Outcome Analysis of Implant Restorations Located in the Anterior Maxilla: A Review of the Recent Literature

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Purpose: *To document the literature regarding outcomes of implant restorations in the anterior maxilla to formulate consensus statements with regard to esthetics in implant dentistry, to provide guidelines to clinicians, and to articulate remaining questions in this area to be addressed by future research.* ***Materials and Methods:*** *The following areas of the recent literature were scrutinized: treatment outcomes of implant therapy for partial edentulism (including maxillary anterior tooth replacement); anterior maxillary single-tooth replacement; effect of implant design, diameter, and surface characteristics; soft tissue stability/contours around anterior implant restorations; ceramic abutments; influence of surgical techniques; and finally, evaluation of patient satisfaction.* ***Results:*** *The use of dental implants in the esthetic zone is well documented in the literature, and numerous controlled clinical trials show that the respective overall implant survival and success rates are similar to those reported for other segments of the jaws. However, most of the published studies do not include well-defined esthetic parameters. Currently, the literature regarding esthetic outcome is inconclusive for the routine implementation of certain surgical approaches, such as flapless surgery and immediate implant placement with or without immediate loading/restoration in the anterior maxilla. Considering anterior single-tooth replacement in sites without tissue deficiencies, predictable treatment outcomes, including esthetics, can be achieved because of tissue support provided by adjacent teeth. The replacement of multiple adjacent missing teeth in the anterior maxilla with fixed implant restorations is poorly documented. In this context, esthetic restoration is not predictable, particularly regarding the contours of the interimplant soft tissue.* ***Discussion and Conclusions:*** *This review has demonstrated that scientific documentation of esthetically relevant and reproducible parameters is rather scarce. Most of the reported outcome analyses primarily focus on implant survival. Elements of anterior implant success such as maintenance or reestablishment of harmoniously scalloped soft tissue lines and natural contours should be included in future studies.* Int J Oral Maxillofac Implants 2004;19(suppl):30–42

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The aim of this section was to scrutinize the most recent literature (1997 to 2003, with some rare exceptions) with respect to publications addressing treatment outcome of implant therapy performed in the esthetic zone in general and the topic of long-term stability of esthetic implant restorations in particular. It is inherent in the nature of a theme comprising numerous subjective parameters, in this particular field of clinical dentistry, that solid scientific and clearly evidence-based data are rather scarce. However, a number of reviews, technical notes, practical guidelines, and procedures, not infrequently in the form of case reports but nevertheless providing valuable information, have been published during the last few years. Consequently, the authors tried to address this situation by pointing out articles in which recommendations were given without a scientifically proven basis. Furthermore, it appeared opportune to limit this review to

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studies related to fixed implant restorations located in the partially edentulous anterior maxilla, and to distinguish between single-tooth replacement and multiple-unit implant restorations carried out in the appearance zone. MEDLINE was used to find relevant English-language articles; searches were performed using key words such as "implants," "anterior maxilla," "outcomes," and "esthetics."

Since this article is part of a consensus conference, a number of unanimously supported statements have been defined that should provide the reader with relevant guidelines for both teaching activities and clinical practice.

Finally, an attempt was made to identify questions that remain unanswered and should be addressed by future research to define more rational, predictable, and reproducible clinical protocols.

TREATMENT OUTCOMES OF IMPLANT THERAPY FOR PARTIAL EDENTULISM, INCLUDING MAXILLARY ANTERIOR TOOTH REPLACEMENT

Numerous recently published studies have focused on treatment outcomes of implant therapy in partially edentulous patients in general and related to maxillary anterior tooth replacement in particular.[1–19] Selected publications that appear to have an impact when it comes to the discussion of esthetic aspects will be reviewed chronologically in this section.

From a retrospective study comprising 1,920 IMZ implants (Interpore International, Irvine, CA), Haas and associates[2] reported a significantly lower cumulative survival rate for maxillary implants (37.9% at 100 months of follow-up) than for mandibular implants (90.4% at 100 months of follow-up). Implants placed in the anterior region of the maxilla failed significantly more often than those placed in the posterior region. Length and diameter of the implants had no significant influence on the cumulative survival rate.

Eckert and Wollan[3] published a retrospective evaluation of up to 11 years of a total of 1,170 implants placed in partially edentulous patients and found no differences in survival rates related to the anatomic location of the implants. A meta-analysis concerning implants placed for the treatment of partial edentulism was carried out by Lindh and coworkers.[4] The 6- to 7-year survival rate for single-implant crowns was 97.5%, while the survival rate of implant-supported fixed partial dentures (FPDs) was 93.6%.

Wyatt and Zarb[5] published a longitudinal study on 77 partially edentulous patients, involving 230 implants and 97 FPDs, with an observation period of up to 12 years (mean 5.41 years) after loading. The average implant success rate was 94%, while the continuous stability of the related prostheses (fixed partial dentures) corresponded to 97%. This study comprised 70 anterior and 31 posterior maxillary implants. No significant differences with respect to longevity could be detected either between anterior and posterior locations or between maxillary and mandibular implant restorations.

A 3-year prospective multicenter follow-up report (designed as a randomized clinical trial [RCT]) on the immediate and delayed-immediate placement of implants was published by Grunder and coworkers,[6] comprising 264 implants placed in 143 patients. Over a period of 3 years, the implant survival rate was 92.4% in the maxilla and 94.7% in the mandible.

