Improvements in Implant Dentistry over the Last Decade: Comparison of Survival and Complication Rates in Older and Newer Publications

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Purpose: *The objective of this systematic review was to assess and compare the survival and complication rates of implant-supported prostheses reported in studies published in the year 2000 and before, to those reported in studies published after the year 2000.* ***Materials and Methods:*** *Three electronic searches complemented by manual searching were conducted to identify 139 prospective and retrospective studies on implant-supported prostheses. The included studies were divided in two groups: a group of 31 older studies published in the year 2000 or before, and a group of 108 newer studies published after the year 2000. Survival and complication rates were calculated using Poisson regression models, and multivariable robust Poisson regression was used to formally compare the outcomes of older and newer studies.* ***Results:*** *The 5-year survival rate of implant-supported prostheses was significantly increased in newer studies compared with older studies. The overall survival rate increased from 93.5% to 97.1%. The survival rate for cemented prostheses increased from 95.2% to 97.9%; for screw-retained reconstruction, from 77.6% to 96.8%; for implant-supported single crowns, from 92.6% to 97.2%; and for implant-supported fixed dental prostheses (FDPs), from 93.5% to 96.4%. The incidence of esthetic complications decreased in more recent studies compared with older ones, but the incidence of biologic complications was similar. The results for technical complications were inconsistent. There was a significant reduction in abutment or screw loosening by implant-supported FDPs. On the other hand, the total number of technical complications and the incidence of fracture of the veneering material was significantly increased in the newer studies. To explain the increased rate of complications, minor complications are probably reported in more detail in the newer publications.* ***Conclusions:*** *The results of the present systematic review demonstrated a positive learning curve in implant dentistry, represented in higher survival rates and lower complication rates reported in more recent clinical studies. The incidence of esthetic, biologic, and technical complications, however, is still high. Hence, it is important to identify these complications and their etiology to make implant treatment even more predictable in the future.* INT J ORAL MAXILLOFAC IMPLANTS 2014;29(SUPPL):308–324. doi: 10.11607/jomi.2014suppl.g5.2

Key words: *biologic complications, dental implants, esthetic complications, failures, fixed dental prosthesis, implant dentistry, marginal bone loss, single crowns, survival, success, systematic review, technical complications*

In recent years, a number of systematic reviews on the survival and complication rates of fixed implant-supported prostheses have been published. The reviews focused on implant-supported single crowns (SCs)[1,2] or on multiple-unit implant-supported fixed dental prostheses (FDPs)[3,4,5] and reported high 5- and 10-year survival rates for both types of prostheses. Due to these good results, fixed implant-supported prostheses are fully accepted as a reliable treatment option for the replacement of single or multiple missing teeth today.[1,4]

In the daily clinical practice, however, patient (and clinician) satisfaction is not only influenced by survival rates. Survival rates in general represent prostheses that remained in clinical service for a defined follow-up period. However, those prostheses were not necessarily free of complications. Both implant-supported

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SCs as well as implant-supported FDPs suffer from different kinds of biologic or technical complications as the reviews indicated.[1,5] These complications lead to the need for corrective treatment, increasing the total chairside time and the treatment costs. As a consequence, a reduction of the general satisfaction with the prosthesis may occur.[6]

The etiology of biologic complications is mostly patient-based and can be multifactorial (eg, hereditary susceptibility to peri-implantitis, bad oral hygiene, excess cement).[7] A reduction of risk therefore implies good patient compliance and intensive oral care. Biologic risk can only be minimally influenced by modification of the implants, implant surfaces, and components, according to the current literature.

Technical problems are mostly related to the materials and the design of the components.[8] Studies have shown various types of technical problems, like prosthetic fixation screw or abutment loosening, fractures of components (eg, abutments, screws), fractures of reconstructive materials (eg, chipping of veneering ceramic), and loss of retention of cemented prostheses due to fracture of the luting cement.[1,5] In contrast to the biologic risks, the technical outcome can be improved with technical amendments.

In order to reduce the risk for technical complications, the materials and components used for the implant-supported prostheses are, therefore, constantly being enhanced. Some improvements have already led to better outcomes. As an example, after the introduction of implant-supported SCs, very high numbers of abutment or occlusal screw loosening were reported.[9,10] The change of screw material from titanium to gold and the use of defined screw fixation torques led to significant lowering of the incidence of screw loosening.[9,10] Screw loosening is still one of the most frequently reported complications for implant-supported reconstruction. Therefore, further refinements are desired, and debates about the best materials and techniques for the implant-supported prostheses are continually raised.[1,4]

The introduction of new restorative materials, such as ceramic zirconia for the abutment and framework, can on the one hand improve the outcomes (esthetics), but on the other increase technical problems. It has been shown that the veneering ceramics for zirconia-based prostheses exhibited very high rates for fracture and chipping.[11–13] Thus, not all further developments were really an improvement.

Very little scientific evidence is currently available to help determine whether changes in materials and implant components in the last decades have influenced survival rates of implants and implant-supported prostheses and the incidence of biologic and technical complications.

The objective of this systematic review was to assess and compare the survival and complication rates of implant-supported prostheses reported in studies published in the year 2000 and before to those reported in studies published after the year 2000.

MATERIALS AND METHODS

Focus Question

The following focus question was developed using a PICO approach:

Have the survival rate of implant-supported prostheses and the incidence of complications changed over the last decade?

Search Strategy and Study Selection

Three Medline (PubMed) searches were performed for articles published in the Dental Literature in English and German. The first one covered the time period 1990 to September 2012 utilizing both MeSH terms and free text words. The following search terms were used: “implant*”, “cement*” or “screw*”, “fix*” or “retain*”, “single-crown”, “single crowns” “FPD”, “FDP”, “bridge”, “reconstruct*” and “suprastruct*”. Moreover, the terms “long-term”, “long term”, “longitud*”, “survival” or “failure”, “complicat*”, “technical” or “biological” were utilized. In addition, Cochrane Library and Embase searches were conducted applying the same search terms.[10] The second search was an updated search from a previous systematic review[1] covering the time interval through the end of August 2011. The following MeSH terms were selected for the search: “dental implants” AND (“crowns” OR “survival”).[2] The third search was performed for studies published between May 1, 2004, and August 31, 2011,[5] using the following MeSH search terms: “dental implants” AND (“denture, partial, fixed” OR survival). Additionally, the studies from the predecessor systematic review were included, encompassing publications from 1966 through the end of April 2004.[14] All three searches were complemented by manual searches of the bibliographies of all full-text articles and related reviews, selected from the electronic search. Furthermore, manual searching was applied to relevant journals in the field of interest (Table 1).

