)[34]	RCT	14	14	ND	DBBM	Nonres	7	ND	–	ND	64	–
		14	14	ND	DBBM	Res	7	ND	–	ND	71	–
Buser et al (2002)[35]	PS	40	40	66	AB IO	Nonres	8.9	3.5	60	3.5	2.5	100
Hellem et al (2003)[36]	PS	27	29	74	A+DBBM	None	6	ND	36	ND	0	97
Knapp et al (2003)[37]	PS	12	12	ND	BG	Nonres	6	ND	–	1.1	50	–
Feuille et al (2003)[38]	PS	10	10	ND	FDBA	Nonres	6	ND	–	3.2	ND	–
Maiorana et al (2005)[39]	PS	14	14	ND	AB IO	None	5.4	5.4	–	5.7	14.3	–
		12	12	ND	AB+DBBM	None	5.4	5.4	–	5.3	8	–
von Arx and Buser (2006)[40]	PS	42	58	58	AB+DBBM	Res	5.8	ND	–	4.6	7	–
Strietzel et al (2007)[41]	PS	10	10	10	ALP HA	None	7	3.5	-	2	50	-
Levin et al (2007)[42]	RS	50	50	129	AB IO	Res	5.2	ND	24	ND	ND	96.9
Hämmerle et al (2008)[43]	PS	12	15	14	DBBM	Res	9.5	4	-	3.6	0	-

RCT = randomized controlled trial; PS = prospective study; RS = retrospective study; No. of augm = number of augmentation procedures; ND = no data; A = autogenous bone; AB = autogenous block; EO = extraoral donor site; IO = intraoral donor site; AP = autogenous particulate; AG = allograft; ALP = alloplast; DBBM = deproteinized bovine bone mineral; BG = bioglass; FDBA = freeze-dried bone allograft; HA = hydroxyapatite; Res = resorbable; Nonres = nonresorbable; Healing augm = mean healing time from augmentation to implant placement; Healing impl = mean healing time from implant placement to loading; Follow-up = mean period of loading; Gain width = gain in alveolar ridge width at reentry; Implant survival = implant survival after at least 12 months of loading.

Table 4 Vertical Ridge Augmentation

Study	Study type	No. of patients	No. of augm	No. of implants	Grafting material	Membrane	Simul/ staged	Healing augm (mo)	Healing impl (mo)	Follow-up (mo)	Gain height (mm)	Complication rate (%)	Implant survival (%)
Corrente et al (1997)[44]	RS	11	11	22	Coral	None	Simul	ND	6	–	2.1	0	–
Simion et al (1998)[45]	PS	10	10	22	DFDBA	Nonres	Simul	ND	9.3	–	3.1	20	–
		10	12	30	AP	Nonres	ND	ND	7	–	5	20	–
Sethi and Kaus (2001)[32]	PS	60	ND	118	AB IO	ND	Staged	4.5	6	22	ND	0	98
Simion et al (2001)[46]	RS	11	11	24	DFDBA	Nonres	Simul	ND	10	39.3	ND	18	100
		32	34	79	AP	Nonres	Simul	ND	10.4	30.4	ND	19	100
Artzi et al (2003)[47]	PS	10	10	20	DBBM	None	Staged	9	ND	–	5.2	20	–
Roccuzzo et al (2004)[48]	PS	18	18	37	AB IO	None	Staged	4.6	ND	–	4.8	22	–
Chiapasco et al (2004)[49]	RCT	11	11	25	AB IO	Nonres	ND	6.5	4	35.5	4.8	27	100
Proussaefs and Lozada (2005)[50]	PS	12	12	ND	AB+DBBM	None	Staged	5	5	–	5.8	25	–
Smolka et al (2006)[51]	PS	10	10	20	AB EO	ND	Staged	6	3	21.3	11.8	30	95
Merli et al (2006)[52]	RS	11	11	18	AP	Nonres	Simul	ND	6.2	–	ND	8	–
Verhoeven et al (2006)[53]	PS	13	13	30	AB EO	ND	Simul	ND	ND	105.6	7.2	23	100
Levin et al (2007)[42]	RS	50	50	129	AB IO	Res	Staged	5.2	ND	24	ND	ND	96.9
Merli et al (2007)[54]	RCT	11	11	11	AP	Nonres	Simul	ND	4.6	–	2.8	45	–
		11	11	11	AP	Res	Simul	ND	4.6	–	2.1	36	–
Roccuzzo et al (2007)[55]	RCT	12	12	ND	AB IO	None	Staged	4.7	ND	–	3.6	50	–
		12	12	ND	AB IO	None	Staged	4.6	ND	–	4.8	33	–

RCT = randomized controlled trial; PS = prospective study; RS = retrospective study; No. of augm = number of augmentation procedures; ND = no data; AB = autogenous block; EO = extraoral donor site; IO = intraoral donor site; AP = autogenous particulate; Coral = xenograft of coralline origin; DFDBA = demineralized freeze-dried bone allograft; Res = resorbable; Nonres = nonresorbable; Simul = implant placed simultaneously with augmentation; Staged = implant placed in a second stage; Healing augm = mean healing time from augmentation to implant placement; Healing impl = mean healing time from implant placement to loading; Follow-up = mean period of loading; Gain height = gain in alveolar ridge height at reentry; Implant survival = implant survival after at least 12 months of loading.

Table 5 Sinus Augmentation Lateral Window Technique

Study	Study type	No. of patients	No. of augm	No. of implants	Implant surface	Grafting material	Membrane	Simul/ staged	Initial bone height (mm)	Healing augm (mo)	Healing impl (mo)	Follow-up (mo)	Complication rate (%)	Implant survival (%)
Small et al (1993)[56]	CS	27	45	111	R	DFDBA+coral	+	Simul	ND	NR	9	37.6	7	100
Blomqvist et al (1996)[57]	RS	49	93	171	M	AB EO	–	Simul	ND	NR	9	30.0	ND	82.5
Lundgren et al (1996)[58]	CS	10	10	30	M	AP	–	Sta	ND	6	6	26.0	ND	100
Daelemans et al (1997)[59]	CS	33	44	121	M	AB EO	–	Simul	ND	NR	5.5	40.2	2.2	92.2
Lundgren et al (1997)[60]	CS	10	20	26	M	AB EO	–	Sta	ND	6	6	16.0	ND	76.9
Valentini and Abensur (1997)[61]	CS	10	12	28	R	DFDBA+DBBM	–	Simul	ND	NR	9.4	25.0	ND	92.8
	CS	10	16	32	R	DFDBA+DBBM	–	Sta	ND	6.4	6	29.0	ND	96.8
Blomqvist et al (1998)[62]	PS	50	97	202	M	AB EO	–	Sta	ND	5.3	6	16.0	ND	84.2
Peleg et al (1998)[63]	CS	20	20	55	R	A+DFDBA	+	Simul	ND	NR	9	26.4	ND	100
van den Bergh et al (1998)[64]	RS	42	62	161	R	AP	–	Sta	ND	4	4	34.0	5	100
Zitzmann and Schärer (1998)[65]	CS	10	ND	20	M	DBBM	+	ND	3.2	ND	ND	16.5	0	100
Johansson et al (1999)[66]	PS	39	78	131	M	AB EO	ND	Simul	ND	NR	6	36.0	20.5	75.3
Keller et al (1999)[67]	RS	37	58	139	M	AB EO	ND	Simul	ND	NR	ND	41.0	0	85.6
Mazor et al (1999)[68]	CS	10	10	10	R	A+DFDBA	+	Simul	5.4	NR	9	36.0	0	100
Peleg et al (1999)[69]	CS	63	63	160	R	A+DFDBA	–	Simul	4.0	NR	9	31.0	0	100
Valentini et al (2000)[70]	CS	15	20	57	ND	DBBM	+	Sta	1.8	6	9	48.0	6.6	98.2
van den Bergh et al (2000)[71]	CS	24	30	69	R	DFDBA	–	Sta	ND	6	4	30.6	13	100
Wannfors et al (2000)[72]	RCT	20	40	76	M	AB EO	ND	Simul	ND	NR	6	12.0	ND	79
	RCT	20	40	74	M	AP	ND	Sta	ND	6	6	12.0	ND	89
Cordioli et al (2001)[73]	CS	12	ND	27	R	A+DFDBA	+	Simul	4.4	NR	10.8	12.0	0	96
Hallman et al (2001)[74]	PS	20	30	79	M	A+DBBM	–	Sta	2.7	6.7	3	36.0	10	89
Kahnberg et al (2001)[75]	PS	26	39	93	M	AB EO	–	Simul	2.5	ND	6	47.4	ND	61.2
Raghoebar et al (2001)[76]	RS	99	182	392	M	AB EO	–	ND	3.0	ND	6	58.0	18	91.8
Tawil and Mawla (2001)[77]	RCT	29	30	61	M	DBBM	+/-	ND	ND	NR	ND	22.4	ND	85.0
Hallman et al (2002)[78]	PS	20	30	79	M	A+DBBM	–	Sta	2.7	6	6.7	12.0	10	92.4
Hallman et al (2002)[79]	RCT	11	11	33	M	AP	–	Sta	ND	6.5	6	12.0	ND	82.4
	RCT	11	11	35	M	A+DBBM	–	Sta	ND	6.5	6	12.0	ND	94.4
	CS	10	14	43	M	DBBM	+	Sta	ND	8.5	6	12.0	ND	96
Kan et al (2002)[80]	RS	ND	73	195	R	DFDBA+DBBM	ND	ND	ND	NR	ND	41.6	ND	88.6
	RS	ND	11	33	R	A+DFDBA	ND	ND	ND	NR	ND	41.6	ND	100
Pejrone et al (2002)[81]	CS	13	26	87	M	AB EO	ND	Sta	ND	6	6	12.0	0	94
Mangano et al (2003)[82]	CS	12	12	28	R	Allopl HA	–	Simul	4.5	NR	5.5	12.0	0	100
Reinert et al (2003)[83]	RS	30	58	200	ND	AB EO	–	Sta	3.7	5	6	24.0	7	95
Stricker et al (2003)[84]	PS	41	66	183	R	AP	–	ND	ND	ND	4.1	17.2	ND	99.5
Valentini and Abensur (2003)[85]	CS	10	12	28	ND	DFDBA+DBBM	–	Simul	ND	NR	9	106.8	0	82.1
	CS	11	13	32	ND	DBBM	–	Simul	ND	NR	9	56.4	0	92.6
	CS	28	37	100	ND	DBBM	–	Sta	ND	6	6	68.4	3.6	98
Hallman and Nordin (2004)[86]	RS	50	71	196	R	DBBM	ND	Sta	ND	8	2.5	20.0	3	96
Hallman and Zetterqvist (2004)[87]	PS	20	30	79	M	A+DBBM	–	Sta	2.7	6	6.7	60.0	10	88.6
Hatano et al (2004)[88]	RS	191	294	361	M	A+DBBM	–	Simul	ND	NR	7.5	20.5	ND	94
Lundgren et al (2004)[89]	CS	10	12	19	R	Coagulum	–	Simul	ND	NR	6	12.0	0	100
Shlomi et al (2004)[90]	CS	63	73	253	ND	A+DBBM	+	ND	5.0	ND	6	18.0	ND	91

Table 5 continued Sinus Augmentation Lateral Window Technique

Study	Study type	No. of patients	No. of augm	No. of implants	Implant surface	Grafting material	Membrane	Simul/ staged	Initial bone height (mm)	Healing augm (mo)	Healing impl (mo)	Follow-up (mo)	Complication rate (%)	Implant survival (%)
Hallman et al (2005)[91]	PS	20	30	79	M	A+DBBM	ND	Sta	2.7	6	6.7	36.0	10	89
Rodoni et al (2005)[92]	CS	13	13	13	M	DBBM	+	ND	ND	ND	ND	31.1	0	100
Wiltfang et al (2005)[93]	RS	61	ND	349	ND	AP	ND	Sta	ND	4	6	54.0	4	94.6
Mangano et al (2006)[94]	CS	24	29	57	R	Allopl HA	–	ND	ND	ND	4.4	36.0	0	100
Orsini et al (2006)[95]	CS	10	10	10	R	DBBM	+	Sta	ND	5	6	12.0	0	100
Becktor et al (2007)[96]	CS	12	ND	36	M	AB EO	–	ND	ND	ND	7.4	45.7	ND	94.4
Chen et al (2007)[97]	RS	33	33	47	R	Coagulum	–	ND	ND	ND	9	24.0	ND	100
Krennmair et al (2007)[98]	RS	25	25	28	R	A+DBBM	+	Simul	7.8	NR	6	44.5	ND	100
	RS	12	12	12	R	A+DBBM	+	Sta	3.5	ND	9	44.5	ND	100
Mangano et al (2007)[99]	RCT	20	ND	50	R	DBBM	–	Simul	4.5	NR	6	12.0	0	96
	RCT	20	ND	50	R	Allopl HA	–	Simul	4.5	NR	6	12.0	0	96
Marchetti et al (2007)[100]	CS	30	48	140	ND	A+DBBM	–	ND	3.2	5	5	12.0	13	94.9
Mardinger et al (2007)[101]	PS	25	30	88	R	DBBM	+	Simul	2.0	NR	6.6	34.5	4	92
	PS	30	30	76	R	DBBM	+	Simul	ND	NR	6.1	39.1	7	98.7
Thor et al (2007)[102]	CS	20	27	44	R	Coagulum	–	Simul	4.6	NR	6	27.5	ND	97.7

RCT = randomized controlled trial; CCT = controlled clinical trial; PS = prospective study; RS = retrospective study; CS = case series; No. of augm = number of sinus augmentation procedures; ND = no data or data cannot be separated; Impl surf = implant surface; R = rough; M= machined; A = autogenous bone; AB = autogenous block; EO = extraoral donor site; AP = autogenous particulate; DFDBA = demineralized freeze-dried bone allograft; Allopl HA = Alloplastic hydroxyapatite; Simul = implant placed simultaneously with augmentation; Sta = implant placed in a second stage; + = membrane was used; – = membrane was not used. Initial bone height = Initial subantral bone height; Healing augm = mean healing time from augmentation to implant placement for staged procedures; NR = not relevant due to the study design; Healing impl = mean healing time from implant placement to loading; Follow-up = mean follow-up period after loading; Implant survival = implant survival after at least 12 months in function.

or with a suction device during preparation of the implant bed.[16,23] A resorbable membrane was applied in four groups of patients,[9,11,18,23] while no membrane was used in another three.[9,12,16] Data on defect fill and the percentage of cases with complete regeneration of the defects could be extracted from all the studies, and averaged 83.8% and 68.8%, respectively. Membrane or graft dehiscence was reported in 15.5% of the cases. There was only one study using autografts (11 patients with 32 implants) presenting data on implant survival, which was reported to be 94% after 12 months of loading.[23] Eight studies (269 patients with 386 implants) evaluated the use of DBBM with[8,14,17,19–22] or without[15] the use of a membrane. A mean defect fill at reentry of 88.9% (based on six studies) and a percentage of cases with complete defect fill of 67.7% (based on 3 studies) was found. The rate of dehiscences was 12%. Four studies (145 patients with 210 implants) with follow-up periods of 42 to 60 months after prosthetic loading reported implant survival rates of 93% to 100% (median 95.4%).[15,19,21,22]

When the data set was divided according to the use of nonresorbable membranes,[5,6,13,21] resorbable membranes,[9,11,13,14,17,18,20,23,24] or no membrane,[9,12,15,16] the percentages of defect fill were 75.7%, 87%, and 75.5%; the percentage of cases with complete defect fill were 75.5%, 75.4%, and 56.4%; the rates of membrane/graft dehiscences were 26.3%, 14.5%, and 15.4%; and the implant survival rates were 92.9% to 100% (median 96.5%) with nonresorbable membranes and 94% to 100% (median 95.4%) with resorbable membranes. None of the included studies contained data on implant survival after at least 12 months of loading without the use of a membrane.

Analyzing augmentation of dehiscence-type defects alone, 525 patients received 813 implants showing buccal dehiscences. Five hundred twelve of the implants were followed for 12 to 59 months after loading and had survival rates of 92.6% to 100% (median 94%).[6,7,10,19,21,23] The augmentation procedures provided on average a defect fill of 85.5%,[5,6,8,9,12–15,17,18,20,21,23,24] and complete regeneration was accomplished in 68.5% of the cases.[5,9,12,15,17,18,21,23] Infectious complications were recorded in 13.7% of the cases.[5,6,8,9,12–15,17,18,20,21,23,24]

Grafting of fenestration-type defects was documented in four studies (54 patients, 126 implants).[7,11,16,22] In two studies, the mean defect fill and percentage of cases with complete bone fill at reentry were 84.9% and 68.6%, respectively.[11,16] The two other studies showed implant survival rates of 100% after 24 to 60 months of functional loading.[7,22] The mean complication rate was 2.5%.[11,22]

Table 6 Transalveolar Sinus Floor Elevation

Study	Study type	No. of patients	No. of augm	No. of implants	Grafting material	Simul/ Staged	Initial bone height (mm)	Follow-up (mo)	Implant survival (%)
Zitzmann and Schärer (1998)[65]	PS	20	ND	59	DBBM	Simul	8.8	16.5	95
Fugazzotto and De Paoli (2002)[103]	RS	150	167	167	A	Sta	ND	20.1	97.8
Winter et al (2002)[104]	RS	34	58	58	Coagulum	Simul	2.9	22	91.4
Brägger et al (2004)[105]	PS	19	25	25	A+DBBM	Simul	7	12	96
Deporter et al (2005)[106]	RS	70	104	104	DBBM	Simul	4.2	37.7	98
Leblebicioglu et al (2005)[107]	PS	40	54	75	Coagulum	Simul	8.8	25	97.3
Rodoni et al (2005)[92]	RS	18	18	18	DBBM	Simul	ND	42.6	100
Ferrigno et al (2006)[108]	PS	323	588	588	AP	Simul	7.7	53.7	94.8
Stavropoulos et al (2007)[109]	RCT	26	26	35	A+BG	Sta	6.4	12	83
Krennmair et al (2007)[98]	RS	14	14	14	DBBM	Simul	9.6	44.5	100
Fermergård and Åstrand (2008)[110]	RS	36	ND	53	Coagulum	Simul	6.3	12	96

RCT = randomized controlled trial; PS = prospective study; RS = retrospective study; No. of augm = number of sinus augmentation procedures; Simul = implant placed simultaneously with augmentation; Sta = implant placed in a second stage; Initial bone height = initial subantral bone height; Follow-up = mean follow-up period after loading; Implant survival = implant survival after at least 12 months of loading; ND = no data; A = autogenous bone; AP = autogenous particulate; DBBM = deproteinized bovine bone mineral; BG = Bioglass.

Four of the included studies were RCTs, and all randomizations were related to the use of membranes.[8,9,13,24] Schlegel and coworkers[9] randomized 40 implant sites with exposed implant threads to be augmented with autogenous bone chips with or without a resorbable membrane. The authors stated that the use of a membrane increased the defect fill, but presented no statistics to support the conclusion. Another RCT compared two different resorbable membranes versus no membrane over an allogenic grafting material.[24] No differences in defect fill could be demonstrated using a membrane, but a significantly increased width of the augmented volume was shown. No difference was found between the two resorbable membranes tested. Two RCTs evaluated the use of a resorbable versus a nonresorbable membrane to cover DBBM particles.[8,13] Both studies showed similar amounts of defect fill with the two membrane types, but the use of nonresorbable membranes was accompanied by more wound healing complications.

Horizontal Ridge Augmentation

Two categories of studies on horizontal ridge augmentations were included: *(1)* studies that reported on the augmentation procedure itself, where the successful outcome was the possibility to place implants of the desired dimensions in the ideal positions for the later suprastructure, without the need for additional grafting, and *(2)* studies that evaluated implant survival in horizontally augmented alveolar ridges.

A total of 107 studies were screened as full text, and 20 of these were included, reporting data on 593 patients with 1,034 implants (Table 3).[7,25–43] Twelve of these studies contained specific data on the horizontal ridge augmentation.[25,28,29,31,33,35,37–41,43] A total of 225 patients underwent 247 horizontal ridge augmentation procedures. After a mean healing period of 7.3 months, an average gain in ridge width of 3.6 mm could be recorded. The mean complication rate was 12.2%. However, when the complication rate was calculated for studies with the use of nonresorbable membranes, resorbable membranes, or no membranes, the corresponding rates were 23.6%, 18.9%, and 9.4%. Six studies reported data on the percentage of sites where additional grafting was needed in conjunction with implant placement.[28,29,36,40,41,43] This was the case in 11.1% of the cases.

Implant survival after a minimum of 12 months of loading was calculated based on 10 studies including 425 patients and 925 implants.[7,26,27,29,30,32,33,35,36,42] The horizontal ridge augmentations had been performed on average 6.3 months prior to implant placement. In total, 97% to 100% (median 100%) of the implants were still present after 12 to 60 months of function.

When the augmented sites were covered with nonresorbable membranes, the mean gain in ridge width was 2.9 mm,[7,25,28,29,34,35,37,38] the percentage of cases that did not need additional grafting was 80.8%,[28,29] and the complication rate was 23.6%.[25,28,29,34,35,37] The corresponding figures for the use of resorbable membranes were 4.2 mm, 95.9%, and 18.9%.[31,34,40,43] When no membrane was used, the results were 4.5 mm, 86.1%, and 9.4%.[26,29,33,36,39,41]

The results after horizontal ridge augmentation may also be divided according to whether a space-maintaining autogenous bone block is used as opposed to a particulated bone graft or a granular bone-substitute material. In studies utilizing autogenous bone blocks alone or in combination with a membrane and/or a bone-substitute material,[25–27,29,30,32,33,35,36,39,40,42]

the mean gain in ridge width was 4.4 mm, the percentage of cases that needed no additional grafting was 97.2%, and the complication rate was 3.8%. When no autogenous block graft was used, the corresponding figures were 2.6 mm, 75.6%, and 39.6%.[7,28,29,31,34,37,38,41,43]

Only one grafting protocol for augmenting localized bone defects in the horizontal dimension was documented in three or more studies. Autogenous block grafts from intraoral donor sites were used in nine studies comprising 283 patients with 594 implants.[25–27,30,32,33,35,39,42] Four studies contained data on width gain at reentry,[25,33,35,39] two of which reported on the same group of patients.[25,35] The average gain in ridge width was 4.3 mm after a mean healing period of 6.8 months, with a complication rate of 3.9%. Seven studies reported implant survival rates of 96.9% to 100% (median 100%) after 12 to 60 months of loading.[26,27,30,32,33,35,42]

One RCT compared the use of a resorbable versus a nonresorbable membrane to cover DBBM for horizontal ridge augmentation.[34] Both groups experienced high frequencies of membrane exposures (64% and 71%). General improvement of the volume and shape of the alveolar ridges was reported, but no measurements were presented to support this statement.