Moberg and colleagues[7] published a prospective evaluation of single-tooth restorations supported by ITI hollow-cylinder dental implants (Institut Straumann, Waldenburg, Switzerland) placed in the anterior maxilla involving 30 implants. After a mean observation period of 3.4 years, the cumulative success rate was 96.7%. Nineteen implants had been restored with octa-abutments and screw-retained metal-ceramic crowns, while 10 implants received all-ceramic crowns cemented to conical solid abutments. Only minor bone loss had occurred around the implants, and no other significant complications were observed.

The long-term results of 1,964 implants (Brånemark [Nobel Biocare, Göteborg, Sweden]; Frialit-1 and Frialit-2 [Friadent, Mannheim, Germany]; IMZ [Interpore International]; and Linkow [Linkow, New York, NY]) over 16 years were recently evaluated retrospectively to determine the respective success.[8] For all systems, mandibular implants were generally more successful than maxillary implants. The overall preprosthetic loss rate was 1.9%, and 4.3% of implants were lost after prosthetic treatment. Single-tooth replacements were among those with the most predictable treatment outcomes.

The survival and stability of 6 implant designs from the time of placement to 3 years later were evaluated in a multicenter study involving more than 2,900 implants.[9] When considering the post-loading analysis, the authors concluded that uncoated implants (commercially pure titanium and titanium alloy screws) showed increased stability following loading (up to 99.4% survival) in comparison to hydroxyapatite (HA)-coated implants, which showed a slight decrease in stability.

The same authors,[10] analyzing the same clinical material published in the previous study, emphasized that reporting of implant survival rates based on the

postloading method provides more favorable survival rates. Accounting for all implants, however, provides a more accurate method of determining survival.

Davarpanah and coworkers[11] carried out a prospective controlled multicenter clinical trial comprising 1,583 3i implants (Implant Innovations, Palm Beach Gardens, FL) with a 1- to 5-year observation period. With a cumulative implant survival rate of 96.5%, their data confirmed the high overall degree of predictability of implant therapy in partially edentulous jaws. More specifically, they found a slightly higher survival rate in the maxilla (97.2%) than the mandible (95.8%), but a similar survival rate in anterior (96.7%) and posterior (96.5%) segments. In addition, this clinical study gives evidence of high success rates using different threaded implant designs.

Leonhardt and associates[12] followed long-term (10 years) a cohort of 15 prospectively documented patients who had been treated for advanced periodontal disease and thereafter had been enrolled in a maintenance program. The reported cumulative implant survival rate was 94.7% after 10 years. Furthermore, the results of the study suggested that the presence of certain putative periodontal pathogens in implant sites may not be associated with impaired implant treatment. The authors claimed that these species were most probably part of the normal resident microbiota of most individuals and may therefore be found at random in both stable and progressing peri-implant sites.

Biologic outcomes of implant-supported restorations in the treatment of partial edentulism were investigated in a longitudinal clinical evaluation.[13] A total of 1,956 Brånemark System implants were placed in 660 patients between 1982 and 1998. The resulting estimated cumulative survival rates were 91.4% for all implants and 95.8% for all restorations over a period of 16 years. Neither jaw site nor implant position (anterior/posterior) had any significant effect on the outcomes.

The radiographic analysis of the same clinical material,[14] assessing marginal bone height maintenance, confirmed the excellent prognosis of the currently utilized implants to support restorations in the treatment of partial edentulism. More specifically, no statistically significant differences in bone level change were predicted either for anterior or posterior sites or for single-tooth implant restorations or connected implants.

The clinical effectiveness of fixed implant prosthodontic management of anterior maxillary partial edentulism was recently investigated in 19 cases in a long-term prospective study.[15] In this study, the implant-supported FPDs had been followed for an average of 12 years (range from 7 to 16 years). The overall survival rate of the implants was 92%, thus demonstrating a high survival rate for Brånemark System implants supporting FPDs for the management of anterior partial edentulism.

More recently, Carr and colleagues[16] reported a cumulative survival rate of 97% in a retrospective cohort study of 308 patients and 674 single-stage dental implant prostheses with a follow-up of up to 7 years. No failures were recorded after 13 months. Prosthetic complications were low (less than 4%), especially for fixed implant prostheses. It was concluded that the clinical performance of 1-stage dental implant prostheses demonstrated a high level of predictability.

In a prospective multicenter clinical trial, the long-term performance of 3i machined-surface implants was investigated.[17] A total of 1,179 3i standard threaded and self-tapping implants were followed for up to 6 years, including a significant number of single-tooth replacements in the anterior maxilla. The respective life table cumulative success rate was 91.1%.

There have been very few systematic reviews conducted according to the principles of evidence-based dental medicine and implementing the standards established by the Cochrane Collaboration. Two such reviews were conducted by Esposito and associates.[18,19] In their first systematic review,[18] the authors aimed to test the null hypothesis that there was no difference in clinical performance between various types of osseointegrated root-form implants, with the awareness that dental implants are currently available in different materials and shapes and with different surface characteristics. In particular, numerous implant surface modifications have been developed for enhancing clinical performance. Consequently, the authors included all RCTs of oral implants, comparing those with different materials, shapes, and surface properties and having a follow-up of at least 1 year. Thirty publications, representing 13 different RCTs, were identified. Five of these RCTs (7 publications), which reported results from a total of 326 patients, were suitable for inclusion in the review. Six implant systems were compared—Astra Tech (Astra, Mölndal, Sweden); Brånemark; IMZ; ITI; Steri-Oss (Nobel Biocare); and Southern (Irene, South Africa)—with a follow-up ranging from 1 to 3 years. There was no evidence that any of the implant systems was superior to the other. More RCTs should be conducted, with a follow-up of at least 5 years and including a sufficient number of patients, to determine whether a true difference exists.