Inclusion Criteria

This systematic review was based on randomized controlled clinical trials (RCTs), controlled clinical trials (CCTs), prospective cohort studies, prospective case series, and retrospective studies. The additional inclusion criteria for study selection were:

Table 1 Search Strategy

Focus question	**Have the survival rate of implant-supported reconstructions and the incidence of complications changed over the last decade?**
Search strategy	
Population	Partially edentulous patients with single-implant FDPs or multi-unit partial/full FDPs
Intervention or exposure	1 year of clinical follow-up, and after 5 and 10 y of follow-up
Comparison	Different decades/timepoints of intervention and/or publication
Outcome	Survival and complication rates over time
Search combination	Sailer et al[10]: used “”implant*”, “cement*” or “screw*”, “fix*” or “retain*”, “single-crown”, “single crowns” “FPD”, “FDP”, “bridge”, “reconstruct*”and “suprastruct*”. Moreover, the terms “long-term”, “long term”, “longitud*”, “survival” or “failure”, “complicat*”, “technical” or “biological” Jung et al[2]: used “dental implants” and (“crowns” OR “survival”). Pjetursson et al[5]: used “dental implants” AND (“denture, partial, fixed” OR survival). All these search terms were MeSH terms.
Database search	
Electronic	Medline (PubMed), Cochrane Library, and Embase
Journals	*Clinical Oral Implants Research, International Journal of Oral and Maxillofacial Implants, International Journal of Oral Surgery, Journal of Prosthetic Dentistry, International Journal of Periodontics and Restorative Dentistry, International Journal of Prosthodontics, Clin Implant Dent Relat Res, Journal of Clinical Periodontology, Journal of Oral Rehabilitation, British Dental Journal, Journal of Prosthodontics, Implant Dentistry, Journal of Periodontology, International Journal of Epidemiology, European Journal of Oral Sciences, Australian Dental Journal, Clinical Oral Investigations, Dental Materials, Journal of the Canadian Dental Association, Quintessence International, Journal of Oral Implantology, Clinical Implant Dentistry and Related Research*
Selection criteria	
Inclusion criteria	This systematic review was based on randomized controlled clinical trials (RCTs), controlled clinical trials (CCTs), prospective cohort studies, prospective case series, and retrospective studies. The additional inclusion criteria for study selection were: Human trials with minimum of 10 subjects. Studies reported in English and German language and published in dental journals. Patients were examined clinically at the follow-up visit. Publications based on patient records only, on questionnaires or interviews were excluded. Studies reported details on the characteristics and outcome of the suprastructures. For the short-term data, the studies had to have a mean time of functional loading of at least 1 year. For the longitudinal data, the studies had to have a mean follow-up time of 5 years or more.
Exclusion criteria	The main reasons for exclusion were lack of detailed information on the reconstruction design and no detailed information on the outcome of the reconstruction at the follow-up visit, or mean observation period not fulfilling the inclusion criteria and studies with less than 10 subjects. Furthermore, publications based on questionnaires or interviews without clinical examinations, multiple publications on the same patient cohorts, and case descriptions of failures without relevant information on the entire patient cohort were excluded.

- Human trials with a minimum of 10 subjects.
- Studies reported in English and German language and published in dental journals.
- Patients examined clinically at the follow-up visit. Publications based on patient records only, on questionnaires or interviews were excluded.
- Studies reporting details on the characteristics and outcome of the suprastructures.
- For short-term data, the studies had to have a mean time of functional loading of at least 1 year.
- For longitudinal data, the studies had to have a mean follow-up time of 5 years or more.

Selection of Studies

Titles and abstracts of the searches were always screened by at least two independent reviewers for possible inclusion in the reviews. The full text of all studies of possible relevance was then obtained for independent assessment by the reviewers. Any disagreement was resolved by discussion.

The first search extending through August 2011 identified 59 full-text articles that gave information on the clinical performance of cemented and screw-retained implant-supported prostheses with a functional loading of at least 1 year.[10] The extended search up to September 2012 identified two additional publications fulfilling the inclusion criteria. In the second search, the original search extending until August 2006 identified 24 studies reporting on implant-supported single crowns (SCs) with a mean follow-up time of 5 years or more.[1] The extended search, through August 2011, added 22 new publications to the included studies.[2] In the third search, identifying implant-supported fixed dental prosthesis (FDPs) with a mean follow-up time of at least 5 years, the original search extending until May 2004 identified 21 studies.[14] The extended search through August 2011 identified an additional 11 studies.[5]

The results of the present systematic review are based on a total of 139 included studies.

Excluded Studies

The main reasons for exclusion were no detailed information on the prostheses design and no detailed information on the outcome of the prosthesis at the follow-up visit, mean observation period not fulfilling the inclusion criteria, and studies with less than 10 subjects. Furthermore, publications based on questionnaires or interviews without clinical examinations, multiple publications on the same patient cohorts, and case descriptions of failures without relevant information on the entire patient cohort were excluded.

Data Extraction

From the included studies, information on failures of the supporting implants and the prostheses was extracted. Information on esthetic, biologic, and technical complications was also retrieved. Biologic complications were characterized by a biological process affecting the supporting tissues. Soft tissue complications and peri-implantitis characterized by a substantial (> 2 mm) marginal bone loss were included in this category.

Technical complications were characterized by mechanical damage of implants, abutments, and/or the suprastructures. Among these, fractures of implants, screws, or abutments; fractures of the luting cement (loss of retention); fractures or deformations of the framework or veneers; and screw or abutment loosening were included. From the included studies, the number of events for all of these categories was abstracted and the corresponding total exposure time of the implants, abutments, and prostheses was calculated.

Statistical Analysis

By definition, failure and complication rates are calculated by dividing the number of events (failures or complications) in the numerator by the total exposure time (implant, abutment, or reconstruction time) in the denominator.

The numerator could usually be extracted directly from the publication. The total exposure time was calculated by taking the sum of:

- Exposure time of implants, abutments, or prostheses that could be followed for the entire observation time.
- Exposure time up to a failure of implants, abutments, or prostheses that were lost due to failure during the observation time.
- Exposure time up to the end of observation time for implants, abutments, or prostheses that did not complete the observation period due to reasons such as death, change of address, refusal to participate, non-response, chronic illness, missed appointments, and work commitments.

For each study, event rates for implants, abutments, or prostheses were calculated by dividing the total number of events by the total implant, abutment, or prosthesis exposure time in years. For additional analysis, the total number of events was considered to be Poisson distributed for a given sum of abutment exposure years, and robust Poisson regression with a logarithmic link-function and total exposure time per study as an offset variable was used.[15] Robust Poisson regression allowed calculation of standard errors and 95% confidence intervals, which incorporated heterogeneity among studies.

Five-year survival proportions were calculated via the relationship between event rate and survival function S, $S(T) = \exp(-T \text{ *event rate})$, by assuming constant event rates.[16] The 95% confidence intervals for the survival proportions were calculated by using the 95% confidence limits of the event rates. Multivariable robust Poisson regression was used to formally compare publication years and to assess other study characteristics. All analyses were performed using Stata version 12.