Vertical Ridge Augmentation

Seventy-six studies were evaluated as full text. Of these, 14 were found to contain data on implant survival after at least 12 months of loading and/or on the efficiency of the augmentation procedure (Table 4).[32,42,44–55] A total of 596 implants were placed in 315 patients. In 6 studies, 187 patients with 425 implants were followed for 22 to 105 months of function. Implant survival rates ranged from 95% to 100% (median 100%).[32,42,46,49,51,53] The efficacy of the augmentation protocols to allow later implant placement was documented in 10 studies including 162 patients with 226 implants.[44,45,47–51,53–55] The mean gain in ridge height at reentry was 4.8 mm and the average percentage of cases that allowed implant placement in the planned position without the need for additional grafting was 73.6%. Exposure of the augmentation material was reported in 18.8% of the cases.

Comparing the data when a membrane was used,[42,45,46,49,52,54] or no membrane was used,[44,47,48,55] the gain in ridge height was 3.5 mm vs 4.2 mm, the percentage of cases that required no regrafting was 67.2% vs 80%, and the complication rate was 23.2% vs 25.3%. When cases treated with an autogenous block graft[42,48,50,52,53,55] were compared to cases treated with a particulated autograft or a bone-substitute material,[44–47,49,52,54] the corresponding figures were 3.7 mm vs 3.6 mm (gain in ridge height), 83.1% vs 67.4% (cases not needing regrafting), and 29.8% vs 21.0% (complication rate).

Only intraorally harvested autogenous block grafts and autogenous particulate were documented in three studies or more. A total of 152 patients had 284 implants placed in alveolar ridges vertically augmented with block grafts harvested from the mandibular chin or body/ascending ramus.[32,42,48,55] Roccuzzo and coworkers[48,55] reported an average gain in ridge height of 4.5 mm at reentry 4.6 months after augmentation without the use of barrier membranes. Additional grafting or regrafting was necessary in 24% of the cases. After loading times of 22 and 24 months, two studies reported implant survival rates of 96.9% and 98%, respectively.[32,42] Five studies described the use of autogenous bone chips harvested intraorally and covered with a titanium-reinforced nonresorbable membrane [45,46,49,52,54] or with a resorbable membrane supported by miniplates.[54] One hundred seventy-four implants were placed in 86 patients. Three studies reported a mean gain in ridge height of 3.6 mm.[45,49,54] Additional grafting at reentry was necessary in 35% of the cases.[45,52,54] Complication rates were reported in all five studies, averaging 24.2%. Only two of the five studies contained data on implant survival.[46,49] Forty-three patients with 104 implants were followed for 30 and 36 months of loading, respectively, and reported 100% survival rates.

Two RCTs compared different grafting protocols for vertical ridge augmentation. Merli and coworkers[54] compared particulated autografts covered either by osteosynthesis miniplates in combination with a resorbable collagen membrane or by a titanium-reinforced nonresorbable membrane in a total of 22 patients. No differences in augmented bone height (2.8 mm vs 2.1 mm) or in complication rate (45% vs 36%) could be demonstrated. The effect of covering an autogenous bone block harvested intraorally with a titanium mesh was evaluated in the other RCT.[55] A statistically significantly larger gain in ridge height was obtained by covering the block graft with a titanium mesh than when no mesh was used (4.8 mm vs 3.6 mm). A third RCT compared vertical ridge augmentation using distraction osteogenesis with the results obtained by using autogenous particulate in combination with titanium-reinforced nonresorbable membranes.[49] Distraction osteogenesis is evaluated in a parallel review in this supplement (Chiapasco et al). In the 11 patients augmented with autograft and a membrane, the survival rate of the 25 placed implants was 100% after 35.5 months of loading, but one-third of the implants showed progressive marginal bone loss.

Maxillary Sinus Floor Elevation—Lateral Window Technique

A total of 179 studies were evaluated as full text, 47 of which were included (Table 5).

In 1,571 patients, 5,388 implants were inserted in 2,180 augmented sinuses.[56–107] From 19 studies, the mean initial subantral bone height before grafting was calculated to be 3.8 mm.[65,68–70,73–76,78,82,83,87,90,91,98–102] For simultaneous implant placements and two-stage placements, the mean heights were 4.4 mm and 2.9 mm, respectively. In two-stage procedures, the mean healing time from grafting to implantation was 5.9 months. Infectious complications were reported in 4.7% of the cases.[56,59,64–71,73,74,76,78,81–83,85–87,89,91–95,99–101] The average healing time from implant placement until loading was 6.5 months. Implant survival ranged from 61.2% to 100% (median 95.5%) after 12 to 107 months of prosthetic loading.[56–107] When the material was divided according to the surface of the implants used, the corresponding figures were 61.2% to 100% (median 89%) after 12 to 60 months for machined-surface implants[57–60,62,65–67,72,74–79,81,87,88,91,92,96] and 88.6% to 100% (median 100%) after 12 to 45 months of loading for rough-surfaced implants.[56,61,63,64,68,69,71,73,80,82,84,86,89,94,95,97–99,101,102]

A barrier membrane was used to cover the lateral window in 12 studies (282 patients, 803 implants).[56,63,65,68,70,73,79,90,92,95,98,101] No membrane was used in 27 studies (1,000 patients, 3,165 implants).[57–62,64,69,71,74–76,78,79,82–85,87–89,94,96,97,99,100,102] The implant survival rates with and without the use of a membrane were 92% to 100% (median 100%) and 61.2% to 100% (median 94.7%) after loading periods of up to 48 and 107 months, respectively. Excluding studies using smooth-surfaced implants, the survival rates ranged from 92% to 100% (median 100%) with the use of a barrier membrane after up to 45 months of loading, compared to 93% to 100% (median 100%) without the use of a membrane after up to 36 months of loading.

A bone-substitute material was used alone in 16 studies (388 patients, 1,344 implants),[56,61,65,70,71,77,79,80,82,85,86,92,94,95,99,101] whereas 30 studies used autografts alone or a combination of autografts and a bone-substitute material (1,183 patients, 4,044 implants).[57–60,62–64,66–69,72–76,78–81,83,84,87,88,90,91,93,96,98,100] The mean initial bone height for the two groups was 3.4 mm and 3.9 mm, respectively. For two-stage procedures, the mean healing time before implant placement was 6.6 months and 5.6 months, respectively. In the "bone-substitute group," the implant survival rates after up to 107 months of loading ranged from 82% to 100% (median 96.8%). In comparison, the survival rates in the "autograft group" ranged from 61.2% to 100% (median 94.2%) after up to 60 months of loading. Excluding studies using smooth-surfaced implants, the survival rates ranged from 88.6% to 100% (median 96.8%) with the use of a bone-substitute material alone[56,61,71,80,82,86,94,95,99,101] after up to 42 months of loading, compared to 96% to 100% (median 100%) after up to 45 months of loading when particulated autograft was included in the grafting material.[63,64,68,69,73,80,84,98]

Eight grafting protocols for maxillary sinus floor elevation procedures were documented in three or more studies.

Three case series (63 patients, 110 implants) presented data on maxillary sinus floor elevation procedures without the use of a grafting material. Instead, the simultaneously placed implants acted as tent poles for the elevated sinus membrane, allowing a coagulum to occupy the created space.[89,97,102] After an average of 12 to 27.5 months of loading, the survival rate ranged from 97.7% to 100% (median 100%).

A total of 10 studies used autogenous block grafts for augmenting the maxillary sinus, all of which were harvested from the iliac crest.[59,60,62,66,67,72,75,76,81,96] In 5 studies (155 patients),[59,66,67,72,75] 560 implants were placed simultaneously with the grafting procedure, whereas 4 studies (85 patients, 351 implants)[60,62,72,81] used a staged approach (2 studies did not separate staged and simultaneous implant placements[76,96]). The overall implant survival rate after a period of function up to 58 months ranged from 61.2% to 94.4% (median 84.9%). For simultaneous and staged implant placements in autogenous bone blocks, the corresponding survival rates were 61.2% to 92.2% (median 79%) and 76.9% to 94.4% (median 89.1%), respectively.

Six studies (185 patients, 830 implants) presented data on maxillary sinus floor elevations using particulated autografts from different donor sites.[58,64,72,79,84,93] Most of the studies (five) used a staged approach,[58,64,72,79,93] where the mean healing time before implant placement was 5.3 months. The survival rate after 12 to 54 months of loading was 82.4% to 100% (median 97.1%).

DBBM alone was used for maxillary sinus floor elevation in 10 studies (338 patients, 874 implants).[65,70,77,79,85,86,92,95,99,101] The initial bone height was reported in 4 of the studies, with an average of 2.8 mm. Three studies contained data on implant placement at the time of the augmentation procedure,[85,99,101] whereas 5 studies delayed implant placement for an average of 6.7 months.[70,79,85,86,95] Implant survival after up to 68 months in function ranged from 85% to 100% (median 97%).

Alloplastic particulate in the form of hydroxyapatite was used as a grafting material for maxillary sinus floor elevations and presented in 3 studies from

the same group (56 patients, 135 implants).[82,94,99] After a period of function up to 36 months, the survival rate was 96% to 100% (median: 100%).

Four studies presented the use of a composite graft consisting of particulated autograft and allograft in 94 patients with 338 implants (two studies did not report the number of patients).[63,68,69,80] All four studies reported 100% implant survival after loading periods of up to 42 months.

Autografts were combined with DBBM in nine studies.[74,78,79,87,88,90,91,98,100] However, four studies reported on the same pool of patients at different time points.[74,78,87,91] Therefore, only clinical data from the latest follow-up were included.[87] A total of 908 implants were placed in 352 patients. The height of the initial ridge was presented for five patient pools with an average of 4.4 mm.[79,87,90,98,100] The implant survival rate was 89% to 100% (median 94.3%) with a follow-up of 12 to 60 months after loading.

A combination of DFDBA and DBBM was used in three studies[61,80,85] comprising the augmentation of 113 maxillary sinuses (the number of patients was not reported by Kan et al[80]) and the placement of 283 implants. After a period of function of up to 107 months, the implant survival rate ranged from 82.1% to 96.8% (median 90.7%).

Three studies included randomization of two different grafting protocols.[72,79,99] Wannfors and coworkers[72] randomized 40 patients with edentulous maxillae to have bilateral maxillary sinus floor elevation performed with either autogenous bone blocks from the iliac crest in combination with immediate implant placement (76 implants) or particulated autogenous bone (also from the iliac crest) in a two-stage procedure (74 implants placed after 6 months of graft healing). The implant survival rate after 12 months of function was 79% in the block graft group and 89% in the particulate group. The difference was not statistically significant.

Eleven patients in whom bilateral augmentation of the maxillary sinus was indicated were randomized in a split-mouth design to be grafted with particulated autogenous bone harvested from the mandibular ramus or a mixture of 80% DBBM and 20% particulated autograft.[79] After a healing period of 6.5 months, 33 implants were placed in the autograft side and 35 implants were placed in the composite side. After 12 months of loading, the survival rate for the implants placed in 100% autograft was 82.4%, versus 94.4% for the implants placed in 80% DBBM and 20% autograft. This difference was also not statistically significant.

Mangano and coworkers[99] compared the use of DBBM versus an alloplastic HA for maxillary sinus floor elevation. Forty patients were randomized to receive one of the two augmentation materials. A total of 100 implants were placed simultaneously with the augmentation procedure—50 in each group. Both groups had an implant survival rate of 96% after 12 months of loading.

Transalveolar Sinus Floor Elevation

A total of 16 studies were screened as full text. Data from 11 studies were included (Table 6).[65,92,98,103–110] One thousand and fifty-four sinus floor elevations using the transalveolar approach (2 studies did not report the number of augmentation procedures[65,110]) were performed in 750 patients with a mean initial subantral bone height of 6.9 mm (2 studies did not present data on initial bone height[92,103]). A total of 1,196 implants were followed for a period of up to 64 months after prosthetic loading, with an implant survival rate ranging from 83% to 100% (median 96%).

Three studies reported results after elevating the sinus floor without the introduction of a grafting material in 110 patients (186 implants) with a mean initial bone height of 6 mm.[104,107,110] The mean implant survival was 91.4% to 97.3% (median 96%) after up to 25 months of loading. The highest number of patients (473) were grafted with autogenous bone, with 755 implants placed in a mean initial ridge height of 6.6 mm and followed for up to 54 months of loading.[103,108] The implant survival rates were 97.8% and 94.8%, respectively. DBBM alone was used as grafting material in four studies reporting on 122 patients with a mean initial bone height of 7.5 mm, in which 195 implants were placed.[65,92,98,106] The survival rate was 95% to 100% (median 99%) after a follow-up period of 12 to 45 months after loading.

The only RCT describing the transalveolar approach in maxillary sinus floor elevations was not randomized regarding the grafting protocol but had two different implant designs.[109]

No studies compared the lateral window technique with the transalveolar approach for similar indications.

DISCUSSION

Survival rates of implants placed in conjunction with augmentation of dehiscence-type defects or fenestration-type defects (median 95.4%), implants placed in bone augmented in the horizontal and vertical dimensions (medians both 100%), and implants placed in augmented sinuses, using the lateral window technique (median 95.5%) or a transalveolar approach (median 96%), are comparable to survival rates of implants placed in pristine bone. This is in accordance with a previous systematic review.[111] However, these high survival rates are almost exclusively based on observational, nonrandomized, uncontrolled studies.

Augmentation of dehiscence-type defects and fenestration-type defects resulted in 54% to 97% resolution of the former defects (mean 81.7%), and complete defect fill was reported in 68.5% of the cases. In contrast, very limited resolution of the defects could be observed when no augmentation was performed in an RCT by Dahlin and coworkers[112] (this specific RCT could not be included in the present review, since only seven patients were treated). Irrespective of the grafting protocol employed, complete defect fill could not be predictably accomplished. Augmentation of fenestration-type defects was accompanied by fewer membrane exposures and infectious complications than augmentation of dehiscence-type defects (2.5% vs 13.7%). When fenestration-type defects are augmented, the augmentation material can, most often, be placed with a safe distance to the incision line. This is not the case when dehiscence-type defects are augmented. Any minor opening in the suture line may, therefore, lead to exposure of the membrane or grafting material.

It seems to make no difference whether a resorbable or a nonresorbable membrane is used to cover the defect area.[8,13] However, the use of a membrane may increase the augmented volume as compared to when no membrane is used.[24] Comparable results were obtained with regard to implant survival and amount of defect fill when a nonresorbable membrane alone, autogenous particulate, or DBBM was used to cover dehiscence-type defects and fenestration-type defects.

In horizontal ridge augmentations, the use of nonresorbable membranes seems to provide less gain in ridge width, increased need for additional grafting procedures, and higher complication rates as compared to the use of resorbable membranes or no membrane at all. However, a confounding factor may be that nonresorbable membranes were mainly utilized to cover granular grafting materials,[7,28,29,34,37,38] and only seldom autogenous bone blocks.[25,35] Based on these findings, the most predictable horizontal ridge augmentation seems to involve an autogenous block graft alone or in combination with a particulated bone graft or bone-substitute material, with or without the concomitant use of a resorbable membrane. The included studies did not provide conclusive evidence as to whether or not barrier membranes protect autogenous bone grafts against resorption. The same conclusion was drawn by a recent review of animal and human studies.[113] There are some clinical and experimental data to support the premise that resorption of autogenous block grafts may be reduced by combining the block graft with a bone-substitute material with a low substitution rate.[39,114] However, no RCTs have tested this hypothesis.

Implants placed in vertical ridge augmentations showed very high survival rates (median 100%) after an average loading time of more than 3 years. The only RCT contributing to this high implant survival rate revealed that 32% of the implants did not meet the success criteria by Albrektsson et al[115] after 3 years of function because of crestal bone loss.[49] In addition, a loss of the augmented height of 50% after 10 to 11 years of function was observed in another long-term study, despite a 100% implant survival rate.[53] Only one study has reported positive results using a granular grafting material without any space-keeping mechanisms other than the tenting effect of the simultaneously placed implants.[44] Otherwise, whenever a granular or particulated grafting material was utilized for a vertical ridge augmentation procedure, a titanium mesh, a titanium-reinforced membrane, or miniplates were used to protect the augmented volume. The use of block grafts seemed to yield more gain in ridge height and a greater reduction in the need for additional grafting procedures than the use of granular grafts. However, in contrast to horizontal ridge augmentations, the rate of dehiscences also seemed to increase with the use of block grafts. This may be caused by the increased stretching of the covering soft tissues elicited by the larger blocks, which may compromise tension-free primary closure.

Maxillary sinus floor elevation using the lateral window technique is a predictable treatment procedure with a low complication rate of 4.7% and a median implant survival rate of 95.5%. It has been debated whether the use of a barrier membrane to cover the lateral window increases the implant survival rate. There seemed to be a tendency toward better prognosis when a membrane was used (98% vs 92.7%). If the studies using implants with machined surfaces were excluded, the survival rates with and without the use of a barrier membrane were almost identical. However, it should be noted that by eliminating smooth-surfaced implants, the cases treated with implants placed simultaneously with transplanted autogenous bone blocks from the iliac crest were also eliminated. The block grafts seem to reduce the survival rate of implants compared to particulated autografts, and hence might be an important confounding factor. Therefore, when particulated autografts or bone-substitute materials are utilized, it cannot be assumed that the use of a barrier membrane to cover the lateral window will improve the implant survival rate dramatically.

An arbitrary initial ridge height of 5 mm has often been mentioned as a threshold for the possibility of simultaneous implant placement and maxillary sinus floor elevation. However, several of the included

studies present favorable results from simultaneous procedures in initial ridges of 2 to 4 mm.[69,73,99,101] Therefore, the decision whether to use a simultaneous or a staged approach should be based on an individual evaluation of bone quantity and quality, and thus the possibility of achieving primary implant stability.

Whether autografts improve the prognosis of maxillary sinus floor elevation procedures is an ongoing discussion. A Cochrane review concluded that bone-substitute materials may replace autografts in this indication.[3] Data from the present review support this conclusion. No tendency was observed toward a lower implant survival rate in sinuses augmented with bone-substitute materials alone (96.1%) versus augmentation protocols including particulated autogenous bone (95.8%). Another matter of discussion is whether autografts accelerate the bone healing within the augmented volume. With the transplantation of autogenous bone, osteogenic cells and osteogenic growth factors are brought to the augmented site.[116] This is not the case with bone-substitute materials. It may, therefore, be anticipated that the ingrowth of newly formed bone is delayed with bone-substitute materials compared to autografts, and that implant placement (in two-stage procedures) and loading therefore will have to be postponed. In the included studies reporting on two-stage procedures, the average healing time from augmentation to implantation was 6.6 months in the bone-substitute studies and 5.6 months in the studies where autografts were included. The healing periods between implant placement and loading were almost identical (6.5 vs 6.6 months).

Several grafting protocols using autogenous bone from intraoral donor sites and/or bone-substitute materials are well documented, with low complication rates and high implant survival rates. However, data from maxillary sinus floor elevations with autogenous bone blocks from the iliac crest showed a tendency toward lower survival rates (83.5%), especially when implants were placed simultaneously (78.7%). In addition, the surgical procedure is more complicated and the morbidity is higher.

Maxillary sinus floor elevation using the transalveolar approach may be a valid and less invasive supplement to the lateral window technique. A prerequisite for using this technique is that primary implant stability can be achieved. In cases where primary stability cannot be reached, where perforations of the sinus membrane arise, or where other complications are observed, the surgeon must be able to switch to the lateral window technique in order not to be forced to abort the surgery. In principle, there is no evidence to recommend a minimum initial bone height above which a maxillary sinus floor elevation using the transalveolar approach is feasible. Winter and coworkers[104] presented a mean initial bone height of 2.9 mm. However, the mean initial bone height was 6.9 mm as opposed to 3.8 mm in the studies on the lateral window technique. At present, it is not clear whether the introduction of a grafting material improves the prognosis. Maxillary sinus floor elevation procedures using the transalveolar approach have been endoscopically controlled.[117] Perforations of the sinus membrane were observed which could not be recognized clinically, and grafting material was displaced into the sinus cavity. From a clinical point of view, it may, therefore, be advantageous to use an autogenous material to prevent foreign body–related sinus infections.

CONCLUSIONS

A large but heterogeneous body of literature was available regarding augmentation of localized bone defects in the alveolar ridges after including all levels of clinical evidence except expert opinions. Based on these data it was possible to accept the hypothesis that survival rates of implants placed in augmented bone are comparable to those of implants in pristine bone. The overall level of evidence supporting the hypothesis lies between level A and level B.

In dehiscence-type defects and fenestration-type defects, the best documented augmentation protocols are DBBM covered with a membrane, particulated autograft with or without a resorbable membrane, and a nonresorbable membrane alone.

In horizontal ridge augmentations, the best documented grafting protocol includes an intraorally harvested autogenous bone block alone or in combination with DBBM and with or without coverage of a barrier membrane.

Augmentations in the vertical dimension have mainly been performed using autogenous bone grafts, either as intraorally harvested blocks or as particulate supported by a space-keeping device.

In maxillary sinus floor elevations using the lateral window technique, the following grafting protocols may be considered well-documented: coagulum (in combination with immediate implant placements), autogenous particulate alone or in combination with DBBM or DFDBA, DBBM alone or in combination with DFDBA, and an alloplastic HA alone.

The best documented sinus grafting materials using the transalveolar approach are coagulum, particulated autograft, and DBBM.

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Bone Augmentation Procedures in Implant Dentistry

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Purpose: *This review evaluated (1) the success of different surgical techniques for the reconstruction of edentulous deficient alveolar ridges and (2) the survival/success rates of implants placed in the augmented areas.* ***Materials and Methods:*** *Clinical investigations published in English involving more than 10 consecutively treated patients and mean follow-up of at least 12 months after commencement of prosthetic loading were included. The following procedures were considered: onlay bone grafts, sinus floor elevation via a lateral approach, Le Fort I osteotomy with interpositional grafts, split ridge/ridge expansion techniques, and alveolar distraction osteogenesis. Full-text articles were identified using computerized and hand searches by key words. Success and related morbidity of augmentation procedures and survival/success rates of implants placed in the augmented sites were analyzed.* ***Results and Conclusion:*** *A wide range of surgical procedures were identified. However, it was difficult to demonstrate that one surgical procedure offered better outcomes than another. Moreover, it is not yet known if some surgical procedures, eg, reconstruction of atrophic edentulous mandibles with onlay autogenous bone grafts or maxillary sinus grafting procedures in case of limited/moderate sinus pneumatization, improve long-term implant survival. Every surgical procedure presents advantages and disadvantages. Priority should be given to those procedures which are simpler and less invasive, involve less risk of complications, and reach their goals within the shortest time frame. The main limit encountered in this literature review was the overall poor methodological quality of the published articles. Larger well-designed long-term trials are needed.* Int J Oral Maxillofac Implants 2009;24(suppl):237–259

Key words: *alveolar bone loss, alveolar ridge augmentation, atrophy, autogenous bone, graft material, oral implant*

Dental rehabilitation of partially or totally edentulous patients with oral implants has become a routine treatment modality in the last decades, with reliable long-term results.[1–12] However, unfavorable local conditions of the alveolar ridge, due to atrophy, periodontal disease, and trauma sequelae, may provide insufficient bone volume or unfavorable vertical, horizontal, and sagittal intermaxillary relationships, which may render implant placement impossible or incorrect from a functional and esthetic viewpoint.