In their second systematic review,[19] Esposito and coworkers tested the null hypothesis that there was no difference between different interventions for

maintaining or re-establishing healthy tissues around dental implants. In this context, 9 RCTs were identified. Five of these trials, which represented data from a total of 127 patients, were suitable for inclusion in the review. The reviewers concluded that there is only a little reliable evidence to support the effectiveness of one intervention over another for maintaining the health of peri-implant tissues. There is a definite need for RCTs investigating the most effective approach for the treatment of peri-implantitis.

TREATMENT OUTCOMES OF IMPLANT THERAPY FOR MAXILLARY ANTERIOR SINGLE-TOOTH REPLACEMENT

A prospective study on the longitudinal clinical effectiveness of osseointegrated dental implants for single-tooth replacement reported a 100% survival rate for the 27 anterior maxillary implants involved.[20] The observation period ranged from 1.4 to 6.6 years (mean 2.9 years). This was one of the first studies suggesting that the osseointegration technique could be successfully adapted for use in patients with a single missing tooth.

In a retrospective study of 236 patients treated with single-tooth implant restorations in the anterior maxilla,[21] a Kaplan-Meier survival rate of 89% was found for an observation period of 10 years. The failure rate for lateral incisor replacement was lower than that for the central incisors. Furthermore, 5% of the related prosthetic suprastructures had to be replaced during the 10 years of observation.

Excellent 5-year multicenter results for 71 single-tooth replacements in the anterior maxilla (implant success rate of 96.6%) were reported by Henry and coworkers.[22] However, this group mentioned an associated 10% esthetic failure rate.

Kemppainen and colleagues[23] prospectively documented 102 implants (Astra and ITI) for single-tooth replacement in the anterior maxilla in 82 patients and found survival rates of 97.8% and 100%, respectively, after 1 year.

In another prospective study of single-tooth maxillary anterior implants in 15 patients, there was a 100% survival rate after 2 years of function.[24] At crown insertion (6 months after implant placement), the mean bone level was located 0.47 mm apically from the top of the implants. No significant additional changes in crestal bone level occurred during the remainder of the study.

In a review article,[25] the potential effects of adult growth and aging on maxillary anterior single-tooth implants were addressed. The authors pointed out that growth changes do occur in adults and result in adaptive changes in the teeth over time, both vertically and horizontally, and in alignment. The changes may require maintenance adjustments or possible remaking of the implant crown as a result of adult growth, wear, or the esthetic changes of aging.

Astra single-tooth implants, placed for the replacement of anterior maxillary teeth, were evaluated prospectively in a 5-year clinical trial involving 15 implants.[26] No implant losses were observed, and no abutment screw loosening or soft tissue problems occurred. At crown insertion, the mean bone level was 0.46 ± 0.55 mm to 0.48 ± 0.56 mm apical to the top of the implant neck, and there were no statistically significant changes in the radiographic bone level over the 5 years of the study. One crown was recemented after 18 months in function and 1 crown was replaced because of a fracture to the porcelain incisal edge.

As part of a large multicenter study, various implant-supported prosthesis designs were evaluated for effectiveness following 36 months of clinical function.[27] A success rate of 98.1% was found with regard to cemented anterior maxillary single-tooth prostheses, reinforcing the predictability of this specific suprastructure design.

The clinical effectiveness of angulated implant abutments was evaluated in a 5-year randomized clinical trial that included a significant number of anterior maxillary single-tooth restorations.[28] High overall survival rates were reported, and an increasing degree of angulation did not negatively affect the survival rate. Furthermore, good esthetic and functional outcomes were observed.

The survival rates of immediately restored single-tooth implants, placed either immediately in fresh extraction sockets or in healed sites, were studied by Chaushu and coworkers[29] in a controlled clinical trial. Twenty-eight immediately loaded implants, 19 placed in extraction sockets and 9 in healed sites, were followed for 6 to 24 months. The respective survival rates were 82.4% (extraction sockets) and 100% (healed sites). While the reported radiographic marginal bone loss after 3 to 6 months did not extend beyond the implant-abutment junction, no information related to soft tissue stability was provided. Within the limits of this study, it was concluded that immediate loading of single-tooth implants placed in healed sites is a possible treatment alternative, whereas immediate loading of single-tooth implants placed in fresh extraction sockets carried a risk of failure of approximately 20% in this patient population.

The influence of flap design on peri-implant interproximal crestal bone loss around maxillary anterior single-tooth implants was investigated

prospectively by Gomez-Roman.[30] A widely mobilized flap design that included the papillae was compared to a limited flap design that protected the papillae. The amount of interproximal crestal bone loss was associated with the type of flap design; the limited flap design led to statistically significantly less crestal bone loss.

A long-term follow-up of 76 single-tooth Brånemark System implants was recently published by Haas and associates,[31] who reported a Kaplan-Meier survival probability of 93% after 120 months. Seventy-four percent of the sites showed healthy peri-implant soft tissues. For 15 implants (22%), bone resorption of more than 2 mm was observed on intraoral radiographs. The mean bone resorption was 1.8 mm in the maxilla and 1.3 mm in the mandible and did not increase with time.

Andersen and colleagues[32] prospectively evaluated the success rate of immediately restored single-tooth ITI plasma-sprayed (TPS) solid-screw implants in the anterior maxilla. Temporary acrylic resin restorations were adjusted to prevent any direct occlusal contacts and connected 1 week after implant placement. After 6 months, the transitional restorations were replaced by definitive ceramic crowns. None of the 8 implants were lost during the 5-year observation period, and the mean marginal bone level increased by 0.53 mm (range, –0.83 to +1.54 mm) from placement to the final examination. Only minor complications were noted, and overall patient satisfaction was high.