RESULTS

Study Characteristics

The 139 included studies were divided into three categories. The first group was a group of 61 studies reporting on the clinical performance of cemented and screw-retained implant-supported prostheses of different types. This group included 37 studies reporting on implant-supported single crowns (SCs), 16 studies that reported on implant-supported partial fixed dental prostheses (FDPs), and 18 studies reporting on implant-supported fixed complete dentures (FCDs), with various mean follow-up periods ranging from 1 to 10 years.[10] The result for this group is referred to as the overall results. The second group was a group of

Table 2 Comparison of the Implant Survival Rate in Articles Published Before and After 2000

	Published before 2000		Published after 2000		
	Annual failure rate (95% CI)	5-year survival rate (95% CI)	Annual failure rate (95% CI)	5-year survival (95% CI)	*P* value
Overall results	0.29% (0.15–0.57)	98.6% (97.2–99.3)	0.39% (0.25–0.63)	98.1% (96.9–98.8)	.466
Implant-supported SCs	0.60% (0.39–0.90)	97.1% (95.6–98.1)	0.56% (0.40–0.78)	97.2% (96.2–98.0)	.815
Implant-supported FDPs	1.28% (1.05–1.56)	93.8% (92.5–94.9)	0.81% (0.57–1.14)	96.1% (94.4–97.2)	.021

Table 3 Comparison of the Prosthetic Survival Rate in Articles Published Through and After 2000

	Published through 2000		Published after 2000		
	Annual failure rate (95% CI)	5-year survival rate (95% CI)	Annual failure rate (95% CI)	5-year survival rate (95% CI)	*P* value
Overall results	1.34% (0.65–2.77)	93.5% (87.1–96.8)	0.59% (0.38–0.91)	97.1% (95.6–98.1)	.050
Cemented reconstructions	0.99% (0.58–1.69)	95.2% (91.9–97.2)	0.42% (0.23–0.75)	97.9% (96.3–98.8)	.030
Screw-retained reconstructions	5.07% (1.17–22.07)	77.6% (33.2–94.3)	0.65% (0.39–1.10)	96.8% (94.6–98.1)	.004
Implant-supported FCDs	NR	NR	0.86% (0.45–1.66)	95.8% (92.0–97.8)	NA
Implant-supportzed SCs	1.54% (1.01–2.34)	92.6% (88.9–95.1)	0.58% (0.35–0.95)	97.2% (95.3–98.3)	.002
Implant-supported FDPs	1.34% (0.69–2.62)	93.5% (87.7–96.6)	0.73% (0.55–0.97)	96.4% (95.3–97.3)	.087

NR = not reported; NA = not applicable.

46 studies reporting on 3,199 implant-supported SCs with a mean follow-up time of at least 5 years.[2] The last group was a group of 32 studies reporting on 1,881 implant-supported FDPs with a mean follow-up period of at least 5 years.[5]

The year of publication for the 139 studies (see reference list) included in this systematic review ranged from 1994 to 2012.[2–14,17–141] Thirty-one publications were classified as older studies published in the year 2000 or before and 108 were classified as newer studies published after the year 2000. From the 61 studies reporting on overall results, the year of publication ranged from 1995 to 2012. Twelve of the studies were classified as older studies and 49 as newer studies published in the present millennium. Out of the 46 studies reporting on implant-supported SCs, the publication year ranged from 1995 to 2012. Eight of the studies were considered older studies and 38 newer studies published after the year 2000. For the 32 studies reporting on implant-supported FDPs, the year of publication ranged from 1995 to 2012. Eleven of the included studies were considered older studies, and 21 were considered newer studies published after the year 2000.

Survival

Survival was defined as the implants or prostheses remaining in situ with or without modification over the observation period.

Implant survival. The annual implant failure rates in the older publications ranged from 0.29% to 1.28%, translating into 5-year survival rates of 93.8% to 98.6%. The annual failure rates in the newer publications ranged from 0.39% to 0.81%, translating into a 5-year survival rate of 96.1% to 98.1% (Table 2). Comparing the survival rates in the older publications with the survival rates in the newer publications, there was only a minor difference ($P = .466$, .815) of the overall results and for the implant-supported SCs. However, for the implant-supported FDPs there were significantly ($P = .021$) less implant failures in the newer studies and the 5-year implant survival rate increased from 93.8% in the older studies to 96.1% (Table 2).

Survival of Prostheses. The annual failure rate of prostheses in the older publications ranged from 0.99% to 5.07% (Figs 1 to 6), translating into a 5-year survival rate of 77.4% to 95.2%. The highest 5-year survival rate in the older studies was seen for cemented prostheses, and the lowest survival rate was reported for screw-retained prostheses (Table 3**).** The range in annual failure rates of different types of prostheses was significantly reduced in the newer publications. They ranged from 0.42% to 0.86%, translating into a 5-year survival rate of 95.8% to 97.9% (Table 3, Figs 1 to 6). Formally comparing the survival rates of prostheses in the older publications with the survival rates in the newer publications, there was a marked reduction of failures, translating into increased survival rates of implant-supported prostheses in the more recent studies. The difference reached statistical significance ($P = .002$ to .050) for all types of prostheses analyzed, except for implant-supported FDPs ($P = .087$)

(Table 3). The most pronounced improvement was seen for screw-retained prostheses, with a 5-year survival rate of 77.6% in the older studies compared with a 5-year survival rate of 96.8% in the newer studies (Table 3).

Esthetic Complications

For implant-supported SCs, there were 12 studies reporting on the esthetic outcome of the treatment. In the older studies the annual rate of implant-supported SCs with semioptimal or unacceptable esthetic outcomes was 3.47%, translating into a 5-year complication rate of 15.9% (Table 4). In the newer studies, the annual rate of esthetic complications was reduced to 1.12%, translating into a 5-year complication rate of 5.4%. The difference in the incidence of esthetic complications between the older and the newer studies did not, however, reach statistical significance ($P = .085$) (Table 4).

Biologic Complications

Peri-implant mucosal lesions were reported in various ways by the different authors. Several studies provided information on soft tissue complications, peri-implantitis, and marginal bone loss, while other studies reported signs of inflammation (pain, redness, swelling, and bleeding) or soft tissue complications, defined as fistula, gingivitis, or hyperplasia.

For implant-supported SCs and implant-supported FDPs, information on biologic complications was extracted from the included publications.

For implant-supported SCs, the annual rate of biologic complications was reduced from 2.56% in the older studies to 1.31% in the new studies, translating into a reduction in 5-year complication rate from 12.0% to 6.4% (Table 3). This difference, however, did not reach statistical significance ($P = .252$). No formal comparison could be made regarding marginal bone levels around implant-supported SCs, because this complication was not reported in the older studies.