Five main methods have been described to augment bone volume of deficient sites: *(1)* osteoinduction through the use of appropriate growth factors[13,14]; *(2)* osteoconduction, in which a grafting material serves as a scaffold for new bone formation[14,15]; *(3)* distraction osteogenesis, by which a fracture is surgically induced and the two bone fragments are then slowly pulled apart, with spontaneous bone regeneration between the two fragments[16,17]; *(4)* guided bone regeneration (GBR), which allows spaces maintained by barrier membranes to be filled with bone[18–25]; and *(5)* revascularized bone grafts, where a vital bone segment is transferred to its recipient bed with its vascular pedicle, thus permitting immediate survival of the bone and no need for a remodeling/substitution process.[26–29]

Whereas osteoinduction with growth factors such as bone morphogenetic proteins (BMPs) is still in an experimental phase and/or has extremely limited clinical applications, inlay or onlay bone grafts, GBR, split ridge/ridge expansion techniques, and alveolar distraction osteogenesis represent commonly applied

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methods to recreate correct intermaxillary relationships and adequate bone morphology and volume for implant placement. Yet, despite an increasing number of publications related to the correction of deficient edentulous ridges, much controversy still exists concerning which is the more suitable and reliable technique. This is often because the publications are of insufficient methodological quality (inadequate sample size, lack of well-defined exclusion and inclusion criteria, insufficient follow-up, lack of well-defined success criteria, etc).

The objective of this review was to analyze publications related to augmentation procedures and to evaluate *(1)* the success of different surgical techniques for the reconstruction of the deficient alveolar bone and *(2)* the survival/success rates of implants placed in the reconstructed areas.

CRITERIA FOR CONSIDERING STUDIES

Types of Studies

The basis of this review was represented by the reviews published by Hämmerle et al,[25] Esposito et al,[30] and Chiapasco et al.[31] To expand these reviews and not limit the literature search to randomized clinical trials, any clinical investigation published in the English language and involving more than 10 consecutively treated patients, with a mean follow-up of at least 12 months after the start of prosthetic loading, was included.

It is worth noting that the authors arbitrarily decided to use a minimum *mean* follow-up of 12 months (not a minimum follow-up of 12 months) as a cutoff, because many publications reported wide ranges of follow-ups. To remove these articles could have meant a loss of valuable data.

Publications in which the same data were reported in later publications by the same groups of authors were not considered.

Types of Participants

Only patients presenting with deficient edentulous ridges following atrophy, periodontal disease, and trauma sequelae were considered. Patients affected by bone defects following ablation for tumors or osteoradionecrosis, as well as bone defects related to congenital malformations (such as cleft lip and palate or major craniofacial malformations), were excluded from this analysis because the initial clinical situation is very different and not comparable.

Types of Interventions

Only articles related to endosseous root-form titanium implants were considered. The following surgical procedures were considered: onlay bone grafts, sinus floor elevation via a lateral approach, Le Fort I osteotomy with interpositional grafts, split-ridge/ridge expansion techniques, and alveolar distraction osteogenesis. Guided bone regeneration procedures and correction of dehiscences and fenestrations were excluded from this review because they are described and discussed by Jensen and Terheyden in a parallel review in this same issue. Also, pre-implant reconstructions with revascularized free flaps were excluded from this review, as no articles fulfilling our inclusion criteria were found in the literature.

Outcome Measures

Success rates of augmentation procedures, related morbidity, as well as survival and success rates of implants placed in the augmented sites were analyzed.

SEARCH METHOD

Full-text articles published in English were found with a computerized search through MEDLINE from 1975 to January 2008. Key words used in the search included: *atrophy, alveolar bone loss, mandible, maxilla, edentulous jaw, edentulous maxilla, edentulous mandible, preprosthetic surgery, oral surgical procedure, alveolar ridge augmentation, oral implant, osseointegrated implant, dental, endosteal, endosseous, dental implantation, implant-supported, dental prosthesis, implant-supported dental prosthesis, guided bone regeneration, guided tissue regeneration, bone transplantation, graft, bone graft, onlay bone graft, calvarium, iliac crest, ilium, distraction osteogenesis, expansion, Le Fort I, maxillary sinus, sinus lift, sinus floor elevation, oral sagittal osteotomy, split crest, ridge expansion, humans, follow-up study, retrospective study, prospective study, comparative study, randomized clinical trials, free flap, revascularized free flap, fibula, iliac free flap, morbidity, donor, distraction osteogenesis, alveolar distraction osteogenesis, inlay bone graft, allograft, xenografts,* and *alloplastic*.

To expand this, a hand search of journal issues from 1975 through January 2008 was undertaken on the following journals: *Clinical Oral Implants Research; The International Journal of Oral & Maxillofacial Implants; Journal of Oral and Maxillofacial Surgery; International Journal of Oral and Maxillofacial Surgery; Journal of Cranio-Maxillo-Facial Surgery; Journal of Prosthetic Dentistry; Scandinavian Journal of Plastic and Reconstructive Surgery; Dental Clinics of North America; Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology; Clinical Implant Dentistry and Related Research; British Journal of Oral and Maxillofacial Surgery; International Journal of Periodontics*

& Restorative Dentistry; Journal of Periodontology; European Journal of Prosthodontics and Restorative Dentistry; Plastic and Reconstructive Surgery; and *Journal of Oral Surgery*. Other articles were identified from the reference lists of the articles found.

Selection Criteria and Data Extraction

The titles and abstracts (when available) of all reports identified were analyzed by the authors. For studies appearing to meet the inclusion criteria, or for which there was sufficient data in the title and the abstract to make a clear decision, the full text of the article was obtained. Data retrieved were recorded on flow sheets including: year of publication; type of study; details of participants, including criteria of inclusion/exclusion; details of the type of intervention; and details of the outcomes reported.

Two independent researchers performed the search of available publications.

RESULTS

The results of the literature review (patients and methods, outcomes, and discussion) are presented separately for each of the five types of surgical interventions.

Onlay Bone Grafts

Patients and Methods. The search provided 331 studies, of which 126 were screened as full text. Of these publications, only 26 were included[12,32–56] (Table 1). Of the 26 publications included in this review, 21 were retrospective studies and 5 were prospective studies; no randomized clinical trials were found.

Overall, 893 patients, presenting with alveolar defects of the jaws that did not allow the placement of implants of adequate dimensions and/or in a correct position from a functional and esthetic viewpoint, were treated by means of autogenous bone grafts taken from intraoral or extraoral sites; 593 defects were localized in the maxilla and 179 in the mandible. Due to insufficient data, it was not possible to attribute the location of atrophy for 149 defects. The number of defects and grafts does not correspond to the number of patients because in some cases bilateral defects as well as defects involving both the mandible and the maxilla were present in the same patient.

Autogenous bone was harvested from the iliac crest in 687 patients, from the calvarium in 44 patients, and from intraoral sites (mental symphysis, mandibular body/ramus, and maxillary tuberosity) in 183 patients. The harvested bone was used as a block in the majority of cases. Particulated bone was associated with bone blocks in cases of simultaneous sinus grafting procedures or as a filling material around/between bone blocks. The bone was used alone in 862 patients, or mixed with allografts or alloplastic materials (hydroxyapatite [HA], β-tricalcium phosphate [TCP]) in 31 patients.

Of 897 defects, 593 involved extended edentulous areas (subtotal or total edentulism of one or both jaws), while 304 had limited extension (one to four missing teeth, on average). A total of 4,390 implants were placed; of these, 291 were placed in reconstructed mandibles and 2,463 in reconstructed maxillae, while for 1,636 implants it was not possible to determine the site of placement (publications reporting both mandibular and maxillary reconstructions). Of the 4,390 implants, 2,186 were placed at the same time as the reconstruction and 1,561 were inserted 3 to 8 months after the reconstructive procedure. For the remaining 643 implants it was not possible to determine the timing of insertion. Of 4,390 implants placed, 3,351 were machined-surface titanium implants and 288 were rough-surfaced implants (including different types of surfaces such as plasma-spray, acid-etched, sandblasted, and HA-coated), while for the remaining 751 implants it was not possible to retrieve pertinent data on the implant surface, either because the implant surface was not specified or because both machined-surface and rough-surfaced implants were used in the same study.

Patients were rehabilitated with both fixed and removable implant-supported prostheses. Prosthetic rehabilitation was started 2 to 26 months after implant placement, with the majority of articles reporting a 4- to 6-month waiting period. Early loading (2 months after implant placement) of implants placed in the reconstructed areas was reported in one publication.[50] Follow-up of patients after the start of prosthetic loading of implants ranged from 6 to 240 months (Table 1).

Outcomes. Postoperative morbidity related to bone harvesting from intraoral sites is mainly represented by temporary neural disturbances involving branches of the inferior alveolar nerve. As reported in the literature, the incidence of neural disturbances related to bone harvesting from the chin ranges from 10% to 50%, whereas those related to bone harvesting from the mandibular ramus range from 0% to 5%.[45,57–60] However, only one of the articles selected for this review reported data related to this aspect[45]: both ramus and chin were used for bone harvesting, and temporary neural disturbances occurred in 0% and up to 80% of the cases, respectively, whereas permanent paresthesia to anterior mandibular teeth occurred in 0% and 13% of the patients, respectively.

For this reason, chin grafts should be considered with more caution, whereas the mandibular ramus is

Table 1 Onlay Bone Grafts (Maxilla and Mandible)—Characteristics of Included Studies

Study	Study type	No. of patients	Defect type (type of atrophy)	Donor site	Graft success (%)	No. of implants (timing)	Implant surface	Follow-up (mo)	Implant survival (%)	Implant success (%)
Adell et al (1990)[32]	RS	23	Maxilla (hor-vert)	Ilium	ND	124 (imm)	Machined	12–120	73.8	ND
Jensen and Sindet-Pedersen (1991)[33]	RS	15	Maxilla (hor-vert)	Ilium/chin	ND	74 (imm)	Machined	6–26	90.2–92.3	ND
Donovan et al (1994)[34]	RS	24	Max+Mand (hor-vert)	Calvarium	100	43 (imm) 50 (del)	Machined	6–45	86–98	ND
McGrath et al (1996)[35]	RS	18	Mandible (hor-vert)	Ilium	100	36 (imm)	HA-coated	12–32	91.6	91.6
Åstrand et al (1996)[36]	RS	17	Maxilla (hor-vert)	Ilium	100	92 (imm)	Machined	36–60	75	ND
Vermeeren et al (1996)[37]	RS	31	Mandible (hor-vert)	Ilium	100	78 (imm)	Rough	12–60	90	ND
Triplett and Schow (1996)[38]	RS	99	Max+Mand (hor-vert)	Ilium/Calvarium/ Chin	90–100	65 (imm) 154 (del)	Machined	12	ND	90.7
Schliephake et al (1997)[39]	RS	137	Max+Mand (hor-vert)	Ilium/Chin	ND	550 (imm) 321 (del)	Machined	12–120	83.4 (1 y) 67.8 (5 y)	ND
van Steenberghe et al (1997)[40]	RS	13	Maxilla (hor-vert)	Ilium	92	72 (imm)	Machined	12–120	ND	85
Verhoeven et al (1997)[41]	PS	13	Mandible (hor-vert)	Ilium	92	30 (imm)	Rough	6–36	100	ND
Lundgren et al (1997)[42]	RS	10	Maxilla (hor-vert)	Ilium	ND	70 (del)	Machined	12–32	80	ND
Widmark et al (1998)[43]	PS	16	Maxilla (hor-vert)	Ilium	ND	81 (imm) 20 (del)	Machined	12	83	83
Keller et al (1999)[44]	RS	32	Maxilla (hor-vert)	Ilium/Calvarium	96	183 (imm) 21 (del)	Machined	7–144	86.3	ND
Chiapasco et al (1999)[45]	CCT	15	Max+Mand (hor)	Ilium/Calvarium/ Chin	100	44 (del)	Rough/ Machined	18–36	100	90.9
Lekholm et al (1999)[46]	RS	56	Maxilla (hor-vert)	Intraoral/Ilium	ND	181 (imm) 75 (del)	Machined	36	60–84	ND
Bahat and Fontanessi (2001)[47]	RS	62	Max+Mand	Ilium/Ramus allograft	92	21 (imm) 310 (del)	ND	12–96	93	93
Bell et al (2002)[48]	RS	14	Mandible	Ilium	100	70 (del)	Rough/ machined	24–48	100	ND
Becktor et al (2002)[49]	RS	90	Maxilla (hor-vert)	Ilium	ND	643 (imm/del)	Machined	22–105	71.6	ND
Raghoebar et al (2003)[50]	PS	10	Maxilla (hor-vert)	Ilium	100	68 (del)	Rough	12	95.6	95.6
Jemt and Lekholm (2003)[51]	PS	10	Maxilla	Chin	100	10 (del)	Machined	24	100	100
Becktor et al (2004)[12]	RS	64	Maxilla (hor-vert)	Ilium	ND	260 (imm) 177 (del)	Machined	27–100	75.1	ND
Iizuka et al (2004)[52]	RS	13	Max+Mand (hor-vert)	Calvarium	100	42 (del)	Rough	6–42	100	97.6
Nyström et al (2004)[53]	RS	30	Maxilla (hor-vert)	Ilium	ND	177 (imm)	ND	36–60	72.8–82.5	ND
van der Meij et al (2005)[54]	RS	13	Mandible	Ilium+HA	92	34 (imm)	Rough	6-90	88.2	88.2
Molly et al (2006)[55]	RS	18	Maxilla	Ilium	ND	85 (imm)	Machined	36–240	77.2–86.7	ND
Levin et al (2007)[56]	RS	50	Max+Mand	Intraoral	ND	129 (del)	ND	6–67	96.9	91.9

RS = retrospective study; PS = prospective study; CCT = controlled clinical trial; max = maxilla; mand = mandible; hor = horizontal defect; vert = vertical defect; TCP = tricalcium phosphate; FDBA = freeze-dried bone allograft; HA = hydroxyapatite; graft success = success rate of the grafting procedure; imm = immediate placement; del = delayed placement; ND= no data.

gaining in popularity due to its advantages as compared to the mental symphysis: the quality of bone is similar (relevant cortical component), the quantity may be greater, and the risk of neural damage is lower.

In cases of bone harvesting from the iliac crest, temporary pain/gait disturbances were the most frequent complaints, but only 9 out of 22 articles reported data on this topic. Long-standing pain/gait disturbances were reported only in 2% of the cases.[33,37,40,42,45,48,61]

In cases of bone harvesting from the calvarium, morbidity was extremely low (0% in the reviewed articles), but only 3 out of 5 articles dealing with calvarial grafts reported pertinent data.[34,45,52]

Uneventful healing/consolidation of both intraoral and extraoral grafts occurred in the majority of patients. Partial loss of the graft due to wound dehiscence/infection occurred in 3.3% of the cases, while total loss of the graft occurred in 1.4% of the cases,[38,40] the majority being related to extensive reconstructions of atrophic maxillae with iliac grafts. However, it is worth noting that only 16 out of 26 articles reported data on this topic. Overall, the survival rate of implants placed in reconstructed maxillae and mandibles was 87% (range 60% to 100%; median 91.5%).

To obtain more information, the survival rates of implants were analyzed according to site of atrophy (maxilla or mandible), type of implant surface, timing of implant placement (in conjunction with the reconstructive procedure or after the consolidation of the graft), and type of graft (intraoral, calvarial, iliac). However, this analysis was limited by the fact that publications did not always separate data concerning these issues.

The overall survival rate of implants placed in reconstructed maxillae (both with one-stage and two-stage placement) after follow-up periods ranging from 6 to 240 months was 79.5% (range 60% to 100%; median 82.7%; mean 81.6% (496 implants were removed out of 2,413 placed).

The mean survival rate of implants placed in conjunction with maxillary reconstructions was 81.8% (range 72.8% to 92.3%). However, it was possible to retrieve pertinent data only from 5 out of 16 articles.[33,36,40,53,55]

The mean survival rate of implants placed in reconstructed maxillae with a staged approach was 89.9% (range 80% to 100%). However, it was possible to retrieve pertinent data only from 3 out of 15 articles.[42,50,51]

Although a higher failure rate was found in patients receiving implants in conjunction with bone grafts, it is difficult to report significant data because 16 out of 21 articles dealing with maxillary reconstructions did not separate maxillary from mandibular implants and/or immediate and delayed implant placement.

The overall survival rate of implants placed in reconstructed mandibles (both with one-stage and two-stage placement) was 94.8% (range 88.2% to 100%; median 91.5%; mean 94%) for a follow-up period of 6 to 90 months (see Table 1 for details).

Implant survival rate was 91.1% (range 88.2% to 100%) for implants placed in conjunction with mandibular reconstruction and 100% for those placed in a staged approach. All implant losses occurred in patients receiving implants at the same time as reconstruction (see Table 1 for details).

With regard to the survival rate of implants according to type of implant surface, it was observed that machined-surface implants showed on average a lower survival rate (range 60% to 100%; median 83%; mean 81.6%) than rough-surfaced implants (range 90% to 100%; median 93.5%; mean 94.2%). However, it must be emphasized that sample sizes were very different (3,351 machined-surface implants and 288 rough-surfaced implants), and no statistically significant comparisons can be made (see Table 1).

As far as the relationship between survival rate and donor site is concerned, the retrieved data demonstrated that the majority of implant failures occurred in patients reconstructed with iliac grafts (failure rate 17.5%). The failure rate for implants placed in calvarial grafts was 6% and that for implants placed in intraoral grafts was 5.5% (see Table 1). However, these percentages should be evaluated with caution because some publications in which different donor sites were used did not separate implant failures according to donor site distribution.

Data were even more insufficient in terms of success rates of implants according to well-defined criteria: only 13 of 26 publications specified the criteria for implant success evaluation (see Table 1). The success rate ranged from 83% to 100% (median 89%), with the majority of articles reporting success rates > 90%, but it is worth noting that the number of implants reported in the above-mentioned publications represented only one-fourth of the total number of implants placed in the grafted jaws (see Table 1).

Discussion. The analysis of available publications demonstrated, on average, poor methodological quality with regard to resorption pattern of the grafted bone, timing of implant placement, evaluation of success of implants according to well-defined criteria, success rate of implants according to type of graft and implant location, and duration of follow-up. A far as this latter aspect is concerned, we had to make some compromises in including articles, because some of them had an extremely wide range of follow-up periods. Some articles with follow-up of

more than 10 years also included patients with a follow-up of 6 months. As one of our initial requirements was a minimum follow-up of 1 year for the inclusion of patients, we had to modify this to require a minimum *mean* follow-up of 1 year to avoid the loss of a relevant amount of data.

Moreover, of 26 publications included in this review, 21 were retrospective clinical series and 5 were prospective studies; no randomized clinical trials were found. However, within the limits determined by the lack of data from randomized clinical trials, some conclusions can be drawn on the following topics.

Bone Resorption Pattern of the Grafted Bone. In the past, before the advent of osseointegrated implants, the reconstruction of atrophic edentulous ridges with onlay bone grafts was criticized because of the relevant resorption that followed prosthetic loading.[62] However, these results were mainly due to the use of completely removable dentures, which adversely affected not only the grafted jaws, but also the non-grafted edentulous ridges.[63] The use of onlay grafts has been reevaluated since the advent of osseointegrated screw-type implants, which seem to inhibit resorption of the residual as well as of the transplanted bone, as demonstrated by a number of publications.[12,34,39,40,42,45,46,49,51,53] However, the capacity of bone grafts in maintaining the original bone volume is variable, and results reported in the literature are contradictory, due to relevant differences in observation periods, type and site of reconstruction, timing of implant loading, use or non-use of provisional dentures on reconstructed sites, and, last but not least, the site of bone harvesting. Overall, there is a paucity of information as far as bone resorption of grafts is concerned. This is because many papers report only survival rates of implants placed in grafts, with no measurement of modifications of graft dimensions, in particular concerning horizontal bone resorption.

With regard to vertical bone resorption of onlay grafts, the following conclusions can be drawn, despite the limits caused by the paucity of available data:

- Bone resorption is greater in the first year after the reconstruction and in the first year after loading of implants, with a significant reduction in the following years.[64]
- Relevant differences in bone resorption were found according to donor sites. In the case of iliac grafts, resorption rates of the initial graft height 1 to 5 years postloading of implants ranged from 12% to 60%.[36,37,39,41–43,46,53,54] In the case of intraoral grafts, there are insufficient data to draw any meaningful conclusion. The best results were found for vertical reconstruction with calvarial grafts, where resorption rates ranged from 0% to 15% of the initial graft height.[34,52] This seems to indicate that cortical thickness and density of donor bone are factors which might influence the resorption pattern.
- Oversized grafts should be harvested to maintain enough graft volume after the initial resorption phase.
- If autogenous bone grafts are used, it is highly recommended to use corticocancellous bone blocks. Cancellous bone alone and particulated bone, if not associated with membranes of titanium meshes, do not provide sufficient rigidity to withstand tension from the overlying soft tissues or from the compression by provisional removable dentures, and may undergo almost complete resorption.[65,66]

Even fewer data are available regarding resorption of horizontal bone grafts, due to the greater difficulty in measuring this parameter (need for computed tomography or calipers instead of simpler methods such as intraoral radiographs). Only two articles reported data on horizontal bone resorption of the graft, which ranged from 10% to 50%.[45,51]

This review seems to demonstrate that, despite the limits mentioned above, reconstruction of atrophic edentulous or partially edentulous jaws with autogenous bone grafts is an acceptable modality in restoring dentition with implant-supported prostheses. However, the pros and cons of bone transplantation must be carefully weighed in terms of economic and biologic costs (morbidity). In particular, the size and the site (maxilla or mandible) of the defect must be carefully evaluated.

In cases of moderate/severe atrophy in partially edentulous patients, other surgical options, such as distraction osteogenesis, guided bone regeneration, and sagittal osteotomies, which may present less morbidity, should be considered. Moreover, it is necessary to consider the area where atrophy has occurred. In recent years, an increasing number of articles related to the use of short implants with apparently acceptable survival rates after the start of prosthetic loading have been published.[67–74] In particular, the atrophic posterior areas, where esthetic problems are frequently not as relevant (with the exception of patients with a gummy smile), may be treated with short implants without any previous reconstruction, taking into account, however, that longer superstructures may represent a prosthetic and functional compromise. On the contrary, the atrophic maxilla does not appear to be "the right candidate" for the use of short implants, as long teeth may represent an unacceptable solution for the

majority of patients. Therefore, patients' expectations should be carefully evaluated preoperatively before a decision is made.