Gibbard and Zarb[33] recently published a prospective 5-year study of implant-supported single-tooth replacements. The original study, initiated in 1986, comprised 42 consecutively treated patients with a total of 49 implants. For the preparation of this report, 30 of the remaining 42 implants were assessed during recall examinations. In addition to well-established success criteria, the study evaluated soft tissue appearance, implant mobility, occlusal parameters, proximal contacts, tightness of crown and abutment screws, and patients' responses on satisfaction questionnaires. The criteria defining success of therapy in implant prosthodontics were met by all 30 of the single-tooth implants, which had been in place for 5 or more years, emphasizing that stable long-term results can be achieved with anterior single-implant crowns.

Krennmair and coworkers[34] retrospectively followed 146 Frialit-2 implants over a 7-year observation period, including 38 placed in maxillary anterior single-tooth sites. The cumulative implant survival rate was 97.3% and that of the crowns was 96.4%. With the low number of abutment screw loosenings (3.5%), the deep internal hexagonal retention compared favorably to the external retention designs. The authors concluded that predominant use of long implants (98.4% were 13 mm or longer) allowed a favorable implant/crown ratio, with the potential for problem-free long-term results.

A 7-year life table analysis of the data from a prospective study of 187 ITI dental implants used for single-tooth restorations evaluated the respective clinical effectiveness.[35] The implants placed in the maxilla (30.5%) yielded a survival rate of 100%. It was concluded that, under standard anatomic conditions (bone site height > 8 mm, thickness > 6 mm), prosthetic restoration of partially edentulous patients with ITI single-tooth implant restorations is a predictable therapy over the long term.

Kan and colleagues[36] evaluated the feasibility of immediate placement and provisionalization of maxillary anterior single-tooth implants in a prospective 1-year study. Thirty-five patients with 1 implant site each were included in this study. At 12 months, all implants remained osseointegrated. The mean marginal bone loss was –0.26 ± 0.40 mm mesially and –0.22 ± 0.28 mm distally, and the mesial and distal papilla level changes from pretreatment to 12 months were –0.55 ± 0.53 mm and –0.39 ± 0.40 mm, respectively. The results of this study suggest that favorable implant success rates, peri-implant tissue responses, and esthetic outcomes can be achieved with immediately placed and provisionalized maxillary anterior single-tooth implants.

Data collected from patients who were treated with anterior maxillary single-tooth implants according to an immediate loading protocol were recently published by Lorenzoni and associates.[37] This prospective 1-year study comprised 9 patients who had received 12 Frialit-2 implants. At the 1-year follow-up, all implants were considered successful, revealing a mean coronal bone level change at 6 and 12 months of 0.45 mm and 0.75 mm, respectively. The authors emphasized that successful immediate loading protocols required careful and strict patient selection aimed at achieving the best primary stability and avoiding any excessive functional and nonfunctional loading.

The same group of authors[38] also published a comparison of immediately loaded implants (n = 14) and nonloaded implants (n = 28). No implant failures were observed up to the prosthetic restoration 6 months postplacement. The mean bone level changes at prosthetic seating were 0.9 mm resorption for the loaded implants and 0.33 mm for nonloaded implants. This difference was statistically significant.

EFFECTS OF IMPLANT DESIGN, DIAMETER, AND SURFACE CHARACTERISTICS

Friberg and coworkers[39] compared the standard Brånemark System implant (n = 275) to the self-tapping Mk II implant (n = 288) (Nobel Biocare) in a controlled clinical trial with an observation period of 5 years. Overall, this study revealed equal cumulative success rates for both implant types. Mandibular implants exhibited greater success rates (100%) than maxillary implants (87%) for both tested designs.

The influence of implant design and surface texture was investigated by Norton[40] by means of a radiographic follow-up of 33 implants loaded for up to 4 years. A most favorable maintenance of marginal bone around the conical collar was revealed, with a mean marginal bone loss of 0.32 mm mesially and 0.34 mm distally for the whole group.

Multicenter data in the form of a controlled clinical trial comparing 2 different surface textures (machined versus TiO-blasted Astra Tech dental implants) were published by Karlsson and associates.[41] One hundred thirty-three implants (48 maxillary and 85 mandibular) were placed in 50 partially edentulous patients and followed for 2 years. The cumulative survival rates were 97.7% for implants and 95.7% for prostheses. There was a slight, but statistically insignificant, difference in survival rates between the 2 surfaces: 100% for TiO-blasted and 95.3% for machined. However, no significant differences in crestal bone loss were found between the 2 types of implants.

Andersen and coworkers[42] evaluated the safety and effectiveness of narrow-diameter threaded implants in the anterior region of the maxilla in a prospective, controlled clinical trial. Two of the 32 reduced-diameter implants, replacing either a central or a lateral incisor, were lost after 6 months, but no other failures were subsequently observed. The radiographically assessed marginal bone loss followed the same pattern as that associated with standard-diameter implants and was a mean of 0.4 mm from the first to the last examination (3 years after loading).

In a randomized, prospective 5-year trial, Gotfredsen and Karlsson[43] evaluated whether there was a difference between machined and TiO_2-blasted implants (Astra Tech) regarding survival rate and marginal bone loss. Forty-eight implants were placed in the maxilla and 85 were placed in the mandible. Fixed partial dentures were fabricated and each supported by at least one machined and one TiO_2-blasted implant. No significant difference in marginal bone loss between the 2 surface groups was found during the 5-year observation period. The cumulative implant survival rates were 100% for the TiO_2-blasted implants and 95.1% for the machined implants.