For implant-supported FDPs, the incidence of biologic complications increased slightly in the newer studies compared with the older ones. On the other hand, the incidence of substantial bone loss ≥ 2 mm decreased slightly. The annual rate of biologic complications by implant-supported FDPs increased from 1.54% to 1.97%, hence the 5-year complication rate increased from 7.4% to 9.4%. The annual rate of marginal bone loss decreased from 0.68% to

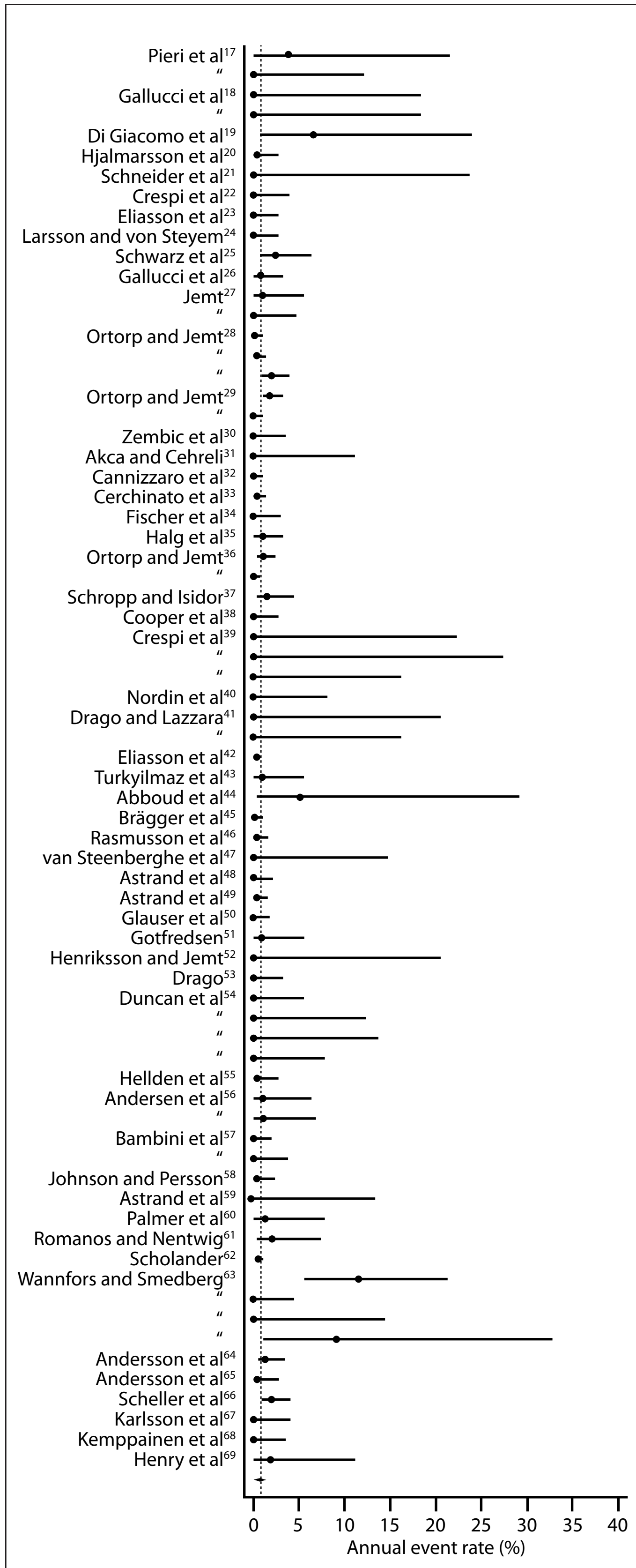

Fig 1 Annual failure rates—overall results. Dots indicate annual failure rates; lines indicate 95% confidence interval.

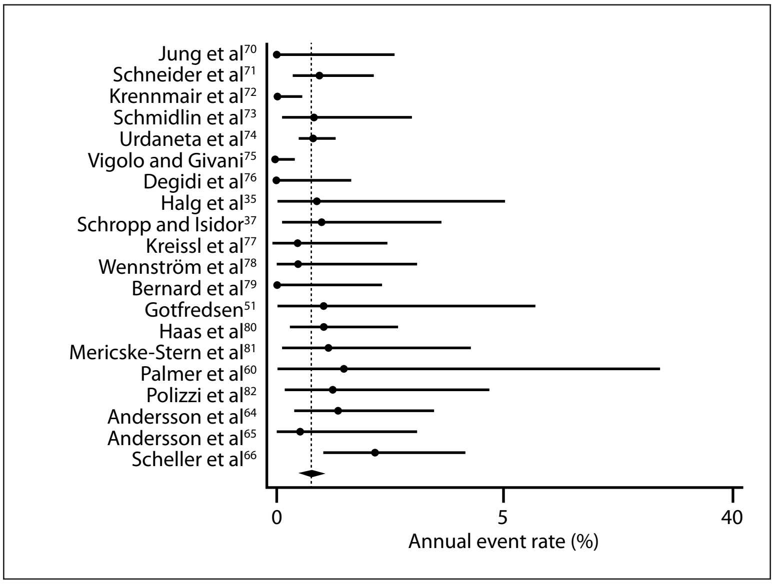

Fig 2 Annual failure rates of implant-supported SCs.

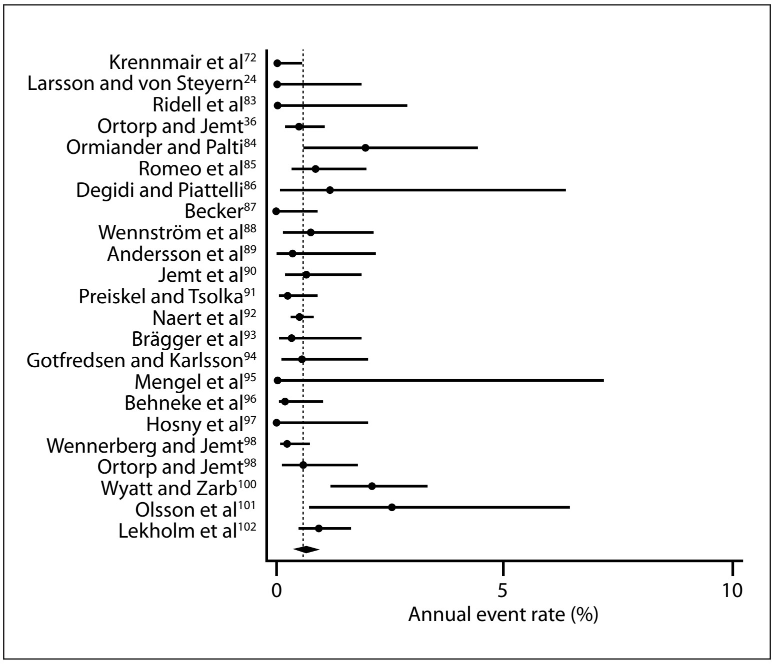

Fig 3 Annual failure rates of implant-supported FPDs.

0.52%, translating into a 5-year complication rate of 3.3% in the older studies compared with 2.5% in the newer studies. The differences regarding biologic complications between the older and the newer studies for implant-supported FDPs at 5 years did not reach statistical significance (*P* = .540, .543) (Table 4).