In severely atrophied edentulous maxillae, relevant resorption of the alveolar process and the presence of nasal and paranasal cavities (maxillary sinuses) leads to a clinical situation that is not compatible with implant placement, because of insufficient quantity and low quality of the residual bone. In these cases, onlay grafts (with or without associated sinus grafts—see next sections for more details) are one of the few options that permit the re-creation of a more favorable environment for implant placement. Other surgical options, such as Le Fort I osteotomy with interpositional bone grafts and microvascular free flaps, are accompanied by even more morbidity, and should be limited to extreme atrophy or severe intermaxillary discrepancy not amenable to treatment with onlay grafts (see next sections for further details).

Conversely, the edentulous mandible, although severely atrophied, may present local conditions that are compatible with safe implant placement also without complex, technically and biologically demanding procedures. It has been demonstrated that, also in the case of severe atrophy, the dense, highly corticalized bone of the mandibular symphysis is able to support the functional demands of removable or fixed implant-supported prostheses also when short implants (less than 10 mm) are used.[75,76] According to the protocol proposed by Keller,[75] short implants can be placed in severely atrophic mandibles without reconstruction when the anterior mandible (interforaminal area) is more than 5 mm in height and at least 6 mm in width. Fifty-seven patients presenting with such conditions received 260 implants loaded with removable or fixed implant-supported prostheses. The survival rate of implants was 93.1%, after a mean follow-up of 59 months, with no significant differences compared to the survival rate of implants placed in atrophic nonreconstructed mandibles. Therefore, reconstruction of the atrophic mandible should be limited to cases where the mandibular bone height and width are less than 5 mm and 6 mm, respectively. In this situation the residual available bone is insufficient for harboring implants of adequate dimensions, and there is a risk of "fatigue" fractures of the mandible. However, if reconstruction of the mandible is the chosen option, calvarial grafts should be preferred to iliac grafts, due to the very limited resorption.[34,52,77] It has been shown that iliac onlay grafts for the reconstruction of edentulous mandibles are exposed to relevant resorption (up to 50%),[37,41] and therefore their use is now questionable.

Timing of Implant Placement. Implant placement both in conjunction with bone grafting and after consolidation of bone grafts have been proposed. Those who advocate simultaneous implant placement[33,36,37,40,41,44,46,53–55,61,78] base their opinion on the fact that resorption of an onlay graft over time is not a linear process but is most pronounced soon after its transplantation.[41,64] Simultaneous implant placement will shorten the waiting time before rehabilitation, thus potentially reducing the risk of bone resorption.

Those who advocate delayed placement[38,42,45,47,48,50–52,56,77] think that simultaneous placement of implants may expose the patient to some risks, which can be summarized as follows: In the case of wound dehiscence, exposure and infection/necrosis of the bone graft may occur and lead to partial or total loss of the graft; immediate implants are placed into avascular bone, which increases the risk of nonintegration.

Conversely, when a delayed protocol is performed, it will be possible to place implants in a revascularized (albeit partly) graft. Since the regenerative capacity of bone is determined by the presence of vessels, bone marrow, and vital bone surfaces, a delayed approach will permit better integration of implants (higher values of bone-implant contact) and better stability of implants, as compared to immediate implant placement.[42,79–81]

Despite these considerations, however, much controversy still exists in terms of timing of implant placement in grafted areas, and no conclusions can be drawn.

Loading Time of Implants Placed in Grafted Areas. Initial reports recommended longer waiting times (6 to 12 months) between implant placement and subsequent abutment connection and prosthetic loading. The rationale was to allow some extra time for graft incorporation, but not too long, taking advantage of the theoretical ability of implants to provide a bone-preserving stimulus in the same way that the presence of healthy teeth preserves the alveolar bone.[61] However, although no conclusive recommendations can be made due to the wide range of waiting times proposed and to the different characteristics of macro-, micro-, and nanogeometry of different implant systems (which may influence osseointegration times), the majority of authors cited in this review suggested waiting times similar to those proposed for implants placed in nonreconstructed bone (3 to 6 months), with no detrimental effects on osseointegration.

It has also been demonstrated by means of resonance frequency measurements that implants placed in grafted bone can achieve stability similar to that of implants placed in native bone only 24 weeks after

their placement.[82] Therefore, longer waiting periods appear to be questionable.

Although limited, there is also evidence that early or immediate loading of implants placed in reconstructed areas may lead to successful integration. Raghoebar et al[50] reported data on early loading (2 months after implant placement) of implants placed in edentulous maxillae augmented with onlay iliac grafts. Of 68 implants placed in 10 patients, 65 survived (95.6%) after 1 year of functional loading. Chiapasco et al[77] reported data on immediate loading (within 48 hours after implant placement) of implants placed in reconstructed edentulous mandibles with calvarial onlay grafts. Of 23 implants placed in six patients, 23 survived (100%) after a follow-up of 12 to 36 months postloading.

Survival and Success Rates of Implants. Survival and success rates of implants placed in reconstructed jaws are, on average, lower than those of implants placed in native bone, in particular in cases where extensive reconstructions were performed. However, it is worth noting that only a few publications reported data based on well-defined criteria. In particular, only two studies[39,49] applied thorough statistical methods for the evaluation of clinical outcomes, with the objective to correlate implant survival/success with factors such as type and dimension of implants, type of opposing arch dentition, type of augmentation technique, patients' gender, and site of reconstruction. The conclusions were as follows:

- The cumulative survival rate of implants demonstrated a progressive decline from 1 to 5 years following the start of prosthetic loading.
- Implants placed in edentulous reconstructed maxillae were associated with survival rates lower than implants placed in reconstructed mandibles. Conversely, the difference between partially edentulous maxillae and mandibles was not statistically significant.
- Onlay grafts from the iliac crest were associated with survival rates lower than grafts harvested from the mandible.
- The time at which implants were inserted into the bone grafts showed no significant effect on the survival rate.
- Implant survival rate tended to improve with increasing implant length.
- The patients' age had no significant impact on implant survival.
- A higher failure rate was found in female patients.
- Many implant failures in the maxilla occurred in only a few patients.
- Implants opposing unilateral occlusal support showed the highest rate of implant failure.
- Implants that opposed a mandibular implant-supported fixed prosthesis or a removable mandibular denture presented the lowest failure rate.

Sinus Floor Elevation

Patients and Methods. The search provided 1,039 studies related to sinus floor elevation via a lateral approach, of which 501 were screened as full-text articles. Of these publications, only 59 were included in the review.[38,44,46,83–138] Some studies, although fulfilling the inclusion criteria, were not considered because the same data were reported in later publications by the same group of authors. Also, as previously stated, transalveolar sinus floor elevation was not considered, as it is analyzed in a parallel review by Jensen and Terheyden in this supplement. Two of the selected studies reported data related to both transalveolar and lateral approaches[95,130]; only the cases related to the lateral approach were considered for this review.

Of the 59 selected studies, 41 were retrospective studies, 12 were prospective studies, 4 were controlled clinical trials, and only 2 were randomized clinical trials. Overall, 4,630 patients were treated by means of 5,573 maxillary sinus augmentation procedures. However, some articles reported only the number of patients without specifying the number of sinus grafting procedures.[46,88,95,107,132,136] A total of 13,889 implants were placed; of these, 5,632 were placed at the same time as the augmentation procedure and 5,271 at a second stage, while for 2,986 implants the timing of implant placement was not specified. Of 13,889 implants placed, 2,431 were machined-surface titanium implants, 6,249 were rough-surfaced implants (including various implant surfaces such as plasma-sprayed, sandblasted, acid-etched, and HA-coated), while for the remaining 5,209 implants it was not possible to retrieve pertinent data on implant surface, either because the implant surface was not specified or because both machined and rough-surfaced implants were used in the same publication.

In 23 out of 59 studies, one grafting material (autogenous bone, bovine bone mineral, calcium sulfate, hydroxyapatite, or allograft) was used alone. In the remaining studies, mixtures of different grafting materials were used, such as autogenous bone + bovine bone mineral (BBM), autogenous bone + HA or TCP, autogenous bone + allograft, HA + allograft, BBM + allograft, autogenous bone + platelet-rich plasma (PRP), allograft + PRP, and BBM + PRP. Only one article reported data on sinus floor elevation without the use of grafting materials[136]; in that study, the mucosa was maintained elevated by implants placed in conjunction with sinus surgery.

Patients were rehabilitated with both fixed and removable implant-supported prostheses. Prosthetic rehabilitation was started 2 to 52 weeks after implant placement (on average 24 weeks after). The follow-up period after the start of prosthetic loading ranged from 6 to 144 months (Table 2).

Outcomes. Data related to intraoperative and postoperative complications were reported in 40 of 59 articles. Uneventful healing of the augmentation procedure occurred in the great majority of the patients. The most frequent intraoperative complication was sinus membrane perforation, which occurred in approximately 10% of the cases (range 4.8% to 58%). In the vast majority of patients, sinus grafting was completed either by closing the perforation with resorbable materials, such as collagen sponge, resorbable membranes, or allograft sheets, or simply by increasing sinus floor mucosa elevation, with no further complications. Only in a very limited number of patients (less than 1%) did the grafting procedure have to be stopped, due to large tears in the membrane.

Postoperative complications occurred in approximately 3% of the patients. The most frequent was infection and/or postoperative maxillary sinusitis. Partial or total graft loss occurred in less than 1% of the patients, whereas the incidence of sinusitis ranged from 0% to 27% (average 2.5%). However, these data were reported in only 40 out of 58 articles, and therefore they must be interpreted with caution.

Overall, 778 out of 13,889 implants were removed. Survival rates of implants ranged from 60% to 100% in the selected studies (median 95%), with the majority of articles reporting values higher than 90%. Success rates of implants according to well-defined criteria ranged from 74.7% to 100% (median 98.5%) (Table 2). However, only 22 out of 59 articles reported data according to well-defined criteria. Therefore, these data should be interpreted with caution.

To obtain more information, the survival rates of implants according to type of graft (autografts, allografts, xenografts, alloplastic materials, or mixtures of those materials), timing of implant placement (in conjunction with the reconstructive procedure or after the consolidation of the graft), type of implant surface, and the quantity and quality of residual bone before grafting procedures should be analyzed. However, meaningful comparisons were rarely possible because the number of patients treated with different materials differed greatly; many publications in which different combinations of grafting materials were used reported data without separating them according to grafting material; and the quantity and quality of residual bone in the posterior maxilla were not always reported, although these parameters may greatly influence the final outcome of implants.

Survival Rates of Implants According to Grafting Material. The use of different filling materials apparently did not significantly influence survival rates of implants (see Table 2). However, comparisons are difficult, due to relevant differences in patients' samples, number of implants placed, and the type of implant surface. Moreover, it was frequently difficult or impossible to retrieve pertinent data related to survival of implants because in many articles different materials or different mixtures were used without separating results.

Only four studies prospectively compared the clinical outcome of implants according to different grafting materials: *(1)* Fugazzotto and Vlassis[96] (Bio-Oss versus allografts and TCP); *(2)* Hallman et al[114] (autogenous bone versus Bio-Oss and a mixture of autogenous and BBM); *(3)* Velich et al[128] (autogenous bone versus calcium carbonate, autogenous bone + HA, autogenous bone + TCP, HA alone, TCP alone, TCP + PRP); and *(4)* Valentini and Abensur[118] (allograft + BBM versus BBM alone). No relevant differences were found, but again, comparison of survival rates is difficult because both immediate and delayed implant placement were performed, thus introducing a bias that may influence the results.

Survival Rate of Implants According to Timing of Implant Placement. As far as the timing of implant placement is concerned, the survival rate of implants placed in conjunction with the grafting procedure ranged from 61.2% to 100% (mean 95%; median 100%), and from 72.7% to 100% (mean 93.7%; median 94%) in the case of a staged approach. However, many articles reporting on both immediate and delayed implant placement did not separate implant failures according to timing of implant placement. It was therefore difficult to obtain reliable information concerning this topic. A staged approach was generally suggested when the residual bone height might be insufficient to guarantee primary stability of implants (on average, when the residual bone height of the alveolar crest was less than 4 mm), while an immediate approach was suggested when enough bone volume was present to allow adequate primary stability of implants (> 5 mm). Only one article[93] reported a successful outcome of implants placed in conjunction with the grafting procedure with a very limited residual bone height (1 to 2 mm). Therefore, no clear indications concerning the timing of implant placement were found in the literature.

A single randomized trial[108] compared 20 patients treated with sinus grafting by means of iliac bone blocks and immediate implant placement with 20 patients treated with particulated iliac bone and

Table 2 Sinus Lifting Procedure (Lateral Approach)—Characteristics of Included Studies

Study	Study type	No. of patients	No. of SFE	Grafting material	No. of implants (timing)	Implant surface	Follow-up (mo)	Implant survival (%)	Implant success (%)
Kent and Block (1989)[83]	RS	11	18	AB	54 (imm)	HA-coated	12–48	100	ND
Tidwell et al (1992)[84]	RS	48	83	AB+HA	203 (del)	HA-coated	12–32	93.6	ND
Raghoebar et al (1993)[85]	RS	25	47	AB	93 (ns)	machined	6–36	94.6	ND
Block and Kent (1993)[86]	RS	32	51	AB/AB+AG/AG	173 (ns)	ND	24–120	75	ND
Chiapasco and Ronchi (1994)[87]	RS	30	43	AB+BBM	41 (imm) 83 (del)	Rough	12–24	93.5	93.5
Hürzeler et al (1996)[88]	RS	133	ND	Various	235 (imm) 105 (del)	Rough	12–60	98.8	90.3
Triplett and Schow (1996)[38]	RS	70	70	AB	69 (imm) 76 (del)	machined	>12	82.6–90.8	ND
Wheeler et al (1996)[89]	RS	24	36	HA/BBM/AB/ AB+HA	66 (ns)	Rough/ machined	6–66	92.4	92.4
Raghoebar et al (1997)[90]	RS	43	81	AB	171 (ns)	Machined	8–62	94.7	ND
Block and Kent (1997)[91]	RS	33	53	AB/AG	173 (ns)	ND	36–134	88.4	ND
Watzek et al (1998)[92]	RS	20	40	BBM/AB+BBM/ AB+HA/AB	145 (del)	Rough	12–70	95.2	74.7
Peleg et al (1998)[93]	PS	20	20	AG+AB	55 (imm)	HA-coated	15–39	100	100
van den Bergh et al (1998)[94]	RS	42	62	AB	161 (del)	Rough	12–72	100	ND
Zitzmann and Schärer (1998)[95]	RS	10	ND	BBM	7 (imm) 13 (del)	Machined	6–24	100	ND
Fugazzotto and Vlassis (1998)[96]	RS	181	194	BBM/AG/TCP	181 (imm) 252 (del)	Rough	6–73	97	97
Blomqvist et al (1998)[97]	PS	50	97	AB	202 (del)	Machined	9–48	84.2	ND
Block et al (1998)[98]	RS	16	27	AB/AB+AG	73 (imm)	HA-coated	63–126	95.9	ND
Peleg et al (1999)[99]	PS	21	24	AG+AB	57 (imm)	HA-coated	36	100	ND
Mazor et al (1999)[100]	PS	10	10	AG+AB	10 (imm)	HA-coated	36	100	100
Peleg et al (1999)[101]	RS	63	63	AG+AB	160 (imm)	HA-coated	24–48	100	ND
Keller et al (1999)[44]	RS	37	58	AB	127 (imm) 12 (del)	Machined	12–144	85.6	ND
Khoury (1999)[102]	RS	216	216	AB/AB+HA	467 (imm)	Rough/ Machined	24–72	94	94
Lekholm et al (1999)[46]	RS	68	ND	AB	330 (ns)	Machined	36	77.9	ND
De Leonardis and Pecora (1999)[103]	CCT	57	65	CS	56 (imm) 74 (del)	Rough/ HA-coated	12	98.5	ND
Olson et al (2000)[104]	RCT	29	45	AG+AB/AB/ HA+AG/HA/AG	120 (ns)	HA-coated/ND	6–71	97.5	ND
Mazor et al (2000)[105]	PS	10	10	HA	26 (imm)	HA-coated	12–24	100	ND
Valentini et al (2000)[106]	PS	15	20	BBM	57 (del)	Rough	36–60	98.2	98.2
Lorenzoni et al (2000)[107]	RS	67	ND	AB/BBM	73 (imm) 25 (del), 78 (ns)	Rough	6–60	95	94
Wannfors et al (2000)[108]	RCT	40	80	AB	76 (imm) 74 (del)	Machined	12	84	ND
Kassolis et al (2000)[109]	PS	14	14	AG+PRP	36 (del)	Machined	12	88.9	ND
Raghoebar et al (2001)[110]	RS	99	182	AB	86 (imm) 306 (del)	Machined	12–124	91.8	90.8
Kahnberg et al (2001)[111]	PS	26	39	AB	91 (imm)	Machined	12–72	61.2	ND
Tawil and Mawla (2001)[112]	CCT	29	30	BBM	41 (imm) 20 (del)	Machined	12–40	85.2	ND
Hallman et al (2002)[113]	PS	20	30	BBM+AB	79 (del)	Rough	18	92.4	ND
Hallman et al (2002)[114]	CCT	21	36	BBM/BBM+ AB/AB	111 (del)	Rough	12	91	ND
Engelke et al (2003)[115]	RS	83	118	TCP+AB	175 (imm) 36 (del)	Rough	6–60	94.8	ND
Stricker et al (2003)[116]	RS	41	66	AB	48 (imm) 135 (del)	Rough	15–40	99.5	97.8
Rodriguez et al (2003)[117]	PS	15	24	BBM+PRP	70 (imm)	ND	6–36	92.9	ND
Valentini and Abensur (2003)[118]	RS	59	78	BBM/BBM+AG	55 (imm) 128 (del)	Rough/ Machined	38–113	94.5	ND
McCarthy et al (2003)[119]	RS	19	27	AB+BBM/ AB+PRP/AB	27 (imm) 49 (del)	Machined	19–72	78.9	ND
Philippart et al (2003) [120]	RS	18	25	AB+PRP	58 (del)	Rough	12–48	91.4	ND
Pinholt (2003)[121]	RS	22	39	AB	104 (del)	Rough/ND	20–67	86.5	ND
Hatano et al (2004)[122]	RS	191	361	BBM+AB	361 (imm)	Machined	6–108	94.2	ND
Hallman and Nordin (2004)[123]	RS	50	71	BBM	196 (del)	Rough	6–42	96	96
Hallman and Zetterqvist (2004)[124]	PS	20	30	AB+BBM	79 (del)	Machined	36	88.6	88.6
Shlomi et al (2004)[125]	RS	63	73	AB+BBM/AB	253 (ns)	HA-coated	24	90.9	ND
Simion et al (2004)[126]	RS	14	16	AB+BBM/AB	16 (imm) 22 (del)	Machined	12–84	92.1	76.3

Table 2 continued Sinus Lifting Procedure (Lateral Approach)—Characteristics of Included Studies

Study	Study type	No. of patients	No. of SFE	Grafting material	No. of implants (timing)	Implant surface	Follow-up (mo)	Implant survival (%)	Implant success (%)
Iturriaga and Ruiz (2004)[127]	RS	58	79	AB	223 (del)	Rough/ Machined/ HA-coated	24–96	100	ND
Velich et al (2004)[128]	RS	624	810	AB+AG/AB	1482 (ns)	Rough/ Machined	60	94.5	ND
Zijderveld et al (2005)[129]	CCT	10	16	AB/TCP	67 (del)	Rough	6–19	100	ND
Rodoni et al (2005)[130]	PS	13	13	BBM	47 (ns)	Machined	37–62	100	100
Butz and Huys (2005)[131]	RS	20	22	AP+AB	48 (imm) 8 (del)	Rough	84	100	100
Wiltfang et al (2005)[132]	RS	61	ND	AB	349 (del)	Rough	54	94.6	ND
Peleg et al (2006)[133]	RS	731	731	AB/DFDBA/ BBM/BBM+AB/ TCP	2132 (imm)	Rough	108	97.9	ND
Galindo-Moreno et al (2007)[134]	RS	70	98	BBM+AB+PRP	48 (imm) 215 (del)	Rough	24	99.0	99.0
Krennmair et al (2007)[135]	RS	37	37	BBM+AB	28 (imm) 12 (del)	Rough	24–66	100	ND
Chen et al (2007)[136]	RS	33	ND	None	47 (imm)	Rough	24	100	ND
Chiapasco et al (2008)[137]	RS	692	952	AB	443 (imm) 1594 (del)	Rough/ Machined	12–144	90–97.6	85.4–95.5
Bornstein et al (2008)[138]	PS	56	59	AB+BBM/ AB+TCP	111 (del)	Rough/ND	60	98	98

RS = retrospective study; PS = prospective study; CCT = controlled clinical trial; RCT = randomized controlled trial; SFE = sinus floor elevation procedures; AB = autogenous bone; AG = allograft; AP = alloplastic material; BBM = bovine bone mineral; PRP = platelet-rich plasma; TCP = tricalcium phosphate; CS = calcium sulfate; HA = hydroxyapatite; DFDBA = demineralized freeze-dried bone allograft; imm = immediate placement; del = delayed placement; ns = implant placement timing not specified; ND = no data.

delayed implants. The authors concluded that there were no significant differences in the survival rates of implants.

Survival Rates of Implants According to Type of Implant Surface. With regard to the survival rates of implants according to type of implant surface, machined-surface implants showed on average lower survival rates (range 61.2% to 100%; mean 88.7%; median 87.5%; 2,431 implants placed, 292 removed) as compared to rough-surfaced implants (range 90.9% to 100%; mean 97.1%; median 98%; 6,249 implants placed, 197 removed). These figures suggest that the roughness of the implant surface may be an important factor in the process of osseointegration of implants placed in grafted sinuses (either with autogenous bone or alloplastic materials) and in the maintenance of crestal bone levels around implants.

Survival Rates of Implants According to Quantity and Quality of Residual Bone. The quantity and quality of residual bone in the posterior maxilla may influence survival rates of implants, independently from the type of grafting procedure. Yet only 43 out of 59 articles reported data on initial residual bone height, and only one article[137] also reported data on residual bone width. It is therefore difficult to know which might be the influence on implant survival—residual bone volume or grafting material. Another parameter that might influence the outcome of implants is the quality of residual bone, but only 6 out of 59 articles reported data on bone quality according to well-defined criteria.[46,95,110,112,117,121]

Discussion. The analysis of the literature seems to demonstrate that maxillary sinus grafting is a reliable surgical technique which permits implants to be placed in the atrophic posterior maxilla with an excellent long-term prognosis. Similar results have been obtained with different grafting materials, such as autogenous bone, allografts, xenografts, alloplastic materials, and mixtures of these materials.