Khang and coworkers[44] recently published results from a randomized controlled trial involving 97 patients that compared dual acid-etched and machined-surface implants in various bone qualities. Of the 432 implants (247 dual acid-etched, 185 machined-surface), 36 implants failed (12 dual acid-etched and 24 machined-surface). The authors concluded that the difference in success rates was most likely attributable to the acid-etched surface characteristics. The greatest performance difference was observed in the conditions of "poor quality" or "soft" bone, where the 3-year postloading cumulative success rates were 96.8% (dual acid-etched) and 84.8% (machined-surface).

The clinical effectiveness of implants with either a sandblasted and acid-etched (SLA) or a TPS surface was recently compared in a controlled clinical trial involving 68 SLA and 68 TPS sites (ITI/Straumann).[45] One year after implant surgery, clinical and radiographic measurements were carried out. No significant differences were found with respect to the presence of plaque, bleeding on probing, mean pocket depth, or mean marginal bone loss. It was concluded that SLA implants were suitable for early loading at 6 weeks.

A randomized controlled trial conducted by Engquist and associates[46] aimed to compare Astra Tech and Brånemark System implants, primarily with respect to marginal bone changes, during an observation period of 3 years. Sixty-six patients were included in the study and randomly assigned to treatment with Astra Tech implants (n = 184) or Brånemark System implants (n = 187). The mean bone loss in the maxilla between baseline and 3 years was 0.2 ± 0.3 mm for Astra Tech implants and 0.2 ± 0.1 mm for Brånemark System implants. In this study, however, the survival rate of Astra Tech implants was significantly higher (98.9%) than that of Brånemark System implants (95.2%).

A new, biologically derived implant design that conceptually may minimize bone remodeling and promote better bone and overlaying gingival contours and stability was recently introduced by Holt and colleagues.[47] The authors claim that the proposed parabolic implant shoulder design is in harmony with the biologic width of the soft tissue around the circumference of the implant when the proximal bone is occlusal to the facial and lingual bone. This is of particular interest in esthetic areas, where interproximal bone loss between implants may cause a reduction in the height of gingival papillae.

The purpose of a prospective clinical trial carried out by Gerber and associates[48] was to examine the

influence of a 1-mm lengthening of the rough surface (TPS) on ITI Esthetic Plus implants on the peri-implant soft and hard tissues. Twelve patients with 21 implants were evaluated 10 and 32 months after implant placement. The mean DIB (distance between implant shoulder and first implant-bone contact) score was 2.19 mm after 32 months. The average DIB score of implant sites adjacent to natural teeth was 1.90 mm (leaving only 0.1 mm of rough surface uncovered). In contrast, the mean DIB scores of implant sites adjacent to other implants (2.63 mm) or distal-extension situations (2.79 mm) were significantly higher. These data indicate that not only the length of the machined implant neck, but also the neighboring structures, influence the peri-implant soft and hard tissues.

To address the still-existing controversy over the long-term clinical effectiveness of HA-coated dental implants, McGlumphy and coworkers[49] published a 5-year prospective study of 429 implants placed in 121 patients. At the time of that report, 375 implants had completed 5 years of clinical follow-up, 282 implants 6 years, and 114 implants 7 years. The cumulative survival rate was 96% at 5 years and 95% at 7 years. It was concluded from that study that the HA-coated cylindric implants provided a predictable means of oral rehabilitation.

SOFT TISSUE STABILITY AND CONTOURS AROUND ANTERIOR IMPLANT RESTORATIONS

Soft tissue stability around implant restorations and adjacent teeth is of paramount importance within the esthetic zone. In this context, in 1997 Jemt proposed a reproducible index to assess the size of the interproximal gingival papillae adjacent to single-implant restorations.[50] Preliminary testing of the index, performed retrospectively on 25 crowns in 21 patients, indicated a significant regeneration of papillae after a mean follow-up period of 1.5 years. It was concluded that this index allows objective assessment of the soft tissue contour adjacent to single-implant restorations.

Scheller and associates[51] addressed soft tissue stability in their 5-year prospective multicenter study of 99 implant-supported single-crown restorations. The authors reported overall cumulative success rates of 95.9% for implants and 91.1% for implant crowns. Soft tissue levels around implant restorations and adjacent teeth remained stable over the entire evaluation period.

Chang and colleagues[52] carried out a comparative evaluation of crown and soft tissue dimensions between implant-supported single-tooth replacements and the contralateral natural teeth, involving 20 patients with an implant in the esthetic zone of the maxilla and a minimal follow-up of 6 months. The results showed that, in comparison with the natural control tooth, the implant crown was longer, had a smaller faciolingual width, was bordered by a thicker facial mucosa, had a lower height of the distal papilla, showed a higher frequency of mucositis and bleeding on probing, and had greater probing depth. With regard to the papillae adjacent to the implant crown, the longitudinal evaluation revealed an improved proximal soft tissue fill. Visual analogue scale (VAS) scoring of the patients' satisfaction with the appearance of their implant crowns showed a median value of 96%, with a range from 70% to 100%. Thus the observed differences between implant crowns and natural teeth may be of minor importance for most patients' subjective appreciation of the esthetic outcome of anterior implant therapy. These findings were confirmed by the same group of authors in a study assessing esthetic outcomes of implant-supported single-tooth replacements by the patient and by prosthodontists.[53] In fact, parameters considered by professionals to be of significance for the esthetic result of the restorative treatment may not be of decisive importance for the patient's satisfaction.