Technical Complications

Abutment or Screw Loosening. The annual rate of abutment or screw loosening in the older publications ranged from 0.79% to 6.08%, translating into a 5-year complication rate of 3.9% to 26.2% (Table 5). The highest incidence of abutment or screw loosening in the older studies was reported for screw-retained prostheses (26.2%) and implant-supported SCs (24.4%), and the lowest complication rate was reported for cemented prostheses (3.9%). In the newer studies, the annual rate of abutment or screw loosening ranged from 0.62% to 2.29%, translating into a 5-year complication rate ranging from 3.1% to 10.8% (Table 5). The highest incidence of abutment or screw loosening in the newer studies was still seen for screw-retained prostheses and the lowest for cemented prostheses. For all types of prostheses, lower incidences of abutment and screw loosening were reported in the newer studies. For screw-retained prostheses and implant-supported SCs, this difference reached statistical significance (*P* = .002, .045) (Table 5).

Abutment or Screw Fractures. The annual rate of abutment or screw fractures in the older publications ranged from 0.16% to 0.44%, translating into a 5-year complication rate of 0.8% to 2.2% (Table 6). In the older studies, this information was not available for screw-retained prostheses and implant-supported FCDs. In the more recent studies, the annual rate of abutment or screw fractures ranged from 0% to 1.20%, translating into a 5-year complication rate between 0% and 5.8% (Table 6). Comparing the overall results in the older and the newer studies in respect to abutment or screw loosening, there was an increase in annual failure rates from 0.27% to 0.56%, representing a change for the 5-year complication rate from 1.3% to 2.8% (*P* = .371). It must, however, be kept in mind that among the older studies, no studies on screw-retained prostheses and implant-supported FCDs were available. When the different types of prostheses were analyzed separately, they all showed a decreased rate of abutment or screw loosening when comparing the older studies with the more recent ones. The difference between the older and the newer studies, however, only reached statistical significance for implant-supported SCs (*P* = .029). The highest 5-year rate of abutment or screw fractures of 5.8% was reported for implant-supported FCDs. For implant-supported screw-retained prostheses, the 5-year complication rate was 4.1%, compared with a complication rate of 0% for implant-supported cemented prosthesis (Table 6).

Fracture of the Veneering Material. The annual rate of fracture of the veneering material in the older publications ranged from 0.28% to 4.28%, translating into a 5-year complication rate of 1.4% to 19.2% (Table 7). The highest 5-year rate of fracture of the veneering material in the older studies was reported for implant-supported FDPs. In the newer studies, the annual rate of fracture of the veneering material ranged from 0.64% to 5.82%, translating into a 5-year complication rate ranging between 3.2% and 25.5% (Table 7). The lowest 5-year rate of fracture of the veneering material was reported for implant-supported SCs, and the highest rate was reported for implant-supported FCDs. Comparing the older studies with the newer studies, there was a significant increase in the incidence of fracture of the veneering material for the overall results ($P < .0001$), for the cemented prostheses ($P = .004$), and for the screw-retained prostheses ($P < .0001$). It must, however, be kept in mind that among the older studies, there were no studies reporting on implant-supported FCDs that showed the highest incidence of complications in the newer studies. On the other hand, there was a significant decrease in fracture of the veneering material reported for implant-supported SCs ($P = .054$) and for the implant-supported FDPs ($P = .013$) (Table 7).

Implant Fractures. Implant fractures are a rare complication. For implant-supported SCs, the annual rate of implant fractures was reduced from 0.06% in the older studies to 0.02% in the newer studies, translating into a reduction in the 5-year complication rate from 0.3% to 0.08% (Table 8). This difference did not reach statistical significance ($P = .271$). For implant-supported FDPs the 5-year rate of implant fractures was the same or 0.5% both on the older and the newer studies (Table 8).

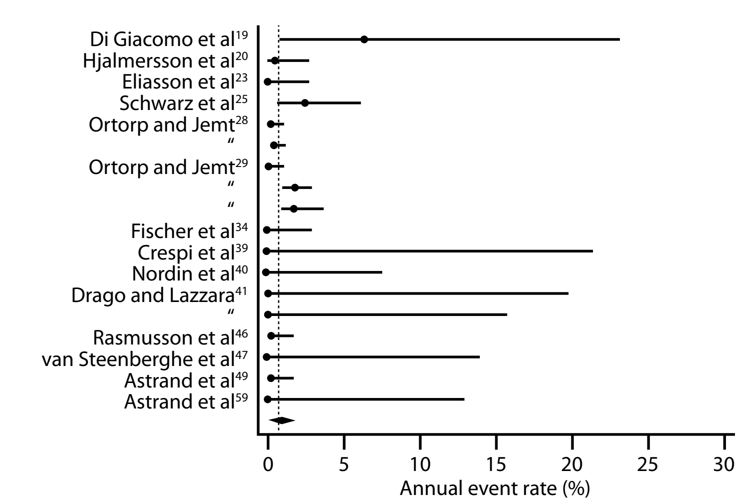

Fig 4 Annual failure rates of implant-supported FCDs.

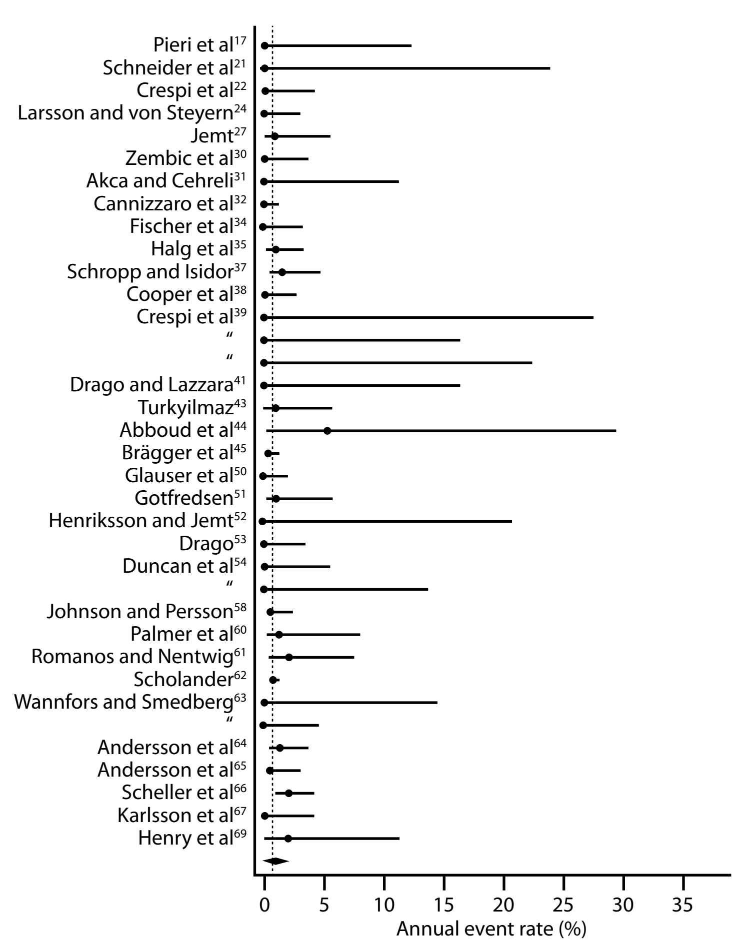

Fig 5 Annual failure rates of implant-supported cemented reconstructions.