Survival rates of implants placed in grafted sinuses are consistent with those of implants placed in nongrafted edentulous maxillae,[1–10] in particular when rough-surfaced implants are used. However, these results should be interpreted with caution, because the analysis of available publications demonstrated, on average, a poor methodological quality with regard to type of study (the majority were retrospective clinical series), description of the initial clinical situation (quality and quantity of posterior maxilla residual bone), success rate of implants according to well-defined criteria, and duration of follow-up. Moreover, it was frequently difficult or impossible to retrieve pertinent data related to survival of implants because in many articles different materials or different mixtures were used without separating results. All these factors may introduce relevant bias and make statistically significant comparisons difficult. In particular, precise data concerning the initial clinical

situation in the edentulous posterior maxilla (ie, residual bone volume and interarch relationship) should always be reported in publications. This aspect is deemed to be important by the authors of the current review, because different amounts of residual bone prior to sinus grafting procedures may influence the final outcome of implants placed in the grafted areas. In particular, if the residual volume of the posterior maxilla is not described in terms of volume, it is difficult to evaluate if the survival rate of implants placed in the grafted area is related to the support offered by the grafted material or to the residual bone.

It is also worth noting that atrophy of the edentulous maxilla develops tridimensionally, and is not only dependent on sinus pneumatization. Therefore, insufficient bone height may also be related to vertical resorption of the alveolar ridge or a combination of vertical resorption and sinus pneumatization. In the first situation, a sinus grafting procedure may be indicated, whereas in the second (vertical atrophy) it may happen that the sinus does not need to be grafted. Instead, a vertical reconstruction to recreate an adequate interarch distance may be the treatment of choice. Moreover, bone resorption of the edentulous ridge may lead to a horizontal discrepancy between the maxilla and the mandible. If the sinus grafting procedure is the only one performed, it may happen that implants will be placed in a palatal position, with a less-than-ideal prosthetic rehabilitation from an esthetic and functional viewpoint.

Therefore, the atrophic posterior maxilla should be evaluated and classified not only in terms of residual bone height and width, but also vertical and horizontal intermaxillary relationships. Consequently, sinus grafting may represent only a part of the reconstructive procedure necessary to reestablish adequate bone volumes and intermaxillary relationships, to optimize implant placement and the final prosthetic results from a functional and esthetic point of view.

Classifications that consider these parameters should be used when reporting data in order to obtain more homogeneous samples of patients, thus simplifying comparisons of clinical outcomes involving different procedures and/or different grafting materials, such as the classifications proposed by Chiapasco et al[137] and Misch et al.[139] As already stated, only 1 article[137] out of 59 correlated survival and success rates of implants placed in grafted sinuses to the initial clinical situation (ie, residual bone height and width of the posterior maxillary ridge, intermaxillary relationships, distance between the maxillary ridge and opposing dentition, etc).

However, within the limits determined by the lack of some data, some conclusions can be drawn on the following topics.

Safety of Sinus Grafting Procedures. Grafting of maxillary sinuses is accompanied by a very low complication rate. It has been demonstrated that the volume reduction of the maxillary sinus following sinus elevation does not interfere with sinus functions.[140] Intraoperative complications, which are mainly represented by sinus mucosa perforations, are well tolerated and followed by normal recovery in the vast majority of cases. The sinus mucosa will usually regenerate over the bone graft postoperatively. The majority of authors suggest treating perforations either by simply folding the sinus mucosa after a more extended elevation, or with resorbable barriers, such as collagen, fibrin adhesive, or resorbable membranes.[94,100,102,110,112,115,116,118,123,125,129]

Complications such as sinusitis tend to occur in previously unhealthy sinuses.[140] Therefore, a thorough preoperative screening of maxillary sinus status is mandatory (ie, CT scans).

Choice of Grafting Material. Nonautogenous grafting materials appear to be reliable for sinus floor elevation, with no significant differences in clinical outcomes and implant survival. Autogenous bone presents similar results, but it has both advantages and disadvantages, which can be summarized as follows:

- Autogenous bone must be harvested from intraoral or extraoral sites, with higher morbidity as compared to nonautogenous materials (ie, risk of neural disturbances in case of intraoral grafts due to possible lesions of the inferior alveolar nerve branches, and gait disturbances in case of harvesting from the iliac crest).
- When a delayed implant placement is indicated, maxillary sinuses grafted with autogenous bone may receive implants earlier than sinuses grafted with nonautogenous bone substitutes, as demonstrated by the systematic review by Pjetursson et al.[141]
- Autogenous bone is the material of choice when sinus grafting procedures must be associated with onlay grafting of the maxilla in the case of severe atrophy.[40,42,44,46,53,137,142] Conversely, there is a lack of information regarding such reconstructions with nonautogenous materials.

Resorption of Grafts Over Time. It has been demonstrated that grafted sinuses may undergo re-expansion over time, in particular in the first 2 to 3 years after the grafting procedure.[122] The use of nonresorbable or slowly resorbable grafting materials should prevent this phenomenon. If particulated autogenous bone is used, a mixture with xenografts or alloplastic materials, such as BBM or HA, should reduce the risk of bone resorption and sinus repneumatization.[84,87,113,114,122–124]

Table 3 Sagittal Osteotomy—Characteristics of Included Studies

Study	Study type	No. of patients	Defect site	Grafting material	Surgical success (%)	No. of implants (timing)	Implant surface	Follow-up (mo)	Implant survival %	Implant success %
Engelke et al (1997)[144]	RS	44	Maxilla	HA+e-PTFE	100	124 (imm)	Machined/Rough/ HA-coated	6–68	91	86.2
Bruschi et al (1998)[145]	RS	303	Maxilla	CLS	100	499 (imm)	Rough	25–60	ND	97.5
Sethi and Kaus (2000)[146]	RS	150	Maxilla	None	ND	449 (imm)	ND	1–93	97	ND
Chiapasco et al (2006)[147]	PS	45	Max/Mand	None	98	110 (imm)	Rough	12–36	97.3	95.4

RS = retrospective study; PS = prospective study; Max = maxilla; Mand = mandible; CLS = collagen sponge; Surgical success = success rate of the surgical procedure; HA = hydroxyapatite; imm = immediate placement; ND = no data.

Timing of Implant Placement. Both immediate implant placement (in conjunction with grafting procedures) and delayed implant placement (after consolidation of the graft has occurred) have been proposed. Although it is impossible to determine a clear indication for immediate or delayed implant placement, the majority of authors agree in suggesting immediate implant placement when the residual alveolar bone presents adequate quality and quantity to allow primary stability of implants. In general, immediate placement is not indicated when the residual height is less than 4 to 5 mm, and in cases of poor bone quality. Tawil and Mawla[112] demonstrated that immediate implant placement with less than 5 mm residual bone height is followed by significantly lower implant survival rates than placement in more than 5 mm residual bone (56% versus 100%). A previous review of the literature concerning this topic[142] showed lower survival of implants placed in conjunction with the grafting procedure. Only one article reported a successful outcome of implants placed in conjunction with the grafting procedure with a very limited residual bone height (1 to 2 mm).[93] However, no clear indications were found in the literature.

Survival of Implants According to Type of Implant Surface. In the studies analyzed in this review, both machined-surface implants and rough-surfaced implants were used. Regardless of the technical process used to roughen the surface, implants with rough surfaces demonstrated a mean survival rate significantly higher than machined-surface implants (96.9% and 88%, respectively). These results have also been confirmed by a recent systematic review by Pjetursson et al[141]: The authors concluded that statistically significantly higher survival rates were obtained when rough-surfaced implants were inserted, irrespective of the grafting material used.

Loading Time of Implants Placed in Grafted Areas. Implants placed in grafted sinuses were loaded 2 weeks to 13 months afterwards (on average 5 to 6 months after). It is difficult to give clear indications, however, because osseointegration and implant capability to withstand the functional demands of loading are influenced by a large number of factors, including residual bone volume before the grafting procedure, quality of residual bone, type of grafting material, implant dimensions, implant macro- and microgeometry, type of implant surface, type of prosthesis, and type of opposing arch dentition. These considerations were already addressed by Jensen et al[143] in their review on sinus grafting procedures. Since then, no significant information has been added. Therefore, studies addressing these topics are needed.

One of the few aspects which seems to be clarified is that screw-shaped implants with rough surfaces offer a better prognosis than implants with machined surfaces,[143] but data have been retrieved mainly from retrospective studies and not from prospective, comparative studies.

Bone Splitting/Expansion and Immediate Implant Placement

Patients and Methods. The search identified 387 publications, 32 of which were screened as full-text articles. A total of 4 studies were selected.[144–147] Of these, 3 were retrospective clinical studies and 1 was a prospective multicenter clinical study. Overall, 542 patients were treated with bone splitting/expansion of narrow edentulous ridges and immediate placement of implants. A total of 1,182 implants were placed in the expanded edentulous sites at the time of the expansion procedure. The gap created by splitting was either left empty or filled with different materials, such as collagen sponge, BBM, autogenous bone chips, and HA. In one study the interposed grafting material was covered with e-PTFE membranes.[144] Dental rehabilitation with removable or fixed implant-supported prostheses was started 3 to 6 months afterwards. Patients were followed from 1 to 93 months after the start of prosthetic loading (Table 3).

Outcomes. Success rates of the surgical procedures ranged from 98% to 100%. Fracture of the buccal plate was the most common complication.

Implant survival rates ranged from 91% to 97.3% (median 94%), while success rates ranged from 86.2% to 97.5% (median 95.5%) (Table 3).

Discussion. Bone splitting/expansion seems to be a reliable and relatively noninvasive technique to correct narrow edentulous ridges. Survival and success rates of implants placed in the expanded ridges are consistent with those of implants placed in native, nonreconstructed bone. The gap created by sagittal osteotomy/expansion undergoes spontaneous ossification, following a mechanism similar to that occurring in fractures. New bone formation permits a consolidation between the oral and buccal bone plates of the alveolus, and implants placed in expanded ridges seem to withstand the biomechanical demands of loading. However, some considerations have to be made.

Bone splitting/expansion can be applied only when the buccal and palatal/lingual plates are separated by spongy bone. Therefore, the indications are more limited as compared to onlay grafts and GBR, which can be also applied in cases presenting with severe horizontal atrophy.

Another limitation is represented by unfavorable inclination of implants placed in expanded areas. This procedure may lead to excessive buccal inclination of implants, which may create problems from a functional and esthetic viewpoint. In the case of unfavorable bone angularity, GBR or bone grafting techniques seem to represent more adequate surgical procedures.

The significantly higher number of maxillary expansion procedures is explained by the fact that maxillary ridges, due to the lower bone density and thinner cortical buccal plate, are more easily treated than mandibular ridges. Mandibular sagittal osteotomy, although possible, is more difficult due to the denser bone of the buccal plate, as demonstrated by some authors.[147] Drawbacks of this anatomical condition include greater difficulty in expanding, the risk of a more invasive and more traumatic surgical procedure, and the risk of buccal plate fracture.

Although implant survival rates are comparable to those obtained in cases of implants placed in native nonaugmented bone, a paucity of data is available with regard to the stability over time of the initial bone volume obtained after expansion. Only one out of four articles[147] evaluated horizontal bone changes with the aid of surgical calipers, resulting in a median value of 0.5 mm (range 0.5 to 1.5 mm) 3 years after the start of prosthetic loading. It is therefore recommended that future reports address this aspect.

Split-Ridge Techniques with Interpositional Bone Grafts and Delayed Implant Placement

Patients and Methods. Of the initial articles retrieved (374), 6 were screened as full text, but none fulfilled the criteria for inclusion. Therefore, although this procedure has been described in the literature, there are no available data due to insufficient sample size and/or follow-up.

Vertical Distraction Osteogenesis

Patients and Methods. Of the initial 128 articles retrieved, 44 were screened as full text and 7 were considered suitable for inclusion.[148–154] Four of these were prospective clinical studies and 3 were retrospective studies. A total of 181 patients presenting with vertical resorption of partially or totally edentulous alveolar ridges were treated with distraction devices. Both intraoral intraosseous devices and intraoral extraosseous devices were used (see Table 4 for details). The rate of distraction per day ranged from 0.5 to 1.6 mm.

A total of 462 implants were placed, 62 of which served both as intraoral intraosseous distraction devices and as definitive implants for prosthetic restorations. Four hundred implants were placed 2 to 3 months after the completion of distraction, once sufficient maturation of the bone in the distraction gap had occurred.

Prosthetic rehabilitation was started 3 to 6 months after implant placement. Both fixed and removable implant-supported prostheses were used, but only two articles reported adequate information on prosthetic rehabilitation. Follow-up after the start of prosthetic loading ranged from 6 to 72 months (Table 4).

Outcomes. Postoperative recovery after distraction was uneventful in 73% of patients. Minor complications included change of the distraction vector (successfully corrected during distraction with prosthetic/orthodontic appliances) (8.3%), incomplete distraction (2.2%), fracture of the distraction device (1.6%), transient paresthesia in the innervation area of the mandibular nerve (1.6%), and partial relapse of the initial bone gain (7.7%), which nevertheless permitted implant placement after further minor augmentation procedures (it is worth noting that this complication occurred only in patients treated with intraoral/intraosseous devices). Total failure of the procedure was reported in only 2 out of 181 patients (1.1%), whereas major complications such as basal bone fracture and fracture of the distracted bone occurred in 5 patients (2.7%) but were successfully treated and had no consequences as far as the completion of the planned treatment was concerned. Therefore, the overall success rate of the procedure was 98.9%. (Gaggl et al 2000[148] did not report data on complications.)

Table 4 Vertical Distraction Osteogenesis—Characteristics of Included Studies

Study	Study type	No. of patients	Defect site	Type of device	Distr success (%)	Bone gain (mm)	No. of implants (timing)	Implant surface	Follow-up (mo)	Implant survival %	Implant success %
Gaggl et al (2000)[148]	PS	34	Max/Mand	Intraoral/ Intraosseous	ND	3–6	62 (imm)	Rough/ Machined	12	96	ND
Rachmiel et al (2001)[149]	RS	14	Max/Mand	Intraoral/ Intraosseous	97	8–13	23 (del)	Machined	6–20	100	ND
Raghoebar et al (2002)[151]	PS	10	Mand	Intraoral/ Intraosseous	100	6–8	20 (del)	Rough	6–20	95	ND
Jensen et al (2002)[150]	PS	28	Max/Mand	Intraoral/ Intraosseous Intraoral/ Extraosseous	96.7	4–15	84 (del)	Rough	12–60	90.4	ND
Chiapasco et al (2004)[152]	PS	37	Max/Mand	Intraoral/ Extraosseous	97.2	4–15	138 (del)	Rough/ Machined	15–55	100	94
Enislidis et al (2005)[153]	RS	37	Mand	Intraoral/ Intraosseous Intraoral/ Extraosseous	57.8	5–15	93 (del)	ND	6–58	95.7	ND
Uckan et al (2007)[154]	RS	21	Max/Mand	Intraoral/ Intraosseous Intraoral/ Extraosseous	95.8	5–20	42 (del)	ND	8–72	88–94	ND

RS = retrospective study; PS = prospective study; Max = maxilla; Mand = mandible; Distr success = success rate of the distraction procedure; imm = immediate placement; del = delayed placement; ND = no data.

The vertical bone gain obtained at the end of the distraction period ranged from 3 to 20 mm.

Of 462 implants placed, 19 were removed (14 preload, 1 postload, and 4 nonspecified), with an overall survival rate of 95.9% (range 88% to 100%; median 95.5%). All failures occurred in the group in which intraoral intraosseous devices were used.

Success rate according to well-defined criteria[1] was reported only in one article[152] in which no implants (out of 138) were lost, but 8, although osseointegrated, presented peri-implant bone resorption rates higher than those proposed for successful implants, resulting in a success rate of 94.2% (Table 4).

Discussion. Despite the limited number of patients and implants placed in the retrieved articles, the following conclusions can be drawn:

- Distraction osteogenesis provides an opportunity to obtain a natural formation of bone between the distracted segment and basal bone in a relatively short time span, thus avoiding the necessity of autogenous bone harvesting. This leads to a reduction of morbidity and a shortening of operating times. Soft tissues can follow the elongation of the underlying bone (neohistogenesis), and there is a lower risk of infection of the surgical site (0% in this case series). Both limited and extended (fully edentulous patients) defects can be treated.
- Histologic results seem to demonstrate that distraction osteogenesis allows the formation of adequate quality and quantity of bone tissue, which can provide primary stability of implants and favorably withstand the biomechanical demands of loaded implants. Biopsies taken at the time of implant placement, after consolidation of the distracted area,[151,155–159] demonstrated that distraction is able to induce the formation of new bone that matures similarly to natural bone.
- Survival and success rates of implants placed in distracted areas are consistent with those reported in the literature for implants placed in native, nonregenerated/reconstructed bone.[1–10]

However, some disadvantages of vertical distraction osteogenesis must be emphasized:

- Frequent lingual/palatal inclination of the distracted segment has been reported by some authors, with an incidence varying from 13% to 35.4%,[148–154] probably due to local muscle pull, inappropriate device positioning, and/or poor device trajectory. To solve this complication, different solutions have been suggested, including the use of fixed or removable prosthodontic and orthodontic devices to guide the distracted segment to its proper final position. Ideally, a multidirectional alveolar distraction device would allow the vector to be modified and guided in several planes of space. Some authors[160,161] reported their experience with such a device, resulting in a reduced incidence of distracted

Table 5 Le Fort I Osteotomy with Inlay Grafts—Characteristics of Included Studies

Study	Study type	No. of patients	Donor site	Success proc (%)	No. of implants (timing)	Implant surface	Follow-up (mo)	Implant survival (%)	Implant success (%)
Isaksson et al (1993)[164]	RS	12	Ilium	100	59 (imm)	Machined	12–24	79	ND
Cawood et al (1994)[165]	RS	12	Ilium+HA	92	64 (del)	Rough/Machined	12–36	67–95	ND
Krekmanov (1995)[166]	RS	35	Ilium	95	225 (imm)	Machined	12–48	87	ND
Li et al (1996)[167]	RS	20	Ilium	100	139 (imm)	ND	13–62	82	ND
Watzinger et al (1996)[168]	RS	11	Ilium	91	41 (imm) 35 (del)	Rough	30	88	81
Nyström et al (1997)[169]	RS	10	Ilium	100	60 (del)	Machined	15–39	95	ND
Keller et al (1999)[78]	RS	10	Ilium	100	8 (imm) 45 (del)	Machined	6–139	83	ND
Kahnberg et al (1999)[170]	RS	25	Ilium	100	181 (del)	Machined	60	83	ND
Lekholm et al (1999)[46]	RS	20	Ilium	ND	133 (imm)	Machined	12–36	80	ND
Stoelinga et al (2000)[171]	RS	15	Ilium+HA	100	92 (del)	Rough/Machined	12–144	91	91
Yerit et al (2004)[172]	RS	30	Ilium	90	276 (imm)	Rough	12–120	87–91	ND
Hallman et al (2005)[173]	RS	22	Ilium	100	156 (del)	Rough	60	87–94.5	52–70
Chiapasco et al (2007)[174]	PS	39	Ilium	97.5	281 (del)	Rough	12–108	94.5	82.9

RS = retrospective study; PS = prospective study; HA = hydroxyapatite; Success proc = success rate of the procedure; imm = immediate placement; del = delayed placement; ND = no data.

segment malposition, but short follow-ups and lack of sufficient information concerning the success rates of implants placed in the distracted areas do not allow significant conclusions to be drawn.

- The majority of authors reported some relapse of initial bone gain, before implant placement, due to marginal bone loss of the most coronal part of the distracted segment. Therefore, a 20% overcorrection was suggested by one group.[162] Conversely, crestal bone changes around implants after the start of prosthetic loading seem to be similar to those occurring in cases of implants placed in native, nonreconstructed bone, as demonstrated by experimental and clinical studies.[149,150,152,156]
- As compared to other augmentation procedures, such as GBR or bone grafting, vertical distraction does not allow simultaneous correction of narrow ridges, which is only possible with overdistraction of the segment and secondary height reduction until adequate bone width is obtained. However, overcorrection may lead to surrounding soft tissue tears and/or ischemia. The second possibility is secondary bone grafting at the time of distraction device removal,[163] but this procedure eliminates one of the main advantages of alveolar distraction, which is that there is no need for bone harvesting.
- As compared to GBR and grafting procedures, which can be applied both for mandibular and maxillary defects, vertical distraction seems to be more indicated in the correction of mandibular defects. This may be related to difficulties in maintaining an adequate vector in the maxilla, due to inextensibility of palatal fibromucosa. Also, maxillary sinus pneumatization can preclude the possibility of distraction osteogenesis due to insufficient bone height to perform the osteotomy.

Le Fort I Osteotomy with Interpositional Autogenous Bone Grafts

Patients and Methods. The search identified 679 articles. Of these, 31 were screened as full text and 13 were selected[46,78,164–174] (Table 5). Twelve of the selected studies were retrospective clinical studies and 1 was a prospective multicenter clinical study.

A total of 261 patients affected by extreme atrophy of the edentulous maxilla (class VI according to the Cawood and Howell classification [1988][63]) were treated with Le Fort I osteotomy and inlay bone grafts taken from the anterior iliac crest, to correct not only alveolar bone deficiency but also severe intermaxillary discrepancy. One hundred twenty-four patients received 881 implants placed during the same surgical session (6 to 9 implants per patient), while 137 patients received 914 implants in a second stage, after consolidation of the graft occurred (3 to 12 months after reconstruction). A total of 1,795 implants were placed in the reconstructed maxillae. Prosthetic rehabilitation was started 4 to 12 months after implant placement. Both fixed and removable implant-supported prostheses were used for the rehabilitation of treated patients (3 of 13 articles did not report data on prosthetic rehabilitation[46,165,166]). Follow-up after the start of prosthetic loading ranged from 6 to 144 months (Table 5).

Outcomes. Postoperative recovery after Le Fort I osteotomy was uneventful in the majority of patients. In four patients, intraoperative fracture of the palate occurred but with no consequences on the final outcome. In seven patients, postoperative sinusitis occurred, but was successfully treated with antibiotics. In seven patients, minor dehiscence with moderate bone graft fragment exfoliation was reported, with no consequences on the following rehabilitation phases.

In seven patients, dehiscence with partial bone loss/infection occurred, but prosthetic rehabilitation, despite having to be modified, was concluded successfully. A total failure of the procedure was reported only in one patient. The overall complication rate of this surgical procedure was 3.1% (range 0% to 10%).

Of 1,795 implants placed, 218 were removed (overall survival rate 87.9%; range 66.7% to 95%; median 87%). One hundred twenty-five implants were lost in the group where implants were placed in conjunction with Le Fort I osteotomy (881 implants), while 83 were lost in the group in which implants were placed at a second stage (914 implants). An additional 9 implants were lost in one study where both immediate and delayed implants were placed,[78] but it was not reported in which of the two groups of implants these losses occurred.