Jemt[54] published results from a randomized clinical trial comprising 55 patients with 63 single implants, which aimed to restore the gingival contour by means of provisional resin crowns. The data indicated that the use of provisional crowns may restore soft tissue contours faster than healing abutments alone, but the papillae adjacent to single-implant restorations presented similar volume in both groups after 2 years in function. The author focused on the need for more scientific data to evaluate different clinical procedures for optimizing esthetic results in implant dentistry.

The stability of the mucosal topography around 10 anterior maxillary single-tooth implants and adjacent teeth was evaluated by Grunder.[55] The 1-year results revealed that soft tissue shrinkage on the vestibular (labial) aspect of the implant crowns was 0.6 mm on average. The soft tissue volume in the papilla area, however, increased on average by 0.375 mm, and none of the involved papillae lost volume.

In a clinical report, Wheeler and coworkers[56] addressed the various parameters likely to have an impact on tissue preservation and maintenance of optimum esthetics. The authors pointed out that recently developed tapered implants facilitate immediate implant placement, predictably preserving the osseous structure surrounding the extraction

socket. Along the same line, the use of special custom healing abutments may significantly contribute to the preservation of the crestal soft tissues, including the papillae.

The incidence of gingival recession around implants was evaluated in a 1-year prospective study comprising 63 implants.[57] The investigation, which measured the soft tissue around implants following surgery, aimed at determining whether a predictable pattern of soft tissue changes could be identified. Eighty percent of all sites exhibited recession on the buccal aspect, and the majority of the recession occurred within the first 3 months. The authors claimed that, as a general rule, one can expect approximately 1 mm of recession from the time of abutment connection surgery.

Choquet and coworkers[58] carried out a retrospective clinical and radiographic evaluation of single-tooth implants located in the maxillary anterior segment. The study comprised 26 patients and 27 implants and their respective natural control teeth. In particular, 52 papillae were available for specific esthetic evaluation. The data indicated that when the measurement from the interproximal contact point to the bone crest was 5 mm or less, the papilla was present in almost 100% of cases. When the distance was ≤ 6 mm, the papilla was present 50% of the time or less. The authors concluded that these results clearly showed the influence of the bone crest on the presence or absence of papillae between implants and adjacent teeth.

Hermann and associates[59] have emphasized that gingival esthetics strongly depends on a stable and constant vertical dimension of healthy periodontal soft tissues, commonly referred to as *biologic width*. The purpose of their experimental study was therefore to histometrically assess peri-implant soft tissue dimensions dependent on varying locations of a rough/smooth implant border in 1-piece implants or a microgap (interface) in 2-part implants in relation to the bone crest. Two-piece implants were placed according to either a submerged or a nonsubmerged protocol. The results suggest that the gingival margin is located more coronally and biologic width dimensions are more similar to natural teeth around 1-piece nonsubmerged implants compared to either 2-piece nonsubmerged or 2-piece submerged implants.

Oates and colleagues[60] evaluated long-term changes in soft tissue height on the facial surface of dental implants. One hundred six 1-stage ITI implants, located in the anterior maxilla and mandible, were analyzed in 39 patients. The purpose of the study was to assess the long-term changes in the position of the facial (vestibular) soft tissue margins following restoration of the respective implants. There were no implant failures over a period of 2 years. Overall, on the facial aspect of 61% of the 106 implants, there was 1 mm or more of soft tissue recession, whereas 19% of the implants showed 1 mm or more of gain in soft tissue height. It was concluded that the potential for significant changes in soft tissue levels (loss or gain) after completion of restorative therapy needs to be considered for implant therapy in the esthetic zone.

Organization of the connective tissue barrier around long-term loaded implant abutments was recently investigated in humans.[61] Block specimens containing smooth titanium implant abutments and the surrounding supracrestal connective tissue, obtained from patients rehabilitated for at least 1 year, were investigated histologically. The histologic features comprised a connective tissue rich in collagen fibers, organized in bundles, and presenting a constant spatial arrangement similar to that found in animal trials. Circular fibers, the most common, were located externally and longitudinal fibers more internally. Radial fibers inserted on the abutment surface, similar to those of the periodontal system, were not observed in any case.

The predictability of soft tissue form around single-tooth implant restorations has been addressed in a recently published retrospective study.[62] This photographic examination followed 55 single-implant restorations in 51 patients for a period of 1 to 9 years. Papillae regenerated in 83.9% of implants, for a mean growth of 0.65 mm mesially and 0.62 mm distally. The sulcular apex receded in 59% of patients, for a mean of 0.06 mm. Complete papilla fill was noted in 75% of patients examined. The author concluded that predictable soft tissue profiles can be achieved with a simplified implant prosthetic protocol that progresses directly from healing abutments to definitive crowns in most cases.

The effect of intracrevicular restoration margins on peri-implant health around esthetic implants was studied by Giannopoulou and coworkers[63] in 45 systemically healthy patients with 61 maxillary anterior implants. Clinical, microbiologic, and biochemical parameters were recorded at baseline and again after 3 years. The only statistically significant differences between baseline and follow-up examination concerned probing pocket depth and DIM (distance between implant shoulder and mucosal margin) measurements, which increased slightly. Based on an observation period of up to 9 years (mean 6.8 years at the time of the follow-up examination), it was concluded that in patients with appropriate oral hygiene, the intracrevicular position of the restoration margin does not appear to adversely affect peri-implant health and tissue stability.