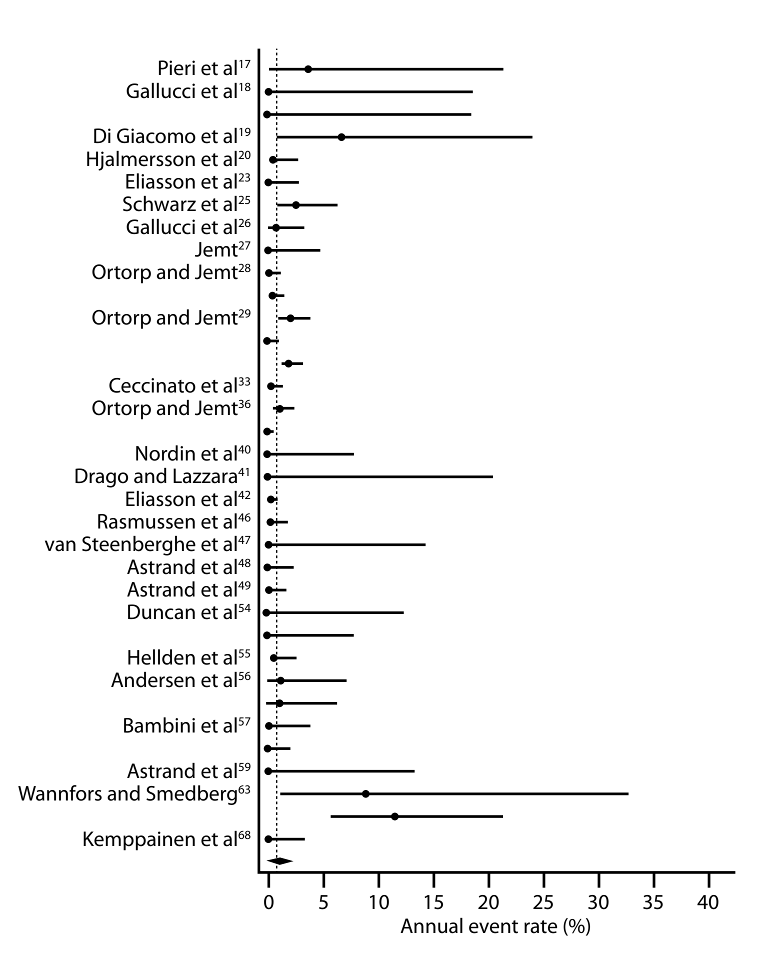

Fig 6 Annual failure rates of implant-supported screw-retained reconstructions.

Fracture of the Framework. Fractures of the framework of the prosthesis are also a rare complication. For implant-supported FDPs, the annual rate of framework fractures was reduced from 0.19% in the older studies to 0.04% in the newer studies. This represents a reduction in the 5-year complication rate from 1.0% to 0.2% (Table 8). The difference between the results from the older studies and the newer studies did not reach statistical significance ($P = .128$).

Loss of Retention. The loss of retention for cemented prostheses could only be analyzed for implant-supported SCs. The annual complication rate was reduced from 1.52% in the older studies to 0.63% in the newer studies, translating into a reduction in 5-year rate of loss of retention from 7.3% to 3.1% (Table 8). This difference, however, did not reach statistical significance ($P = .118$).

Total Technical Complications. The annual rate of the total number of reported technical complications in the older publications ranged from 2.32% to 10.46%, translating into a 5-year complication rate ranging from 10.9% to 40.1% (Table 9). The highest 5-year complication rate in the older studies was reported for implant-supported FDPs (40.1%) and for screw-retained prostheses (33.3%), and the lowest survival rate was reported for cemented prostheses (10.8%). In the newer publications, the annual rate of total number of technical complications ranged from 3.55% to 15.19%, translating into a 5-year complication rate ranging from 16.3% to 53.4%. The highest 5-year complication rate was reported for implant-supported FCDs (Table 9). Comparing the older studies with the more recent studies, there was a significant increase in number of technical complications for the overall results ($P = .028$). For the cemented prostheses there was also an increased number of technical complications reported ($P = .225$), but for the screw-retained prostheses the incidence was similar ($P = .808$) in the older and the newer studies. It should also be considered that among the older studies, there were no publications reporting on implant-supported FCDs that showed the highest incidence of technical complications among the newer studies. This fact might skew the outcome. Furthermore, there was a significant ($P = .005$) decrease in the total complication rate reported for implant-supported FDPs in the newer studies compared with the older ones (Table 9).

The 41 meta-analyses (Tables 2 to 9) that were included this systematic review were also performed by dividing the year of publication into three time-interval groups: studies published before the year 2000, studies published between 2000 and 2005, and finally studies published after the year 2005. Interestingly, this analysis showed that most of the significant changes happened in the publication periods before 2000, and between 2000 and 2005. In this time period, important improvements in materials and methods were made in implant dentistry. The only complication that demonstrated significant improvement from the studies published between 2000 and 2005 to the studies published after 2005 was screw or abutment loosening at screw-retained prostheses.

The results for implant-supported SCs and implant-supported FDPs divided into three publication time intervals are presented in Table 10.

Table 4 Comparison of Esthetic and Biologic Complications in Articles Published Through and After 2000

	Published through 2000		Published after 2000		
	Annual complication rate (95% CI)	5-year complication rate (95% CI)	Annual complication rate (95% CI)	5-year complication rate (95% CI)	*P* value
Esthetic complications, SCs	3.47% (0.86–14.08)	15.9% (4.2–50.5)	1.12% (0.68–1.84)	5.4% (3.3–8.8)	.085
Biologic complications, SCs	2.56% (0.82–7.99)	12.0% (4.0–32.9)	1.31% (0.85–2.05)	6.4% (4.2–9.7)	.252
Biologic complications,FPDs	1.54% (0.74–3.20)	7.4% (3.6–14.8)	1.97% (1.31–2.97)	9.4% (6.3–13.8)	.540
Marginal bone loss ≥ 2 mm, SCs	NR	NR	1.31% (0.66–2.58)	6.3% (3.3–12.1)	NA
Marginal bone loss ≥ 2 mm, FDPs	0.68% (0.26–1.80)	3.3% (1.3–8.6)	0.52% (0.38–0.70)	2.5% (1.9–3.5)	.543

NR = not reported; NA = not applicable.