With regard to implant surface, a lower survival rate was observed for machined-surface implants (range 79% to 95%; mean 84.5%; median 83%; 108 implants removed out of 711 placed) compared to rough-surfaced implants (range 82% to 94.5%; mean 90.3%; median 89.5%; 65 implants removed out of 789 placed).

Implant losses occurred both before and after the start of prosthetic loading, but again data are incomplete and it was not possible to specify the exact time distribution of losses.

The survival rate of implants placed in conjunction with the reconstructive procedure was 85.8% (range 79% to 95%; median 84.5%; mean 84.3%). For implants placed in a staged approach, the survival rate was 90.9% (range 66.7% to 95%; median 93%; mean 88.4%). No well-defined implant success criteria were found in the majority of articles, with only three publications[167,171,174] reporting 88.1%, 91%, and 82.9% success rates according to well-defined criteria (Table 5).

Discussion. The analysis of the available publications demonstrated on average poor methodological quality with regard to completeness of follow-up and success criteria of implants. Despite these limits, the following observations can be made:

- Le Fort I osteotomy in association with interpositional bone grafts and immediate or delayed implant placement is a reliable, albeit demanding, procedure that should be limited to severe maxillary atrophy associated with unfavorable intermaxillary relationship. In these situations, techniques such as onlay bone grafting, even if they can recreate adequate bone volumes for implant placement, may not be able to correct an inadequate intermaxillary relationship; this might lead to an inadequate final prosthetic outcome from a functional and/or esthetic viewpoint.
- The procedure is associated with relevant, albeit temporary, postoperative morbidity. Pain and hip-related discomfort were observed in almost all patients but were transient in the majority of cases.
- Partial or total failure of the grafting procedure is very limited (3.1%). Some authors[166,172] consider the preservation of the sinus mucosa a critical factor for reducing this complication, although others reported a 100% success rate of the grafting procedure despite total removal of the sinus mucosa.[78,164,169]
- Survival rates of implants placed in the reconstructed maxillae are, on average, lower (range 66.7% to 95%; mean 87.9%) than those reported for implants placed in native bone. However, it is worth noting that when only rough-surfaced implants are considered, survival rates of implants, although lower, compare favorably with those of implants placed in native maxillary bone (overall survival rate of rough-surfaced implants 91.8%; range 87% to 94.5%).
- The choice of implant placement timing is still controversial, because some authors prefer simultaneous placement[46,164,166,167,172] while others prefer implant placement after graft consolidation.[165,169,170,171,174] Although statistically significant data are difficult to obtain, survival rates were higher for patients receiving implants after the reconstructive procedure than for those receiving implants simultaneously (93% and 84.5% median values, respectively).
- None of the authors proposed immediate loading of implants placed in the reconstructed maxillae.
- No indications have been found concerning the choice of length and diameter of implants placed in the reconstructed areas, although a tendency toward longer implants that can engage the entire volume of the grafted bone has been observed. In fact, a higher failure rate was found with shorter implants.[78,166] On average, six to eight implants per patient have been suggested, but no specific indications concerning the number of implants to be placed were found.

CONCLUSION

This literature review has demonstrated that a wide range of surgical procedures can be used to correct deficient edentulous ridges. On the basis of available data, it is difficult or impossible to determine that one surgical procedure offers a better outcome than another, as far as predictability of the augmentation and survival/success rates of implants placed in the

augmented sites are concerned. Every surgical procedure presents advantages and disadvantages, which must be carefully evaluated before surgery. Moreover, it is not yet known if some surgical procedures that are widely used in clinical practice, such as sinus grafting procedures in the case of limited/moderate sinus pneumatization or reconstruction of atrophic edentulous mandibles with onlay autogenous bone grafts, are really useful for improving the long-term survival of implants.

However, despite recommendations in previous review papers[30,31] for better-designed studies according to the Consolidated Standards of Reporting Trials (CONSORT) guidelines,[175] the main limitation encountered in this literature review was the overall poor methodological quality of the published articles; this may reduce the possibility of drawing significant conclusions.

As suggested by Esposito et al,[30] in order to understand when bone augmentation procedures are needed and which are the most effective techniques for the specific clinical indications, larger, well-designed, long-term trials are needed. It was also stated that it is difficult to provide clear indications with respect to which procedures are actually needed. Priority should be given to procedures that are simpler and less invasive, involve less risk of complications, and reach their goals within the shortest time frame.

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Ridge Preservation Techniques for Implant Therapy

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Purpose: *The aim of this review was to evaluate the techniques and outcomes of postextraction ridge preservation and the efficacy of these procedures in relation to subsequent implant placement.* ***Materials and Methods:*** *A MEDLINE/PubMed search was conducted and the bibliographies of reviews from 1999 to March 2008 were assessed for appropriate studies. Randomized clinical trials, controlled clinical trials, and prospective/retrospective studies with a minimum of five patients were included.* ***Results:*** *A total of 135 abstracts were identified, from which 53 full-text articles were further examined, leading to 37 human studies that fulfilled the search criteria. Many different techniques, methodologies, durations, and materials were presented in the publications reviewed, making direct comparison difficult.* ***Conclusions:*** *Despite the heterogeneity of the studies, it was concluded that ridge preservation procedures are effective in limiting horizontal and vertical ridge alterations in postextraction sites. There is no evidence to support the superiority of one technique over another. There is also no conclusive evidence that ridge preservation procedures improve the ability to place implants.* Int J Oral Maxillofac Implants 2009;24(suppl):260–271

Key words: *dental implants, extraction, grafting, ridge preservation, socket*

The outcome of implant therapy is no longer measured by implant survival alone, but by long-term esthetic and functional success. Today, implant placement should be based on a restoration-oriented treatment plan with correct three-dimensional (3D) positioning of the implant to allow optimal support and stability of surrounding hard and soft tissues.[1]

Soft tissue contour depends on the underlying bone anatomy, since peri-implant soft tissues have rather constant dimensions.[2] This relationship between hard and soft tissues is important for esthetic outcomes in implant patients. Particularly important are the height and thickness of the facial bone wall and the height of the alveolar bone at interproximal aspects. Incorrect 3D positioning of an implant may result in an inappropriate restoration-implant alignment, which can cause difficulty for the restorative treatment. If the implant is placed too far facially, there is a significant risk of recession of the mucosal margin. If it is placed too far palatally, this may result in a poor emergence profile or even ridge-lapping of the restoration. An inappropriate mesiodistal position can affect the papilla size and shape and may cause poor embrasure form or emergence profile. A coronoapical malposition can cause biological complications if the implant is placed too deep or esthetic complications if the metal of the implant shoulder is visible.

Besides a correct 3D position of the inserted implant, the esthetic outcome can also be affected by the amount of bone available at the implant site. It is well documented that the alveolar ridge undergoes resorptive changes following tooth extraction. These changes lead to a decrease in the dimensions of the ridge.[3,4] Implant placement in postextraction sites can usually be managed with bone augmentation procedures with high predictability, provided that at least two intact bone walls remain.[5,6] However, as the time from extraction to implant placement increases, progressive ridge resorption may result in a loss of bone volume to a degree that simultaneous bone augmentation becomes less predictable.[7] Careful preoperative assessment of the site will reveal the anatomy of the alveolar crest and identify any horizontal or vertical deficiencies. Most critical are vertical

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bone deficiencies, as it is difficult to regain vertical height of the ridge.[8,9]

A series of studies in a dog model have been fundamental for our understanding of healing events in postextraction sites and following immediate implant placement. Cardaropoli et al[10] confirmed the sequence of healing events reported by Amler et al.[11] A more recent study by Botticelli et al[12] found substantial bone resorption from the outside of the ridge following implant placement in an extraction socket. Implants were shown by Araujo et al[4] not to prevent modeling of the extraction socket, and Araujo and Lindhe[13] suggested that the greater facial bone loss compared to the lingual wall was due to the relatively greater proportion of bundle or "tooth-derived" bone facially. Recently, implants placed in extraction sockets were demonstrated not to preserve the dimension of the ridge, especially on the facial aspect, and this resulted in some marginal loss of osseointegration.[14] Most recently, Fickl et al[15] showed that elevation of a mucoperiosteal flap resulted in a more pronounced loss of ridge dimension compared to no flap elevation.

Based on this understanding of healing events in postextraction sites, the prevention of ridge resorption following tooth extraction seems important, particularly if implant placement needs to be delayed for 6 months or longer. Implant placement may be delayed due to loss of bone, especially in the following situations: socket walls and sites with limited bone height (eg, postperiodontal disease and large apical defects), socket morphology preventing implant placement in an ideal restorative position, in young patients where active growth is occurring or still has to occur, where the patient cannot afford implant therapy, or where placement is contraindicated by medical health issues. If the dimensions of the ridge could be maintained, this would reduce the need for further augmentation/surgical procedures and simplify implant surgery at a later time.

The aim of this review was to evaluate the literature on ridge preservation and determine what techniques are available and whether they allow successful implant placement.

MATERIALS AND METHODS

Search Strategy

In MEDLINE and PubMed, searches were performed for papers in the English language using the following terms: *dentistry, implants, dental implants, extraction, socket, socket preservation, ridge preservation, implants-ridge preservation, ridge-socket, ridge alteration-extraction,* and *ridge preservation-extraction*. The bibliographies of reviews from 1999 to March 2008 were assessed for appropriate studies.[16–19] In addition, the following journals' websites were searched: *Journal of Periodontology, Clinical Oral Implants Research, International Journal of Oral & Maxillofacial Implants*, and *Journal of Clinical Periodontology*. Authors' names as identified previously were also used. Reference lists of studies identified were searched for further citations.

Selection of Studies

Randomized clinical trials, controlled clinical trials, and prospective/retrospective studies with a minimum of five patients were included. Where a series of papers reported the same study, the paper with the clinical measurements or details about the implant placement was used.

Evaluation of Treatment Outcome

The following data were obtained from each study: number of patients and treated sites, position of sites, augmentation methods for test and control sites, observation period, soft tissue closure, and complications.

Treatment outcome was evaluated as:

- Change in ridge dimensions (in mm or %)
- Successful implant placement
- Implant survival (%)

RESULTS

A total of 135 abstracts were identified, from which 53 full-text articles were further examined, leading to 37 human studies that fulfilled the search criteria and were used in this review. These publications are listed and briefly described in Table 1. In addition, 10 animal studies were incorporated, as these had direct relevance to the topic.

Definitions

Several terms have been used in the literature, including *ridge preservation*, *site preservation*, and *socket preservation*. As the objective of treatment is to limit vertical and horizontal ridge alterations in postextraction sites, the term *ridge preservation* was considered to be a more precise description and hence was used in this review.

Healing of Extraction Sockets

Healing of an extraction socket is characterized by internal changes that lead to formation of bone within the socket and by external changes that lead to loss of alveolar ridge width and height.[3]

Table 1 List and Description of Articles Included

Study	Study type	No. of patients	No. of sites	Position/ characteristics	Test	Control	Observ period	Soft tissue closure	Results	Outcome	Comments
Vance et al (2004)[32]	RCT	24	24 (12/12)	Nonmolar/ND	CMC/CaS with DFDBA and CaS barrier	Bio-Oss & collagen membrane	4 mo	Partial closure by mucosal advancement	Horizontal ridge width same for both groups; vertical midbuccal putty 0.3 ± 0.7 mm, Bio-Oss 0.7 ± 1.2 mm, no difference in soft tissue	No significant difference between groups and all enabled implant placement	Amount of vital bone: putty 61% ± 9%, Bio-Oss 26% ± 20% with more graft particles remaining
Molly et al (2008)[40]	RCT	8	36 (4 groups of 9)	Mixed/Advanced periodontitis	3 groups: PL/PG sponge; DBBM; Biocoral	Clot	6 mo	Yes; also placed e-PTFE at all sites (removed 2 mo later)	% viable bone and % residual particles: PL/PG 27%, 5%; DBBM 20%, 20%; Biocoral 24%, 12%; Control 30%	Implants placed in 25/36 sites, 9 sites excluded due to mechanical/esthetic issues (which groups ND)	Implants 10–15 mm length and 3.75 or 4 mm diameter
Froum et al (2002)[25]	RCT	19	30	Mixed/Periodontitis and prosthetic issues	10 bioactive glass, 10 DFDBA	10 Unfilled	6–8 mo	Primary closure by mucosal advancement	Amount of vital bone: Bioglass 59.5%, DFDBA 34.7%, control 32.4%	All had implants	
Fiorellini et al (2005)[56]	RCT	80 40/40	19: Control 18: 0 rhBMP 22: 0.75 rhBMP 21: 1.5 rhBMP	Maxillary anterior teeth/ND	Sponge soaked in rhBMP-2 of concentrations 0.0, 0.75, and 1.5 mg/mL	Clot	Adequate alveolar bone, max 4 mo	Primary closure by mucosal advancement	Gradient of effect with increasing concentrations observed; 1.5 mg/mL group most effective at preserving bone width	Sites requiring additional bone augmentation at the time of implant placement: 55% (clot), 41% (0 mg/mL), 45% (0.75 mg/mL), 14% (1.5 mg/mL)	Used palatal wall in calculations
Neiva et al (2008)[55]	RCT	24	12/12	Maxillary premolar teeth/ND	Putty & P15 + bioabsorbable collagen wound dressing with suturing	Clot + bioabsorbable collagen and suturing	4 mo	Partial closure by mucosal advancement	Changes in ridge dimensions. Width: test, 1.31 ± 0.96 mm; control, 1.43 ± 1.05 Height: test, 0.15 ± 1.76 mm; control, 0.56 ± 1.04 Similar % of vital bone	Significant differences in height	Implants placed; low percentage of residual particles ~6%; incipient ridge atrophy at 33% of control sites which required grafting at time of placement, but none at test sites
Iasella et al (2003)[24]	RCT	24	12/12	Nonmolar teeth extractions/ND	Mineralized FDBA and collagen membrane	Clot	4–6 mo	Partial closure by mucosal advancement	Horizontal ridge dimensions: test, - 1.2 ± 0.9 mm; control, - 2.6 ± 2.3 mm Vertical dimensions: mesial, midbuccal, distal, test had significantly less loss than control	Most predictable maintenance of ridge by ridge preservation	Allows direct comparison with 3 other studies
Becker et al (1996)[23]	CCT	15	ND	Mixed/ND	Autologous bone (6), DFDBA (7) (+ e-PTFE [5]), MFDBA (7)	See test	4–13 mo	ND	DFDBA/MFBDA, retention of nonvital graft particles with fibrous connective tissue	Use of membrane didn't make a difference	Too many differences for definite conclusion and unclear whether all sites had implants
Lekovic et al (1997)[50]	CCT	10	2 + per patient	Anterior or premolar teeth/ND	e-PTFE	Clot	6 mo	Primary closure by mucosal advancement	EVM and HM not significantly different; IVM significantly reduced	Nonexposed membranes significantly more socket infill and less loss of alveolar bone height	30% membrane exposure and these sites had the same outcome as the controls

Table 1 continued List and Description of Articles Included

Study	Study type	No. of patients	No. of sites	Position/ characteristics	Test	Control	Observ period	Soft tissue closure	Results	Outcome	Comments
Lekovic et al (1998)[51]	CCT	16	2 per patient	Anterior or premolar teeth/ND	Resolut membrane (PL/PG)	Clot	6 mo	Primary closure by mucosal advancement	Test had significantly smaller change in EVM, greater change in IVM and smaller change in HM	Loss of width greater than height	No exposures
Becker et al (1994)[22]	CCT	7	14, 7 paired	ND/Perio (hopeless teeth)	DFDBA	Autologous bone	3–13 mo	Primary wound closure by mucosal advancement	DFDBA does not induce bone formation	DFDBA may impede normal bone healing	All sites implants placed
Tal (1999)[29]	CCT	24	42	Maxillary central incisors/ND	DFDBA	Bio-Oss	4 wk	Soft tissue grafted from palate	Vital bone: no difference between DFDBA and Bio-Oss		Nothing about dimensions and implant placement
Serino et al (2008)[54]	CCT	20	7 Test 9 Control	Monoradicular teeth/ND	Fisiograft	Clot	3 mo	No	Mean bone: test 59.9 ± 22.4%, control 48.8 ± 14.4%	No significant difference; All sites implants	
Serino et al (2003)[53]	CCT	45	26 Test 13 Control	Mixed/ND	PL/PG sponge	Clot	6 mo	No	Midbuccal dimensions: test +1.3 ± 1.9 mm, control −0.8 ± 1.6 mm Well-structured, mature bone in both	All sites implants	Overall less resorption in test group
Luczyszyn et al (2005)[45]	CCT	11	15 pairs	2 Noncontiguous uniradicular teeth/ND	Resorbable HA + ADMG	ADMG	6 mo	Flap replaced in original position	Buccolingual dimension: ADMG only, 5.5 ± 1 mm; ADMG + RHA, 6.8 ± 1.3 mm Histology: ADMG 54% CT/46% bone; ADMG+RHA 57% CT/1% bone/42% RHA	All sites had implants	
Froum et al (2004)[34]	CCT	15	16, 4×4	ND/Periodontitis and prosthetic issues	Group 1 HA + ADMA, Group 2 HA + e-PTFE, Group 3 ABB + ADMA, and Group 4 ABB + ADMA	See test	6–8 mo	Partial coverage by mucosal advancement and a lot of CHX	ADMA/HA vital bone 34.5%, residual graft 4%; ADMA/ABB 41.7%, 12.2%; e-PTFE/HA 27.6%, 11.9%; e-PTFE/ABB 17.8%, 21.4%	Implants in all sites; noted a tendency for greater amount of vital bone with ADMA	Deficient buccal plates; ABB used was Osteograf, 1 ADMA and 6 (75%) e-PTFE removed early
Vasilic et al (2003)[35]	CCT	26	26 pairs	2 or more anterior or premolar teeth/ND	BPBM + collagen membrane	BPBM + autologous fibrinogen/fibronectin	6 mo	Primary closure by mucosal advancement	BPBM/collagen significantly more internal socket fill, less horizontal resorption, less resorption of alveolar bone height	BPBM/collagen better	Abstract only
Howell et al (1997)[57]	CCT	12 (6)	6	Maxillary anterior and premolar teeth/2 Decayed 2 Nonrestored 2 Periodontitis	rhBMP-2 and absorbable collagen sponge	None	16 wk	None	5/6 decreased socket depth	Better than complete infill	Inconclusive

Table 1 continued List and Description of Articles Included

Study	Study type	No. of patients	No. of sites	Position/ characteristics	Test	Control	Observ period	Soft tissue closure	Results	Outcome	Comments
Carmagnola et al (2003)[33]	CPros	121	11 Bio-Gide only, 7 Bio-Gide + Bio-Oss, 10 clot	ND/Postperio-dontitis	Group A Bio-Gide over socket then 4/12 implant. Group B Bio-Oss & Bio-Gide, then implant 7/12	Group C clot and implant 1–15 y	4 or 6 mo and up to 15 y	Partial closure of test sites by mucosal advancement	Quality of bone: Group A lamellar bone and bone marrow; Group B connec-tive tissue and small amounts of bone around graft with 21% remaining graft; Group C mineralized bone and bone marrow	All sites had implants	
Camargo et al (2000)[43]	Pros	16	16/16	2 Anterior or pre-molar teeth/ND	Biogran to socket height and calcium sulphate	Clot	6 mo	Flaps replaced in original posi-tion	Control slightly better external and internal ver-tical measurements and horizontal width changes		Similar protocol to Lekovic studies
Pinho et al (2006)[41]	Pros	10	10/10	2 Maxillary anterior and premolar extractions/ND	Autogenous bone + tita-nium membrane	Clot + titanium membrane	6 mo	Primary closure by mucosal advancement	No significant differences between groups, and complete fill of socket depth	Use of membrane favored prevention of alveolar ridge loss	25% exposure rate
Dies et al (1996)[26]	Pros	12	12	Mixed, but no molars/11 Max-illa; 1 Mandible	3 groups: e-PTFE (6), e-PTFE + DFDBA (4), e-PTFE + Bio-Oss (2)	See test	Up to 9 mo	Complete by mucosal advancement	e-PTFE moderate-high bone density and quality; e-PTFE+DFBDA and e-PTFE+Bio-Oss moderate-high bone density with some remnants	8/12 planned for implants	3/12 membranes exposed
Smukler et al (1999)[21]	Pros	13	6 Socket preservation, 5 Control, 2 Augmented	Mixed/ND	DFDBA + e-PTFE	Clot	9–23 mo	Complete by mucosal advancement	Confusing. Bone volume maxilla: test 55 ± 15 mm, control 57 ± 11 mm Bone volume mandible: test 57 ± 33 mm, control 41 ± 3 mm	Unable to separate socket preservation from aug-mentation	DFDBA remaining 0%–21.5%
Yilmaz et al (1998)[42]	Pros	10	10 Test	Maxillary incisors/ Severe periodonti-tis with functional and esthetic ridge defects	Bioactive alloplastic graft material	Clot	12 mo	Primary clo-sure by mucosal advancement although not well described	Ridge width at 12/12: test 5.7 ± 1.2 mm, con-trol 3.9 ± 0.8 mm Ridge height: test 8 ± 1.6 mm, control 7 ± 0.5 mm	Demonstrated efficiency of this method in preserv-ing bone	Ridges under FPD pon-tics
Nemcovsky and Serfaty (1996)[46]	Pros	23	10 Control	Maxillary anterior teeth/Perio, space, caries, periapical	Nonresorbable HA crystals	None	12–24 mo	Rotated flap to cover socket	Ridge dimensions de-creased: Vertically 1-2 mm, mean 1.4 mm; buccally 0-2 mm, mean 20.6 mm	20 esthetically satisfac-tory and 3 partially satis-factory	Under FPDs
Brugnami et al (1999)[27]	Pros	8	23	Mixed/Hopeless teeth	DFDBA + e-PTFE	None	3–9 mo	Primary closure by mucosal advancement	DFDBA acts as space maintainer and scaffold for migrating osteogenic cells, well incorporated with osteoblasts and osteoclasts	All sites had implants	