CERAMIC ABUTMENTS

Andersson and associates[64] followed 57 patients for 2 years and 34 patients for 3 years in a controlled clinical trial of the CeraOne System (Nobel Biocare). Ninety-five percent of the single-tooth implants studied were restored with all-ceramic crowns. A cumulative implant success rate of 97.3% was reported at the 3-year examination. Two all-ceramic crowns fractured following trauma, but no crowns fractured when exposed to common bite forces. It was concluded that the system consistently achieved good esthetic results and efficiently avoided complications such as screw loosening and fistula formation.

In experiments with dogs, Abrahamsson and colleagues[65] examined whether the material used in the abutment part of an implant system had an influence on the quality of the mucosal barrier that formed following implant placement. The materials tested were commercially pure titanium, gold alloy, highly sintered aluminum oxide (Al_2O_3), and porcelain fused to gold. It was demonstrated that the material used in the abutment portion of the implant influenced both the location and the quality of the peri-implant mucosal attachment. Titanium and ceramic abutments permitted the formation of a mucosal attachment, which comprised epithelial and connective tissue portions that were about 2 mm and 1 to 1.5 mm high, respectively. At sites where gold alloy or metal-ceramic abutments were inserted, soft tissue recession and crestal bone resorption were observed, thereby occasionally exposing the abutment-implant junction. The authors suggested that this was the result of varying adhesive properties of the materials studied or variations in their resistance to corrosion.

In a clinical trial, the eventual influence of different implant abutment materials on bacterial colonization and the role of colonization in the development of peri-implant infections were addressed.[66] For that purpose, samples of titanium and novel ceramic abutments were adapted to the posterior region in 2 mandibular quadrants of 4 volunteers. The maximum colonization was achieved after 24 hours in the oral cavity, and the bacterial counts remained constant over the 14-day experimental period. No significant differences were observed between the 2 materials analyzed in this study.

In a randomized, controlled, multicenter trial, Andersson and coworkers[67] evaluated the short- and long-term clinical function of CerAdapt ceramic abutments (Nobel Biocare) supporting short-span FPDs. One hundred five implants had been placed in a total of 32 patients at 3 different clinics. After 2 years, a cumulative survival rate of 97.1% for implants and a cumulative success rate of 97.2% for FPDs (94.7% for ceramic abutment–supported FPDs and 100% for titanium abutment–supported FPDs) were reported. More crown margins were placed submucosally on titanium (31%) than on ceramic (14%) abutments, and the level of the peri-implant mucosa remained relatively stable. There was some marginal bone loss recorded after 1 year, which was slightly more pronounced around the titanium (0.4 mm) than the ceramic (0.2 mm) abutments. The authors considered the results very encouraging for ceramic abutments supporting short-span FPDs. However, ceramic materials tend to undergo static fatigue, and it is therefore important to wait for the 5-year data before making statements related to the long-term prognosis of such abutments.

Kucey and Fraser[68] reviewed currently available techniques for creating the Procera custom abutment (Nobel Biocare) and described the related clinical and laboratory procedures recommended for the use of this computer-aided design/computer-assisted manufacture (CAD/CAM) implant component. The authors emphasized that well-known problems with inventory of components, incorrect abutment selection, poor tissue contours, and angulation can be avoided, or at least reduced, by using this type of abutment. Concerns about dissimilar metals and about interfaces between machined and cast components are eliminated. They furthermore concluded that the routine implementation of this technology requires experience with direct implant shoulder-level impressions, and that there is potential for complications from incomplete removal of cement.

In their randomized controlled trial, Andersson and colleagues[69] compared results after 1 to 3 years when single-tooth implant crowns were supported either by ceramic (93% success rate) or titanium (100% success rate) abutments. Stable soft tissue and marginal bone situations were found around both types of abutments. Clinicians and patients rated the esthetic results as excellent for nearly all cases. It was concluded that ceramic abutments have an excellent esthetic potential, but the associated guidelines must be meticulously followed because ceramic abutments are more sensitive to handling procedures than titanium abutments.

Boudrias and coworkers[70] presented—in the form of case reports—a newly developed, densely sintered aluminum oxide ceramic abutment, designed and machined using CAD/CAM technology. The authors pointed out that this specific manufacturing method improves clinical management of the submucosal depth of the crown-to-abutment interface and thereby enhances the esthetic qualities of the

resulting restoration. However, because of the inferior mechanical resistance in comparison to titanium abutments, the use of such ceramic abutments should be confined to the restoration of incisors and premolars not subjected to excessive occlusal load.

The bacterial colonization of zirconia ceramic surfaces was recently studied in vitro and in vivo.[71] The authors found that, overall, zirconia ceramic surfaces developed for implant abutments accumulate fewer bacteria than commercially pure titanium, and may therefore be considered as a promising material for abutment manufacturing.

Cho and associates[72] investigated the in vitro fracture strength of implant-supported restorations using milled ceramic abutments and all-ceramic crowns. The fracture strengths under vertical loading were greater than those under oblique loading. However, the fracture strengths of metal-ceramic crowns cemented to titanium abutments were significantly higher than those of all-ceramic crowns cemented to milled ceramic abutments, regardless of loading direction.

In 2003, Andersson and colleagues[73] published prospective multicenter data from a randomized controlled clinical trial comparing the long-term function of CerAdapt ceramic abutments to titanium abutments supporting short-span FPDs. An average 97.2% cumulative success rate was reported after 5 years (94.7% for ceramic and 100% for titanium abutment–supported FPDs). The authors concluded that safe long-term functional and esthetic results can be achieved with CerAdapt alumina ceramic abutments on Brånemark System implants used for short-span FPDs.