Table 5 Comparison of Abutment or Screw Loosening in Articles Published Through and After 2000

	Published through 2000		Published after 2000		
	Annual complication rate (95% CI)	5-year complication rate (95% CI)	Annual complication rate (95% CI)	5-year complication rate (95% CI)	*P* value
Overall results	1.65% (0.75–3.65)	7.9% (3.7–16.7)	1.82% (1.22–2.73)	8.7% (5.9–12.8)	.826
Cemented reconstructions	0.79% (0.57–1.09)	3.9% (2.8–5.3)	0.62% (0.33–1.21)	3.1% (1.6–5.8)	.530
Screw-retained reconstructions	6.08% (3.79–9.74)	26.2% (17.3–38.6)	2.29% (1.47–3.56)	10.8% (7.1–16.3)	.002
Implant-supported FCDs	NR	NR	1.88% (0.63–5.61)	9.0% (3.1–24.4)	NA
Implant-supported SCs	5.58% (1.19–26.11)	24.4% (5.8–72.9)	1.16% (0.66–2.03)	5.6% (3.2–9.6)	.045
Implant-supported FDPs	1.08% (0.78–1.48)	5.2% (3.8–7.1)	0.81% (0.45–1.46)	4.0% (2.2–7.0)	.387

NR = not reported; NA = not applicable.

Table 6 Comparison of Abutment or Screw Fracture in Articles Published Through and After 2000

	Published through 2000		Published after 2000		
	Annual complication rate (95% CI)	5-year complication rate (95% CI)	Annual complication rate (95% CI)	5-year complication rate (95% CI)	*P* value
Overall results	0.27% (0.05–1.35)	1.3% (0.3–6.5)	0.56% (0.29–1.11)	2.8% (1.4–5.4)	.371
Cemented reconstructions	0.28% (0.05–1.50)	1.4% (0.3–7.2)	0%	0%	NA
Screw-retained reconstructions	NR	NR	0.84% (0.42–1.67)	4.1% (2.1–8.0)	NA
Implant-supported FCDs	NR	NR	1.20% (0.31–4.68)	5.8% (1.5–20.9)	NA
Implant-supported SCs	0.16% (0.05–0.49)	0.8% (0.3–2.4)	0.07% (0.02–0.20)	0.3% (0.1–1.0)	.238
Implant-supported FDPs	0.44% (0.23–0.84)	2.2% (1.1–4.1)	0.16% (0.08–0.32)	0.8% (0.4–1.6)	.029

NR = not reported; NA = not applicable.

DISCUSSION

The aim of this systematic review was to investigate the survival and complication rates of implant-supported prostheses in older studies and compare them with survival and complication rates reported in more recent publications.

With the exception of implant-supported FDPs, implant survival rate was similar in the older and in the more recent studies. The overall 5-year implant survival rate and the survival rate for implant-supported SCs was high, ranging between 97.1 and 98.6% in both the older and the newer studies. For implant-supported FDPs, the 5-year survival rate even increased over time.

Considering this, what does it mean for daily clinical practice when the survival rate is increased from 93.8% to 96.1%? A survival rate of 93.8% indicates that 1 implant out of 16 was lost, and 96.1% means that

Table 7 Comparison of Fractures of Veneering Material in Articles Published Through and After 2000

	Published through 2000		Published after 2000		
	Annual complication rate (95% CI)	5-year complication rate (95% CI)	Annual complication rate (95% CI)	5-year complication rate (95% CI)	*P* value
Overall results	0.31% (0.09–1.03)	1.5% (0.5–5.0)	3.65% (2.55–5.23)	16.7% (12.0–23.0)	.0001
Cemented reconstructions	0.28% (0.08–1.01)	1.4% (0.4–4.9)	2.84% (1.04–7.81)	13.3% (5.0–32.3)	.004
Screw-retained reconstructions	0.76% (0.37–1.55)	3.7% (1.8–7.4)	3.95% (2.74–5.69)	17.9% (12.8–24.8)	.0001
Implant-supported FCDs	NR	NR	5.82% (3.77–9.00)	25.3% (17.2–36.2)	NA
Implant-supported SCs	1.27% (0.67–2.41)	6.2% (3.3–11.4)	0.64% (0.43–0.96)	3.2% (2.1–4.7)	.054
Implant-supported FDPs	4.28% (3.10–5.90)	19.2% (14.4–25.5)	1.60% (0.77–3.30)	7.7% (3.8–15.2)	.013

NR = not reported; NA = not applicable.

Table 8 Comparison of Implant Fractures, Framework Material Fractures, and Loss of Retention in Articles Published Through and After 2000

	Published through 2000		Published after 2000		
	Annual complication rate (95% CI)	5-year complication rate (95% CI)	Annual complication rate (95% CI)	5-year complication rate (95% CI)	*P* value
Implant fractures, SCs	0.06% (0.008–0.52)	0.3% (0.04–2.6)	0.02% (0.004–0.07)	0.08% (0.02–0.35)	.271
Implant fractures, FDPs	0.10% (0.03–0.30)	0.5% (0.2–1.5)	0.11% (0.4–0.30)	0.5% (0.2–1.5)	.912
Fractures of the framework, FDPs	0.19% (0.08–0.50)	1.0% (0.4–2.4)	0.04% (0.005–0.27)	0.2% (0.02–1.4)	.128
Loss of retention, SCs	1.52% (0.56–4.17)	7.3% (2.7–18.8)	0.63% (0.30–1.29)	3.1% (1.5–6.3)	.118

NR = not reported; NA = not applicable.

Table 9 Comparison of Combined Complication Rates in Articles Published Through and After 2000

	Published through 2000		Published after 2000		
	Annual complication rate (95% CI)	5-year complication rate (95% CI)	Annual complication rate (95% CI)	5-year complication rate (95% CI)	*P* value
Overall results	3.21% (1.85–5.56)	14.8% (8.8–24.3)	6.33% (4.78–8.38)	27.1% (21.3–34.2)	.028
Cemented reconstructions	2.32% (1.50–3.57)	10.9% (7.2–16.3)	3.55% (2.05–6.17)	16.3% (9.7–26.5)	.225
Screw-retained reconstructions	8.10% (4.02–16.32)	33.3% (18.2–55.8)	7.42% (5.5–10.1)	31.0% (23.9–39.7)	.808
Implant-supported FCDs	NR	NR	15.19% (9.62–24.0)	53.2% (38.2–69.9)	NA
Implant-supported FDPs	10.46% (10.20–10.73)	40.1% (39.9–41.5)	6.37% (4.41–9.20)	27.3% (19.8–36.9)	.005

NR = not reported; NA = not applicable.

1 implant out of 26 was lost. To simplify, for example, 99% survival means loss of 1 implant out of 100, and 90% means loss of 1 implant out of 10. Hence, it has a major influence on the daily practice whether the survival and/or the success rate of an implant-supported prosthesis is 90% or 99%.