Table 1 continued List and Description of Articles Included

Study	Study type	No. of patients	No. of sites	Position/ characteristics	Test	Control	Observ period	Soft tissue closure	Results	Outcome	Comments
Norton and Wilson (2002)[44]	Pros	18	4 Socket preservation, 3 Augmented 40	Mixed/Periodontitis, endodontic problems, and trauma	Bioactive glass (Perioglass/Biogran) + e-PTFE at sites lacking buccal plate	None	3–11 mo	ND	Absence of bone for all cores harvested within 6/12, bone seen 6/12+ but minimal and at periphery	All sites had implants	CSR 90% at 12 mo and 96.8% at 2–4 y
Simon et al (2000)[31]	Pros	10	19	ND/Periodontitis, caries, and fracture	DFDBA & Resolut membrane	None	4 mo	Primary closure by mucosal advancement	Significant nonuniform loss of augmented alveolar height and width during healing	Implants placed	
Sàndor et al (2003)[49]	Pros	21	48 (17 trauma of anterior maxillary teeth)	Mixed/Trauma or ankylosis	Biocoral	None	24 mo	Primary closure by mucosal advancement	Trauma group initially temporary restoration of dimension but only 17.6% didn't need graft at time of implant placement		Subjects young adults; 6.3% failure rate up to 7 y
Norton et al (2003)[37]	Pros	15	13	Mixed/Periodontitis, endodontic problems, and trauma	Bio-Oss, bone shavings, and Bio-Gide	None	15–44 wk (mean 26 wk)	Primary closure by mucosal advancement if possible	Mix of woven, maturing woven, lamellar bone. Mean amounts: 26.9% bone, 25.6% graft, 47.4% fibrous or other connective tissue	Implants placed at all sites	4 membranes exposed and CHX used until site re-epithelialized; survival rate of implants at time of abutment connection 97%
Kfir et al (2007)[52]	Pros	15	15	Mixed/Fracture, perio, endo	Platelet-rich fibrin and titanium membrane	None	8 wk +	Primary closure	All had sufficient bone	8 implants placed with no additional guided bone regeneration	7 (47%) early exposure of membrane
Guarnieri et al (2004)[47]	Pros	10	10	Mixed single-rooted teeth/ND	Medical grade calcium sulphate	None	3 mo	Primary closure by mucosal advancement	Buccolingual dimension enabled “safe” insertion	All had implants	
Artzi et al (2000)[38]	Pros	15	15	Maxillary single-rooted teeth/ND	Bio-Oss	None	9 mo	Pediculated split palatal flap to close	Overall fill of 82.3%, decreased at dehiscenced buccal plates		Still some graft particles (30%) but well-incorporated
Babbush (2003)[30]	Pros	10	10	Mixed single-rooted teeth/ND	Human FDDBM + collagen in a carrier	None	4–21 mo (mean 7.4 mo)	Partial closure by mucosal advancement	% of bone: mean 57.5% ± 11.1%, range 33.1% to 91.5%	All sites had implants	
Brugnami et al (1996)[28]	Pros	6	7	ND/ND	DFDBA + cell-occlusive membrane	None	3–13 mo	?	Well-incorporated DFDBA within new bone	DFDBA useful for new bone growth in sockets	Abstract only
Wang and Tsao (2008)[48]	Pros	5	7	ND/ND	Solvent-preserved cancellous allograft	None	5–6 mo	No, covered with collagen wound dressing	Vital bone 68.5% average, 3.8% residual graft and 27.7% CT/Bone marrow		
Sclar (1999)[39]	Retrosp	131	248	ND/ND	DBBM + collagen wound dressing	None	6–73 mo	No, covered with collagen wound dressing	94% survival rate of implants		

ABB = anorganic bovine bone mineral; ADMA = acellular dermal matrix allograft; ADMG = acellular dermal matrix graft; BPBM = bovine porous bone mineral; CaS = calcium sulfate; CCT = controlled clinical trial; CHX = chlorhexidine; CMC = carboxymethylcellulose; CSR = cumulative survival rates; DFDBA = demineralized freeze-dried bone allograft; e-PTFE = expanded polytetrafluoroethylene; EVM = external vertical measurement; FDBA = freeze-dried bone allograft; FDDBM = freeze dried demineralized bone matrix; FPD = fixed partial denture; HA = hydroxyapatite; HM = horizontal measurement; IVM = internal vertical measurement; MFDBA = mineralized freeze-dried bone allograft; ND = not described; PG = polyglycolide; PL = polylactide; Pros = prospective study; RCT = randomized controlled trial; Retrosp = retrospective; RHA = resorbable hydroxyapatite; rhBMP = recombinant human bone morphogenetic protein; rhBMP-2 = recombinant human bone morphogenetic protein 2.

When a tooth is removed, there is hemorrhage, followed by formation of a blood clot that fills the entire socket.[11] The concomitant inflammatory reaction stimulates recruitment of cells to form granulation tissue. Within 48 to 72 hours, the clot starts to break down as granulation tissue begins to infiltrate the clot, especially at the base and periphery of the socket. By 4 days, the epithelium proliferates along the socket periphery, and immature connective tissue is apparent. After 7 days, the granulation tissue has completely infiltrated and replaced the clot. At this stage, osteoid is evident at the base of the socket as uncalcified bone spicules. Over the next 2 to 3 weeks (3 to 4 weeks after extraction), this begins to mineralize from the base of the socket coronally. This is accompanied by continued re-epithelialization, which completely covers the socket by 6 weeks post-extraction. Further infill of bone takes place with maximum radiographic density at around 100 days.

A number of factors may affect the healing of sockets. The size of the socket is important, with wider sockets requiring more time to bridge the defect than narrower sockets. The sockets of teeth with horizontal bone loss heal more quickly, as the reduced level of the alveolar ridge means less infill is required. Bone does not regenerate to a level coronal to the horizontal level of the bone crest or to the level of the neighboring teeth; ie, 100% socket fill does not occur.[3]

A recent study by Araujo and Lindhe[13] showed that in the first 8 weeks following extraction in a dog model there is marked osteoclastic activity, resulting in the resorption of the facial and lingual bone walls in the crestal region. They noted that the reduction of height was more pronounced at the facial wall. Loss of ridge height was accompanied by a horizontal loss on both facial and lingual walls.

When the healing events are disturbed, pain may result with impaired bone infill. The sequelae may range from hemorrhage, dry socket, and suppurative or necrotizing osteitis to fibrous healing with a lack of bone formation, depending on the stage of healing at the time of interruption. Significant inflammation may result not only in loss of bone infill, but also in sequestration. The end point of disturbed healing may prevent implant placement.[20]

Bone dehiscences or fenestrations that are present at the time of extraction, particularly in the facial or lingual walls, are most likely to be filled by fibrous reparative tissue, which may occupy considerable space in the socket itself. This leads to reduced bone volume and difficulty in ideal implant placement. Dehiscences and fenestrations may result from periapical pathology; tooth position in the alveolus; cracking or fracture of endodontically treated teeth; removal of the facial bone during extraction; or removal of teeth with curved roots or multiple roots, ankylosis, or root fractures.[19]

Materials Used for Ridge Preservation Techniques

The materials used for ridge preservation are those that have been used for guided bone regeneration (GBR) or guided tissue regeneration (GTR), and reflect what is available commercially.

Demineralized freeze-dried bone allograft (DFDBA)[21–31] and deproteinized bovine bone mineral (DBBM)[26,29,32–40] have been used extensively. Other graft materials include autologous bone,[22,23,41] bioactive glass,[25,42–44] hydroxyapatite,[34,45,46] calcium sulphate (CMC/CaS),[47] solvent-preserved cancellous allograft,[48] and biocoral.[40,49]

Membranes placed were most commonly expanded polytetrafluoroethylene (e-PFTE) membranes[21,23,26,28,40,44,48,50] or collagen membranes.[24,31–33,35,37] In addition, a polylactic/polyglycolic membrane was assessed by Lekovic et al[51] and Simon et al.[31] Further membranes investigated were those manufactured from titanium[41,52] or acellular dermal matrix graft (ADMG).[34,45]

Sponges made of polylactic/polyglycolic acid (PL/PG)[53,54] or collagen[39,40,55–57] have been placed in extraction sockets to preserve the ridge. The collagen sponges acted as a carrier for either recombinant human bone morphogenetic protein 2 (rhBMP-2)[56,57] or synthetic cell-binding peptide P-15.[55]

Augmentation Methods Used for Ridge Preservation

From these studies, nine different methods of ridge preservation were identified. The most commonly used method was a graft that was placed in the extraction socket, covered by a membrane followed by flap advancement to achieve complete or partial primary closure.[21,23,24,26,28,30–34,37,40,41,44] The second most commonly employed technique was covering a graft by coronal advancement or rotation of the flap, but without a membrane.[22,25,29,35,36,38,42,46,47,49] Third, membranes alone were placed over the extraction socket and the soft tissue was used to fully or partially cover it.[26,33,40,50–52] Other methods investigated include placement of the graft alone,[43] covering the grafted socket with a membrane alone,[45] ridge preservation solely by coverage with a membrane,[45] placing a graft and covering with a collagen wound dressing,[39,48] placing a sponge in the socket without any coverage,[53-55,57] or placing a sponge with soft tissue coverage.[40,56] Flap elevation was required for all techniques involving a membrane, but not for all procedures with a graft or sponge.

Table 2 Effectiveness of Ridge Preservation Compared to Normal Healing from Studies Using a Comparable Methodology

Study	Method	Duration (mo)	Vertical change (mm, mean ± SD)		Horizontal change (mm, mean ± SD)	
			Test	Control	Test	Control
Lekovic et al (1997)[50]	e-PTFE membrane	6	−0.3 ± 0.3	−0.9 ± 0.3	−1.7 ± 0.6	−4.4 ± 0.5
Lekovic et al (1998)[51]	PL/PG membrane (Resolut)	6	−0.4 ± 0.2	−1.5 ± 0.2	−1.3 ± 0.2	−4.6 ± 0.2
Iasella et al (2003)[24]	FDBA and collagen membrane	4–6	1.3 ± 2.0	−0.9 ± 1.6	−1.2 ± 0.9	−2.6 ± 2.3

e-PTFE = expanded polytetrafluoroethylene; FDBA = freeze-dried bone allograft; PG = polyglycolide; PL = polylactide.

Outcomes of Ridge Preservation

Ridge Preservation Versus Healing by Clot Alone. In a study examining the healing of premolar and molar extraction sockets and measuring dimensions on study casts, Schropp et al[3] reported that the width of the alveolar ridge was reduced by 50%, from a mean of 12 mm to 6.1 mm at 12 months. Two-thirds of the loss occurred in the first 3 months. The loss of height was less substantial, but almost all of the dimensional change took place in the first 3 months. The authors suggested that the bone level at the extraction site rather than the bone level of the adjacent teeth dictated the level to which the bone crest healed after extraction.

Of the studies selected, six included a comparison with an ungrafted socket allowed to heal normally. In all but one study, ridge preservation resulted in statistically significantly greater ridge width and height. Using a bioactive alloplastic graft, Yilmaz et al[42] reported the mean width of the test sites to be 5.7 (± 1.2) mm compared to 3.9 (± 0.8) mm at the control sites. The dimensions for the ridge height were 8.0 (± 1.6) mm for the test and 7 (± 0.5) mm for the control sites. Three of the studies used similar methodology, allowing direct comparison, shown in Table 2 and reproduced from the well-performed study by Iasella et al.[24] All showed significantly better maintenance of ridge width using ridge preservation compared to allowing healing by the clot alone. Iasella et al[24] also reported significantly less change in soft tissue thickness in the test versus the control sites. Camargo et al[43] used the same measurements as the Lekovic studies,[50,51] filling the test sockets with bioactive glass and then calcium sulphate. The authors reported that the unfilled sockets showed slightly better results. Serino et al[53] investigated the effect of filling the extraction socket with a PL/PG sponge and reported that after 6 months the mean distance between the ridge and reference points was +0.2 (± 1.5) mm for the test sites and –0.7 (± 1.2) mm for the controls.

Comparison of Different Grafting Materials. Only three cited publications that reported on the comparison of grafting materials presented clinical measurements. A study by Vance et al[32] compared CMC/CaS mixed with DFDBA against DBBM and a collagen membrane, and found no significant differences between the groups. Using ADMG with or without HA, Luczyszyn et al[45] reported that ADMG alone better maintained ridge width, and use of HA allowed an increased width of keratinized tissue. Neiva et al[55] investigated the placement of a collagen wound dressing with and without Putty/P15, and showed that the addition of the putty resulted in significantly less loss of height.

In summary, there is strong evidence that ridge preservation significantly maintains more ridge width and height, with most grafting materials being effective and only slight differences between them.

Is Primary Wound Closure Necessary? The question of whether ridge-preserved extraction sites require complete soft tissue coverage was not directly addressed. Techniques used ranged from simply placing the graft in the extraction socket[55,57] to raising and replacing a flap in the original position with[45] or without a membrane exposed to the oral cavity.[32,43,53,54] Partial closure without use of a membrane was reported by Yilmaz et al[42] and Babbush.[30] Iasella et al[24] and Carmagnola et al[33] achieved partial closure but covered the exposed socket/graft with a collagen membrane, whereas Froum et al[34] left e-PTFE or ADMG exposed, advising the patients to use chlorhexidine for a prolonged period of time. One study reported the use of a soft tissue graft to completely close the socket.[29] However, the majority of studies reported primary closure. This was either by a coronally advanced flap covering the graft/socket alone[22,25,35,47,56] or covering a membrane[21,26,27,31,41,50–52] or by a pediculated split-thickness palatal flap covering the graft.[38,46]

Given the diversity of soft tissue closure and concomitant procedures, an assessment of whether primary wound closure is necessary for successful outcome is difficult. It would appear that ridge preservation can be successful irrespective of closure technique.

Effect of Tooth Type, Position, and Reason for Extraction. No information was presented showing the effect of tooth type or position in the oral cavity on ridge preservation. The majority of the studies

investigated anterior maxillary single-rooted teeth. In this area, ridge preservation seemed to maintain ridge dimension. Some publications reported on the reason for tooth loss, which included periodontal disease, endodontic failure, restorative failure, caries, fracture, and trauma. However, no comments were made in any of the papers about the cause of tooth removal and the effect this might have had on ridge preservation. It appears that ridge preservation is successful irrespective of the cause of tooth loss.

Use of Antibiotics. Twenty-six of the papers reported the use of antibiotics, either during (4 studies) or after (22 studies) the procedure. Seven studies reported antibiotics not being used, and two studies did not report antibiotic use. Antibiotics used included doxycycline, amoxycillin, augmentin, metronidazole, penicillin V, erythromycin, and cephalosporin, with some used for 5 days, some for 7, and others for 10 or 12 days. Given the wide variety of antibiotics and dose regimes, few conclusions can be drawn regarding the use of antibiotics.

Could Implants Be Placed? The ideal end point of ridge preservation is the ability to place an implant with an appropriate diameter and length in the desired restorative position. In some studies, the end point was not the ability to place an implant, but the amount and type of bone formed or the difference in dimensional changes between augmentation methods. However, implants were reported to have been placed in many of the papers.[22,23,25,28,30–34,40,44,45,47,49,52–56] These studies did not report the size of the implants placed or whether they were placed in an ideal 3D position. Interestingly, Dies et al[26] reported that only 8 out of 12 subjects received implants, but did not state why they could not be placed in the remaining 4 subjects. Sàndor et al[49] grafted anterior maxillary sockets immediately following trauma, but found that only 17.6% of sites did not require further grafting at the time of implant placement. Where studies used a control site filled with a clot alone, very often implants were placed in these sites as well.[50,51,56] In addition, Fiorellini et al[56] noted that 55% of sockets allowed to heal with blood clot alone required subsequent simultaneous augmentation, compared to fewer of the test sites. Most recently, Molly et al[40] reported that 27 of 36 ridge-preserved sites had implants placed. Implants could not be placed in the remaining sites for esthetic and biomechanical reasons.

The evidence would suggest that implants can be placed in both test and control sites, but sites that healed naturally may require adjunctive augmentation procedures. Further studies are required to assess whether an implant of the appropriate dimensions can be placed in the correct restorative position following ridge preservation.

Is Bone Formed in "Preserved" Ridges? The amount and type of bone formed has been the main focus of ridge preservation studies. Healing of a socket follows the outline described previously, and the amount of bone formed depends on the time point when the socket content is examined during the healing process.[26,44] For example, Norton and Wilson,[44] investigating the use of DBBM and an e-PTFE membrane in extraction sockets, noted that sites with fewer than 6 months of healing had no bone, whereas sites with more than 6 months had some bone, but this was minimal and confined to the socket periphery. Techniques for assessing the amount or proportion of newly formed bone in sockets varied, which makes direct comparison problematic. However, in most studies there was some new bone formed.

Overall, DFDBA seemed to be well-incorporated in newly formed bone in the socket,[27,28] and comprised between 35% and 62% of the socket content.[21,25,30,32] However, this did not result in significantly more bone than in control sites with a clot alone[21] or with DBBM.[29] Smukler et al[21] reported that up to 21.5% of the socket was made up of residual DFDBA graft particles. These studies varied in duration from 4 weeks up to 23 months.

DBBM-treated sites showed between 18% and 64% bone fill and 20% to 30% residual DBBM particles at 6 to 9 months.[32–34,37,38,40] However, these particles were well-incorporated.[38]

Using bioactive glass, Froum et al[25] reported mean new bone formation of 59.5%, compared to 34.7% with DFDBA and 32.4% in control sites after 6 to 8 months of healing. A similar percentage was observed by Vance et al[32] using bone putty, a mixture of carboxymethylcellulose (CMC), calcium sulphate (CaS), and DFDBA. Serino et al[54] noted 59.9% bone infill using a PL/PG sponge as opposed to 48.8% in sockets with clot alone. The use of hydroxyapatite resulted in a range of bone, from 1%[45] to 34.5%.[34] Bioactive glass resulted in either very little bone[44] or substantial infill.[25] Wang and Tsao[48] showed a high percentage of vital bone 5 to 6 months after placement of a solvent-preserved cancellous allograft. Molly et al,[40] in a comparative study of three materials, reported a greater mean percentage of vital bone in the sponge group than the DBBM or biocoral groups. However, control sites had the highest amount of vital bone.

Comparative studies have shown mixed evidence that one grafting material is better than another or better than just the clot alone in terms of amount of newly formed bone. Vance et al[32] suggested that the mixture of CMC, CaS, and DFDBA was better than DBBM. Froum et al[34] found that bioactive glass was better than DFDBA or the clot alone. Both Smukler

et al[21] and Serino et al[54] showed that the amount of newly formed bone was the same in both test and control sites. Carmagnola et al[33] reported that the quality of the bone was better with just the clot or a collagen membrane than with DBBM and a collagen membrane.

Many studies used a bone graft material in conjunction with a membrane. It was reported that DBBM or HA used with an ADMG membrane produced markedly better results than with an e-PTFE membrane.[34] Luczyszyn et al[45] reported an ADMG membrane to be much more effective on its own than with an HA graft. Lastly, Pinho et al[41] placed autogenous bone and covered this with a titanium membrane, but showed that the membrane alone was just as effective after 6 months.

Membrane exposure was frequent and affected the amount of bone infill.[50] Not all studies mentioned exposure rates, but Pinho et al[41] reported a rate of 25%. Using a partial-coverage technique, Froum et al[34] had to remove 75% of e-PTFE and 12.5% of ADMG membranes, which may account for the poorer results in the e-PTFE groups. An exposure rate of 31% was noted using a collagen membrane by Norton et al,[37] but this complication could be controlled by intensive use of chlorhexidine, after which the membranes re-epithelialized.

In summary, the use of grafting material allows new bone formation in extraction sockets. However, the different grafting materials and differing healing periods make comparisons between studies difficult. Membranes may increase the amount of newly formed bone in the preserved ridges, but exposure can be detrimental to the regenerative outcome. A substantial number of the publications reported remnants of graft particles, up to 75% in some sites.[37] The long-term effect of residual grafting material on implant survival and success was not reported. The material chosen may reflect operator preference, the substitution rate, the length of time before the implant is to be placed, and what is commercially available. There is a need for standardized studies comparing materials with each other and the clot over fixed time periods.

Long-term Evidence for the Stability of Ridge Preservation or Implants Placed. The majority of papers selected for this review were short-term, with observation periods of less than 6 months. There were few studies that lasted for 12 months or more. Within these short time frames, most techniques seem to maintain ridge dimensions sufficiently for implant placement. Nemcovsky and Serfaty[46] and Yilmaz et al[42] reported that the width of the ridge gained by ridge preservation was maintained under pontics for up to 12 and 24 months, respectively.

Concerning implant survival, only four papers reported such details. In sockets grafted with bioactive glass, Norton and Wilson[44] showed a cumulative success rate of 90% at 1 year and 88.6% at 18 months. In sites grafted with DBBM, Norton et al[37] showed a survival rate of 97% at baseline, the time from implant placement to restoration, which was 13 to 33 weeks. In their cohort of children/young adults, Sàndor et al[49] found 93.7% of implants still to be in function after 3 to 7 years. Lastly, in a retrospective study, Sclar[39] reported a 94% survival rate for implants placed in 248 ridge-preserved sites over 6 to 73 months using the Bio-Col technique.

There is a lack of long-term information on the longevity of preserved ridges and the survival/success of implants placed. There is almost no information on which technique or material provides a more stable long-term result. It would seem prudent not to recommend a particular technique until this information is available.

CONCLUSIONS

The publications reviewed for this paper presented many different techniques, methodologies, durations, and materials, making direct comparison difficult. Irrespective of the heterogeneity of the studies, the following conclusions were reached:

- Ridge preservation procedures are effective in limiting horizontal and vertical ridge alterations in postextraction sites.
- Ridge preservation procedures are accompanied by varying degrees of bone formation and residual graft materials in the extraction socket. This depends on the materials and techniques used.
- There is no evidence to support the superiority of one technique over another.
- The use of membranes requires soft tissue coverage to optimize treatment outcomes. Exposure of membranes may lead to compromised results. e-PTFE membranes that become exposed are more problematic than collagen membranes.
- Primary closure is not always necessary.
- Long-term data on stability of ridge and implant survival and success are limited.
- There are no data on esthetic outcomes.
- There is no conclusive evidence showing that ridge preservation procedures improve the ability to place implants.

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Consensus Statements and Recommended Clinical Procedures Regarding Surgical Techniques

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INTRODUCTORY REMARKS

Techniques and biomaterials associated with the surgical placement of dental implants continue to develop and have facilitated the expansion of clinical indications for implant therapy. However, the variety of procedures and biomaterials available can create a confusing picture for the implant surgeon who has the responsibility for recommending the most appropriate surgical approach with the lowest risk of complications and morbidity to the patient. The aim of group 4 was to review the surgical techniques and biomaterials used in current practice, and to evaluate the evidence supporting the use of these procedures.

Fourteen months prior to the conference, four groups of researchers prepared comprehensive review papers on four different topics: *(1)* clinical and esthetic outcomes of implants placed in postextraction sites, *(2)* bone augmentation procedures in localized defects in the alveolar ridge with different bone grafts and bone substitute materials, *(3)* bone augmentation procedures in extended defects in the alveolar ridge, and *(4)* ridge preservation techniques for implant therapy. The reviewers were asked to review the literature in a systematic manner, to consider all levels of evidence except for expert opinion, and to prepare narrative review papers. At the conference, these review papers were thoroughly critiqued by an international group of specialists in periodontics, oral and maxillofacial surgery, and prosthodontics, each with particular clinical expertise and research experience. First, the group was asked to consider whether the review papers were valid methodologically and whether the conclusions drawn were a fair reflection of the evidence available. Second, additional contributions by group members were called for and the manuscripts were amended if deemed appropriate. Third, preliminary consensus statements and clinical recommendations were drafted and presented to the plenum. Comments and recommendations were received from the plenum, and a final set of consensus statements and clinical recommendations were prepared.