Henriksson and Jemt[74] performed a prospective 1-year follow-up study of custom-made Procera ceramic abutments for single-tooth replacement. Twenty consecutively treated patients were provided with 24 single-implant restorations using customized ceramic abutments. Thirteen crowns were cemented to the abutment and 11 restorations were fabricated by fusing the veneering material directly onto the ceramic abutment. All implants and restorations were in function after 1 year. The authors concluded that these short-term data indicate that customized ceramic abutments are successful and have similar function, regardless of their fabrication mode.

Lang and coworkers[75] evaluated in vitro the precision of fit between the Procera custom abutment and various implant systems. The authors concluded that the abutment's internal hexagon fit the external hexagon of all the implant systems evaluated in the study and that the Procera abutment with its screw can be universally applied. This, in combination with the related CAD/CAM feature of this system, provides a dynamic approach to solving many of the design and spatial needs associated with the numerous clinical implant positions encountered, particularly when it comes to the anterior maxilla.

A recent in vitro investigation examined the fracture resistance of implant-supported all-ceramic abutments—Al_2O_3 and zirconium oxide (ZrO_2)—restored with glass-ceramic (IPS Empress; Ivoclar, Schaan, Lichtenstein) crowns.[76] Within the limitations of this study, the strength of both all-ceramic abutments exceeded the established values for maximum incisal load reported in the literature (90 to 370 N). The ZrO_2 abutments were more than twice as resistant to fracture as the Al_2O_3 abutments.

INFLUENCE OF SURGICAL TECHNIQUES

In a 5-year prospective study,[77] Zitzmann and associates recently assessed whether guided bone augmentation performed simultaneously with implant placement had an adverse effect on long-term survival rates of the implants. The study involved 41 test implants (with GBR) and 112 control implants (without GBR). The cumulative implant survival rates reported were 93% (test group) and 97% (control group). It was concluded that implants placed with or without GBR techniques have comparable survival rates after 5 years, but that bone resorption was more pronounced in GBR sites. Furthermore, the authors emphasized that the use of GBR was indicated when the initial defect size was larger than 2 mm in a vertical dimension.

In a 10-year retrospective clinical analysis evaluating the effect of so-called flapless surgery on implant survival and involving 770 implants placed in 359 patients, Campelo and Camara[78] reported a cumulative success rate that varied from 74% for implants placed in 1990 to 100% in 2000. The authors stressed the advantages of their approach and considered flapless implant surgery as a predictable procedure, provided patients are selected appropriately and proper surgical technique is meticulously followed.

EVALUATION OF PATIENT SATISFACTION

There is an increasing tendency to scientifically evaluate patients' opinions of various types of implant-supported prostheses. Often such evaluations include esthetic parameters as well. Along these lines, de Bruyn and coworkers[79] published a 3-year follow-up study of 61 implant patients treated in private practices according to 3 different well-defined therapeutic modalities. Comfort with eating, esthetics, phonetics, and overall satisfaction improved significantly with treatment, and nearly

all patients said that they would undergo the treatment again or recommend it to others. This included the subjects who had received implant-supported FPDs and who said they experienced their implant restorations as "natural" teeth.

In a similar project, the same group of authors[80] assessed the quality, after 3 years, of fixed implant restorations provided by clinicians who had previously participated in a 2-day postgraduate course focusing on implant-related treatment planning and practical training. The data clearly showed that clinicians previously inexperienced with implant prosthodontics implemented the information from a training course appropriately. They were able to provide clinically acceptable restorations (including the esthetic aspect) with a quality that was stable after 3 years of service.

A quality-of-life (QOL) assessment was carried out recently in patients with implant-supported and resin-bonded fixed prostheses for bounded edentulous spaces.[81] The patients were requested to answer a self-administered QOL questionnaire with 2 major subscales: oral condition–related and general condition–related QOL scores. The authors concluded that multidimensional QOL levels of patients with an implant-supported fixed prosthesis did not exceed those of patients with a resin-bonded fixed prosthesis in a short follow-up period.

A recently published retrospective study focused on patient opinion and professionally assessed quality of single-tooth restorations of Brånemark System implants.[82] Seventy-eight consecutively treated patients received a questionnaire covering esthetics, phonetics, and overall satisfaction. In general, the 48 patients who returned the questionnaire were very positive about these parameters. The additionally performed professional rating after a clinical and radiologic examination revealed that the objective quality was perfect in 17 cases and acceptable in 25 cases, while 1 crown needed major modification to prevent future complications.

Levi and associates[83] assessed patients' self-reported satisfaction with maxillary anterior dental implant treatment. Seventy-eight of 123 eligible subjects responded to the mailed, self-administered, structured questionnaire. In this limited investigation, satisfaction with implant position, restoration shape, overall appearance, effect on speech, and chewing capacity was critical for patients' overall acceptance of the dental implant treatment.

CONCLUSIONS

The present review clearly demonstrates that the use of dental implants in the esthetic zone is well documented in the literature and that numerous controlled clinical trials show that the respective overall implant survival and success rates are similar to those reported for other segments of the jaws. However, most of these studies do not include well-defined esthetic parameters. With anterior single-tooth replacement in sites without tissue deficiencies, predictable treatment outcomes, including esthetics, can be achieved because of tissue support provided by adjacent teeth.

The replacement of multiple adjacent missing teeth in the anterior maxilla with fixed implant restorations is poorly documented. In this context, restoring esthetics is not predictable, particularly regarding the contours of the interimplant soft tissue.

Currently, the literature regarding esthetic outcome is inconclusive for the routine implementation of certain surgical approaches such as flapless surgery and immediate implant placement with or without immediate loading/restoration in the anterior maxilla.

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