Disclosure

All the group members were asked to reveal any conflicts of interest potentially influencing the outcomes of the consensus work. No such conflicts were identified.

IMPLANTS IN POSTEXTRACTION SITES

The following consensus statements and clinical recommendations are derived from the review paper by Chen and Buser, as well as that of Darby et al (on ridge preservation techniques).

Definition of Terms

At the 3rd ITI Consensus Conference in 2003, it was recognized that descriptive terms for the time points for implant placement after tooth extraction encountered in the dental literature were imprecise, and therefore open to interpretation. A classification system for timing of implant placement after tooth extraction was therefore proposed, based on desired clinical outcomes during healing rather than on descriptive terms or rigid time frames following extraction.[1] In this classification system, *type 1* refers to the placement of an implant into a tooth socket concurrently with the extraction; *type 2* refers to the placement of an implant after substantial soft tissue

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Table 1 Advantages and Disadvantages of the Various Time Points for Implant Placement After Tooth Extraction

Classification	Advantages	Disadvantages
Type 1	• Extraction and implant placement are combined in the same surgical procedure • Reduced overall treatment time compared to types 2, 3, and 4 • Peri-implant defects often present as two- or three-walled defects, which are favorable for simultaneous bone augmentation procedures	• Morphology of the site may increase the difficulty of placing an implant in an ideal position • Morphology of the site may compromise initial implant stability • Lack of soft tissue volume makes attainment of tension-free primary closure more difficult • Increased risk of marginal mucosal recession • Inability to predict bone modeling may compromise outcomes
Type 2	• Reduced treatment time • Additional soft tissue volume allows for easier attainment of tension-free closure • Additional soft tissue volume may enhance soft tissue esthetic outcomes • Flattening of facial bone contours facilitates grafting of the facial surface of the bone • Peri-implant defects often present as two- or three-walled defects, which are favorable for simultaneous bone augmentation procedures • Allows for resolution of pathology associated with the extracted tooth	• Two surgical procedures are required • Morphology of the site may compromise initial implant stability
Type 3	• Partial bone healing usually allows implant stability to be more readily attained • Additional soft tissue volume allows for easier attainment of tension-free closure • Additional soft tissue volume may enhance soft tissue-esthetic outcomes • Peri-implant defects often present as two- or three-walled defects, which are favorable for simultaneous bone augmentation procedures • Flattening of facial bone contours facilitates grafting of the facial surface of the bone • Allows for resolution of pathology associated with the extracted tooth	• Two surgical procedures are required • Extended treatment time as compared to type 1 and type 2 placement • Socket walls exhibit varying amounts of resorption • Increased horizontal bone resorption may limit the volume of bone for implant placement
Type 4	• Bone healing usually allows implant stability to be readily attained • Additional soft tissue volume allows for easier attainment of tension-free closure • Additional soft tissue volume may enhance soft tissue esthetic outcomes • Allows for resolution of pathology associated with the extracted tooth	• Two surgical procedures are required • Extended treatment time compared to type 1, type 2, and type 3 placement • Socket walls exhibit greatest amounts of resorption • Greatest chance of increased bone resorption limiting the volume of bone for implant placement

healing has taken place, but before any clinically significant bone fill occurs within the socket; *type 3* is placement of an implant following significant clinical and/or radiographic bone fill of the socket; and *type 4* is placement of the implant into a fully healed site.

In spite of this new classification system, descriptive terms have remained in use since 2003. Therefore, to avoid ambiguity and misinterpretation of the various time points for implant placement after tooth extraction, the descriptive terminology in the *ITI Treatment Guide, Volume 3*, as described above (see also Table 1 in the review by Chen and Buser) was adopted for this Consensus Conference.[2]

The following additional terms were defined:

- *Postextraction implant placement:* Used to collectively describe type 1, type 2, and type 3 implant placements.
- *Early implant placement:* Used to collectively describe type 2 and type 3 implant placements.
- *Peri-implant defect:* The space between the exposed implant surface and the inner surface of the walls of a fresh or healing extraction socket.
- *Ridge preservation:* A procedure to minimize vertical and horizontal ridge alterations in postextraction sites.

Healing and Regenerative Outcomes

Modeling of the ridge after extraction continues to occur following implant placement. Bone augmentation procedures are effective in promoting bone regeneration with immediate and early implant placement. Bone augmentation procedures may compensate for modeling changes and may improve ridge contours. Bone augmentation procedures are more successful with immediate and early implant placement than with late placement.

Survival Outcomes

The survival rates of postextraction implants are high and comparable to those of implants placed in healed sites.

Esthetic Outcomes

Immediate implant placement is associated with risk of mucosal recession. Risk indicators include thin tissue biotype, thin facial bone, dehiscence of the facial bone, and malposition of the implant.

Based on esthetic indices, 80% of immediate implant sites demonstrate satisfactory outcomes.

Ridge Preservation

Ridge preservation procedures following tooth extraction result in a greater orofacial dimension of bone than when no ridge preservation procedures are performed.

Advantages and Disadvantages of Implant Placement Times

There are advantages and disadvantages for each of the time points for implant placement following tooth extraction that should be carefully considered. These are described below and summarized in Table 1.

With immediate implant placement (type 1), combining tooth extraction and implant placement reduces the number of surgical procedures that the patient needs to undergo. The peri-implant defect usually presents as a two- or three-walled defect, which is amenable to simultaneous bone augmentation techniques. In addition, there is an opportunity to attach a provisional restoration to the implant soon after placement so that the patient avoids the need for an interim removable prosthesis. However, these advantages are counteracted by the increased technical difficulty of preparing the osteotomy to allow the implant to be placed with initial stability and in a good prosthetic position. There is also an increased risk of mucosal recession, which may compromise soft tissue esthetic outcomes. Additional hard and soft tissue augmentation procedures are usually required to overcome this risk, further increasing the technical demands of the procedure. Although grafting of the peri-implant defect with particulate bone or bone substitutes is readily achieved, grafting of the external surface of the facial bone is more demanding due to the convexity of the bone wall. If primary soft tissue closure is required, the lack of soft tissue increases the difficulty of attaining tension-free closure. Flap advancement may alter the mucogingival line. Clinicians should be mindful of the fact that bone modeling following tooth extraction is unpredictable. This may potentially lead to suboptimal bone regenerative outcomes and unpredictable dimensional changes.

With early implant placement (type 2), healing of the soft tissues increases the volume of mucosa at the site. This facilitates manipulation of the surgical flaps and allows flap advancement for partial submergence of the implant or primary closure to be more readily achieved. In areas of high esthetic importance, the increased volume of soft tissue may enhance soft tissue esthetic outcomes. In the 4- to 8-week period following tooth extraction, slight flattening of the facial bone wall is commonly observed. This facilitates grafting of the facial surface of the bone with bone substitutes possessing low rates of substitution. These grafts may serve to limit long-term dimensional changes of the ridge. As there is minimal bone regeneration within the socket at this time point, peri-implant defects are usually still present. However, the defects usually present with two or three intact walls, which are amenable to simultaneous bone augmentation techniques. The lack of bone regeneration within the socket may increase the difficulty of attaining initial stability of the implant. This approach allows pathology associated with the extracted tooth to resolve prior to implant placement.

For early implant placement (type 3), partial bone healing in the socket usually allows implant stability to be more readily attained compared to type 1 and type 2 placement. The soft tissues are usually fully healed, allowing tension-free closure of the site. The increased volume of soft tissue may enhance soft tissue esthetic outcomes. However, it should be noted that modeling of the bone is more advanced than with type 2 implant placement. The socket walls exhibit varying degrees of resorption that may limit the volume available for implant placement. Peri-implant defects may still be present, but they are usually reduced in orofacial dimension. Two- and three-walled defects are amenable to simultaneous bone augmentation procedures. Flattening of the facial bone facilitates grafting of the facial surface with bone substitutes, a procedure usually necessary for augmentation of ridge contour. With Type 3 placement, the increased time from tooth extraction allows healing of extended pathological defects to take place.

In late implant placement (type 4), the socket walls exhibit the greatest amount of resorption. Although the soft tissues are fully healed and manipulation of the surgical flaps is facilitated, ongoing modeling and horizontal resorption increases the risk of there being insufficient bone volume to place the implant. Additionally, there is a greater risk that peri-implant defects will present as no- or one-wall defects, compared to immediate and early implant placement.

Clinical Recommendations

- The clinician has the option of placing implants immediately, early, or late following tooth extraction. The advantages and disadvantages of each approach need to be carefully considered in order to reduce the risk of complications. Therefore, to ensure optimum outcomes, a proper risk assessment of the patient and site should be undertaken. This includes an esthetic risk assessment[3] in areas of esthetic importance.
- Whenever implants are placed in postextraction sites, the need for regenerative therapy must always be assessed. Bone augmentation is recommended to compensate for bone modeling, and to optimize functional and esthetic outcomes. In all

four placement protocols the ability to attain primary stability in the appropriate restorative position is a requirement. Presence of an acute infection is an absolute contraindication.
- Immediate implant placement (type 1) may be considered in patients and sites with a low esthetic risk profile.[3] This includes single-tooth sites with thick tissue biotypes and with thick and intact facial bone walls.
- Early implant placement with soft tissue healing (type 2) may be considered in the majority of sites due to an increased volume of soft tissue available. Early implant placement with partial bone healing (type 3) may be considered if primary stability of the implant in the correct restorative position cannot be achieved with type 2 placement.
- In sites where extensive bone modeling is anticipated, late implant placement (type 4) is the least desirable option. When Type 4 implant placement is indicated, ridge preservation procedures using low-substitution–rate graft materials and membranes are recommended. Such indications include the growing patient, where primary stability cannot be achieved with type 1, 2, or 3 placements due to anatomical restrictions, or when a delay in implant treatment is anticipated.

BONE AUGMENTATION PROCEDURES IN LOCALIZED ALVEOLAR RIDGE DEFECTS

The following consensus statements and clinical recommendations are derived from the review paper by Jensen and Terheyden. Aspects of this paper dealing with sinus floor grafting have been incorporated into the next section of these consensus statements.

Definition of Terms

The following definitions were adopted from the *Glossary of Oral and Maxillofacial Implants*[4]:

- *Autograft* (synonymous with *autogenous graft*): Tissue transferred from one location to another within the same individual.
- *Allograft:* A graft between genetically dissimilar members of the same species.
- *Xenograft:* A graft taken from a donor of another species.
- *Alloplast:* Inorganic, synthetic, or inert foreign material implanted into tissue.
- *Dehiscence:* A buccal or lingual bone defect in the crestal area extending apically at an implant.
- *Fenestration:* A buccal or lingual window defect of either bone or soft tissue, occurring over a root, implant, or alveolar ridge.

General Statements

There are a variety of augmentation materials available with different biologic and mechanical properties, ranging from particulate alloplastic materials to intraorally harvested block grafts.

There are a variety of defect situations with increasing complexity, ranging from fenestrations to dehiscences to lateral deficiencies to vertical deficiencies including combinations of these.

Survival rates of implants placed in regenerated bone after treatment of localized defects in the alveolar ridge are comparable to survival rates of implants placed in native bone. It was not possible to demonstrate the superiority of one augmentation technique over another based on implant survival rates.

Dehiscence and Fenestration-type Defects

Augmentation of dehiscence and fenestration-type defects is effective in reducing the amount of exposed implant surface. Complete resolution of dehiscence and fenestration-type defects cannot be predictably accomplished, regardless of which grafting protocol is employed.

Increased defect fill was observed when the augmentation procedure included the use of a barrier membrane.

Survival rates of implants placed simultaneously with augmentation of dehiscence or fenestration-type defects are high.

Horizontal Ridge Augmentation

Techniques are available to effectively and predictably increase the width of the alveolar ridge. Augmentation utilizing autogenous bone blocks with or without membranes results in higher gains in ridge width and lower complication rates than use of particulate materials with or without a membrane. Survival rates of implants placed in horizontally augmented alveolar ridges are high.

Vertical Ridge Augmentation

Techniques are available to increase the height of the alveolar ridge. However, the predictability is substantially lower and the complication rate substantially higher than with horizontal ridge augmentation procedures.

Augmentation utilizing autogenous bone blocks with or without membranes results in higher gains in ridge height than use of particulate materials with or without a membrane.

Survival rates of implants placed in vertically augmented alveolar ridges are high.

Maxillary Sinus Floor Elevation Using the Transalveolar Approach

Maxillary sinus floor elevation using the transalveolar approach is predictable for augmenting bone in the posterior maxilla. A variety of grafting materials can be safely and predictably used, alone or in combination. These materials include autografts, allografts, xenografts, and alloplastic materials. At present, it is not clear whether the introduction of a grafting material improves the prognosis.

Clinical Recommendations

- Dehiscence and fenestration-type defects may be successfully managed using a particulate autograft, allograft, or xenograft covered with a membrane.
- Horizontal ridge augmentations often require the use of an autogenous block graft, which may be combined with a membrane and/or a particulate autograft, allograft, or xenograft.
- Vertical ridge augmentations most often require the use of an autogenous block graft, which may be combined with a membrane and/or a particulate autograft, allograft, or xenograft. Despite the use of an autogenous block graft, elevated rates of complications and a need for additional grafting have to be anticipated. Even localized vertical bone deficiencies may require advanced surgical procedures like distraction osteogenesis, interpositional grafts, or onlay grafts from extraoral donor sites.
- The clinician should be aware that the obtainable defect fill decreases and complication rates and need for additional grafting procedures increase with more demanding defect types. The augmentation material should be selected according to the biologic and mechanical characteristics needed in the specific clinical situation.
- The use of a membrane is indicated whenever a particulate material is applied.

BONE AUGMENTATION PROCEDURES IN EXTENDED ALVEOLAR RIDGE DEFECTS

The following consensus statements and clinical recommendations are derived from the review paper by Chiapasco et al. These statements also incorporate aspects of the review paper by Jensen and Terheyden that deal with sinus floor grafting.

Definition of Terms

The following definitions were adopted from the *Glossary of Oral and Maxillofacial Implants*[4]:

- *Onlay graft:* A graft used in block form and fixed upon the cortical surface of the recipient bed with a screw. The origin may be an autograft, allograft, alloplast, or xenograft.
- *Maxillary sinus floor elevation:* An augmentation procedure for the placement of implants in the posterior maxilla where pnuematization of the maxillary sinus and/or vertical loss of alveolar bone has occurred.
- *Split-ridge technique:* An augmentation procedure to increase the width of a narrow residual ridge by surgically splitting it or expanding it with a series of osteotomes of increasing diameter.
- *Distraction osteogenesis:* A surgical process for reconstruction of skeletal deformities that involves gradual controlled displacement of surgically created fractures to simultaneously expand soft tissue and bone volume.

General Statements

Several surgical procedures are available and effective for the augmentation of deficient edentulous ridges, allowing implants to be placed. However, most of the studies are retrospective in nature, with small sample sizes and short follow-up periods. Therefore, direct comparisons between studies should not be made and definitive conclusions cannot be drawn.

Onlay Bone Grafting of Severely Resorbed Edentulous Ridges

Autogenous onlay bone grafting procedures are effective and predictable for the correction of severely resorbed edentulous ridges to allow implant placement. Uneventful healing/consolidation of grafts taken from intra- and/or extraoral donor sites occurs in the majority of cases.

Acceptable survival rates of implants placed in maxillae and mandibles reconstructed with autogenous onlay bone grafts are reported. The survival rates are slightly lower than those of implants placed in native bone.

Maxillary Sinus Floor Elevation Using the Lateral Approach

Maxillary sinus floor elevation procedures are predictable for augmentation of bone in the posterior maxilla. A variety of grafting materials can be safely and predictably used, alone or in combination. These materials include autografts, allografts, xenografts, and alloplastic materials. The use of autografts does not influence survival rates of rough-surfaced implants but may reduce healing times.

The quantity and quality of bone in the residual maxilla influence survival rates of implants independently from the type of grafting procedure.

Survival rates of rough-surfaced implants placed in augmented maxillary sinuses are similar to those of implants inserted in native bone.

Split-Ridge/Ridge-Expansion Techniques with Simultaneous Implant Placement

Split-ridge and expansion techniques are effective for the correction of moderately resorbed edentulous ridges in selected cases. Survival rates of implants placed at sites augmented using split-ridge/ridge-expansion techniques are similar to those of implants inserted in native bone.

Split-Ridge Technique with Interpositional Bone Grafts

There is a lack of evidence concerning the split-ridge technique with interpositional bone graft and delayed implant placement.

Vertical Distraction Osteogenesis

Alveolar distraction osteogenesis can be used to augment vertically deficient alveolar ridges in selected cases. It has a high rate of complications, which include change of the distracting vector, incomplete distraction, fracture of the distracting device, and partial relapse of the initial bone gain.

Survival rates of implants placed at sites augmented using distraction osteogenesis are similar to those of implants inserted in native bone.

Le Fort I Osteotomy with Interpositional Autogenous Bone Grafts

Le Fort I osteotomy with interpositional autogenous bone grafting can be used successfully to treat extreme atrophy of the maxilla associated with severe intermaxillary discrepancy. This procedure is technically demanding and is associated with considerable postoperative morbidity.

Survival rates of implants placed after Le Fort I osteotomy with interpositional autogenous bone graft are lower than those reported for implants placed in native bone.

Clinical Recommendations

- Bone augmentation procedures should always follow a prosthetically driven plan to allow ideal three-dimensional implant positioning. The concept of "prosthetically driven bone augmentation" should be taken into consideration whenever possible.

Autogenous Onlay Bone Grafting of Severely Resorbed Edentulous Ridges:

- Onlay bone grafting is a technique-sensitive procedure and is recommended only for well-trained clinicians.
- Both intraoral donor sites (including the mental symphysis, the mandibular body and ramus, and the maxillary tuberosity) and extraoral donor sites (including the iliac crest and the calvarium) can be used for collecting autogenous bone.
- The choice between intraoral and extraoral sites is mainly related to the quantity of bone necessary to reconstruct the deficient alveolar ridge. Preference should be given to donor sites where the cortical component is more prevalent, in order to reduce the risk of early or late resorption of the graft.
- Bone harvesting from the mental symphysis is associated with relevant morbidity, and the quantity of available bone is frequently limited. Neural damage to the incisal nerve occurs frequently. Therefore, the mental symphysis should not be the first choice for harvesting.
- Bone harvesting from the maxillary tuberosity is followed by low morbidity but is not well documented. The quality and quantity of available bone is often poor. Indications are limited to reconstruction of small defects.
- Bone harvesting from the mandibular ramus offers good quality and quantity of available bone, due to the possibility of harvesting from both sides.
- Bone harvesting from the iliac crest offers high quantities of bone. However, the cancellous bone component is dominant and may lead to a higher risk of unpredictable bone resorption. When bone is harvested from the anterior iliac crest there may be associated gait disturbances.
- Bone harvesting from the calvarium offers greater quantities of highly corticalized bone and is associated with low morbidity.
- Accurate modeling and stabilization of the graft with screws, and tension-free primary closure of the overlying flaps, are fundamental for the success of the procedure. Overcorrection of the defect is recommended to compensate for the potential risk of bone resorption. Coverage of the bone grafts with a low-resorption–rate xenograft/alloplastic material, with or without a membrane, may be indicated to reduce bone resorption.
- The economic and biologic costs of bone transplantation must be carefully weighed. In selected clinical situations short and/or reduced-diameter implants may be considered instead.
- The severely atrophic edentulous maxilla frequently needs onlay bone grafts due to poor quality of the residual bone and the presence of pneumatized cavities, including the maxillary sinus and the nose.
- Both implant placement in conjunction with bone grafting and delayed implant placement have been proposed. Delayed implant placement is recommended.

Split-Ridge/Ridge-Expansion Techniques:

- Split-ridge/ridge-expansion techniques are indicated in selected situations where atrophy of the edentulous ridge has developed horizontally and cancellous bone is present between the oral and facial cortical plates, and adequate residual height exists.
- Excessive facial inclination of the alveolar ridge may contraindicate this procedure, as it may worsen the initial situation from a prosthetic point of view.
- The presence of undercuts may increase the risk of bone fracture.
- This technique is mainly indicated in the maxilla. Ridge expansion in the mandible is frequently difficult due to the rigidity of the bone.

Vertical Distraction Osteogenesis:

- Vertical distraction osteogenesis is a technique-sensitive procedure and is recommended only for well-trained clinicians.
- Indications of this technique should be limited to vertically deficient ridges with adequate residual width. As the segment to be distracted has to be at least 3 mm in height, severely deficient mandibles are not good candidates due to the risk of neural damage and/or mandibular fracture.
- The presence of maxillary sinus and/or nasal cavities may be contraindications.
- The rigidity of the palatal mucosa may negatively influence the distraction vector.

Le Fort I Osteotomy with Interpositional Autogenous Bone Grafts:

- Le Fort I osteotomy with interpositional autogenous bone grafts is indicated in cases of extremely severe resorption, and where there is an unfavorable horizontal and vertical intermaxillary relationship.
- This procedure is technique-sensitive and is recommended only for well-trained clinicians.

Sinus Floor Elevation Using the Lateral Approach:

- In sites with limited initial bone height not allowing insertion of the desired implant length, sinus floor elevation via the lateral approach can be used to increase the bone height.
- As atrophy of the maxilla occurs three-dimensionally, the edentulous posterior maxilla should not only be evaluated in terms of initial bone height below the maxillary sinus but also in relation to any vertical and horizontal ridge deficiencies. If relevant vertical/horizontal intermaxillary discrepancy is present, an onlay bone augmentation may be considered to create both sufficient bone volume and proper intermaxillary relationships, to optimize implant placement and related prosthetic restoration.
- Data related to the initial clinical situation should be reported, and defects classified according to well-defined criteria.
- If the initial bone height allows primary implant stability, simultaneous implant placement (one-staged) can be recommended. In situations where primary stability cannot be achieved, the elevation of the sinus floor should be performed in a separate surgical procedure followed by delayed implant insertion (two-staged).
- Rough-surfaced implants should be utilized. Coverage of the access window with a membrane may be considered.

Sinus Floor Elevation Using the Transalveolar Approach:

- Sinus floor elevation using the transalveolar approach can be recommended in sites with sufficient alveolar crest width, initial bone height of 5 mm or more, and relatively flat sinus floor anatomy.
- The main disadvantage of this technique is possible perforation of the sinus membrane, which is difficult to manage. Therefore, the transalveolar technique should only be performed by clinicians with experience in performing sinus floor elevation via the lateral approach.
- A prerequisite for using this technique is that primary implant stability is achieved.

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