For all groups of implant-supported prostheses, there was a substantial to significant improvement in survival rates comparing the older studies with the newer studies. In the older studies, the 5-year survival rates were between 77.6% and 95.2%, compared with survival rates between 95.8% and 97.9% in the newer studies. The most significant improvement was reported for screw-retained implant-supported prostheses.

A positive improvement was also seen regarding esthetic outcomes comparing the older to the newer studies. This might represent a positive learning curve regarding improved understanding of biologic principles that must be respected during implant treatment in areas of esthetic priority. This might also represent a positive influence of new materials like ceramics, most specifically zirconia, that make it possible to improve the esthetic outcome of the treatment.[1,103] The results regarding biologic complications were not consistent. For implant-supported SCs, the incidence of biologic complications decreased from the older studies compared with the newer studies. For implant-supported FDPs, there was a slight increase in biologic complications and a slight decrease in the number of implants with substantial marginal bone loss. The changes in esthetic outcomes and biologic complications did not reach statistical significance.

For most of the implant-supported prostheses, there were slightly to significantly fewer incidences of screw or abutment loosening and fractures, again displaying an improvement of the materials and methods. For screw-retained prostheses, the rate of screw or abutment loosening was reduced from 26.2% to 10.8%, and for implant-supported SCs the complication rate was reduced from 24.4% to 5.6%. One of the reasons for the significant reduction in screw or abutment loosening was a clear outlier among the older studies, Henry et al,[104] reporting on the first generation of single crowns on Brånemark implants. This group reported on titanium screws replaced with new gold abutment screws and new abutments replaced with older ones, resulting in dramatically reduced screw loosening.

Fracture of the veneering material was the most frequently reported technical complication. Comparing the rate of this complication within the older and the newer studies, the results varied significantly. For implant-supported SCs and implant-supported FDPs with at least 5 years of follow-up time, there was a significant decrease in the incidence of veneering material fractures. One of the reasons for this is probably that several studies reporting on implant-supported prostheses with gold-framework and acrylic veneers are included in the group of older studies. It has been demonstrated in previous systematic reviews[4,14] that implant-supported prostheses with acrylic veneers have a significantly lower survival rate than implant-supported metal-ceramic prostheses. On the other hand, the fracture rate of veneering material reported in studies with shorter follow-up time was significantly increased in the newer studies compared with the older studies. The risk of fracture of the veneering material was increased with the size of the reconstruction. The lowest 5-year complication rate (3.2%) was reported for implant-supported SCs, and the highest complication rate (25.3%) was reported for implant-supported FCDs. It is difficult to speculate what could be the reason for increased rate of fractures of the veneering material. One explanation could be a tendency to evaluate and report complications in more detail in recent publications. A minor ceramic chipping is a typical complication that could go unnoticed if the clinical examiner is not carefully investigating the prostheses. This could also explain the fact that the total number of technical complications was significantly higher in the newer studies compared with the older studies. Another explanation could be the increased application of more delicate types of prostheses, eg, zirconia- or titanium-based implant FDPs. The veneering ceramics for these types of framework materials exhibited high rates of chipping in clinical studies.

The high rate of technical complications must be given serious consideration. The 5-year rate of technical complications ranged from 16.3% to 53.2%. The lowest rate was reported for cemented prostheses and the highest rate was reported for implant-supported FCDs, where every second prosthesis had a technical complication of some kind. Since the latter observation is only based on very few studies, it has to be interpreted with caution. Specific clinician- or technician-based factors might be one possible reason for these complications.

The 41 meta-analyses performed are based on 139 clinical studies reporting on 8,193 implant-supported prostheses. Therefore, it can be concluded that the results are based on substantial material size. Another strength of the present systematic review is that the methodology used is well standardized in the way the search strategy was performed, the data extraction, and how the statistical approach was performed. Due to the fact that there was a substantial heterogeneity among the included studies, it was decided to use the robust Poisson regression, which incorporated heterogeneity among the studies.

One limitation of this review is that it was mainly based on studies that were conducted in an institutional environment, such as university or specialized implant clinics. Therefore, the long-term outcomes observed cannot be generalized to dental services provided in private practice. A further limitation is that the published information did not allow estimating annual failure rates separately for different time periods or years after insertion of the prosthesis. Thus, it was not possible to estimate whether annual failure rates increased over time. One of the limitations of the present systematic review was that both prospective and retrospective cohort studies and case series were included. To assess the influence of study design, the results from prospective and retrospective studies have been analyzed separately in a recent systematic review.[5,14] In two of the analyses, no influence of study effect could be seen, but in the third analysis higher survival rates were reported for retrospective studies. Hence, it was difficult to draw any robust conclusions regarding the influence of including retrospective studies in the analysis. In the present systematic review, the study design should not be a problem as long as the distribution of retrospective and prospective studies is similar between the older and the more recent study groups.

Table 10 Comparison of Failure and Complication Rates of Implant-Supported SCs and FDPs in Articles Published Before 2000, from 2000 to 2005, and After 2005

	Published before 2000		Published 2000–2005	
	Annual failure/ complication rate (95% CI)	5-year survival/ complication rate (95% CI)	Annual failure/ complication rate (95% CI)	5-year survival/ complication rate (95% CI)
Implant survival, SCs	0.52% (0.35–0.79)	97.4% (96.1–98.3)	0.61% (0.36–1.04)	97.0% (95.0–98.2)
Implant survival, FDPs	1.35% (1.12–1.62)	93.5% (92.2–94.5)	0.81% (0.53–1.22)	96.0% (94.1–97.4)
Survival of implant-supported SCs	1.54% (0.97–2.44)	92.6% (88.5–95.3)	0.83% (0.53–1.30)	95.9% (93.7–97.4)
Survival of implant-supported FDPs	1.57% (0.80–3.07)	92.4% (85.8–96.1)	0.63% (0.49–0.83)	96.9% (95.9–97.6)
Biologic complications, SCs	2.69% (0.85–8.57)	12.6% (4.1–34.8)	1.44% (0.83–2.51)	6.9% (4.0–11.8)
Esthetic complications, SCs	3.47% (0.86–14.08)	15.9% (4.2–50.5)	1.17% (0.40–3.41)	5.7% (2.0–15.7)
Implant fractures, SCs	0.08% (0.009–0.72)	0.4% (0.04–3.54)	0.03% (0.004–0.2)	0.1% (0.02–0.99)
Implant fractures, FDPs	1.35% (1.12–1.62)	6.5% (5.5–7.8)	0.81% (0.53–1.22)	4.0% (2.6–5.9)
Abutment or screw loosening, SCs	6.81% (1.43–32.26)	28.8% (6.9–80.1)	0.95% (0.37–2.49)	4.7% (1.8–11.7)
Fractures of the veneering material, SCs	1.27% (0.67–2.41)	6.2% (3.3–11.4)	0.49% (0.24–1.01)	2.4% (1.2–4.9)
Fractures of the veneering material, FDPs	4.66% (3.54–6.14)	20.8% (16.2–26.4)	1.29% (0.68–2.43)	6.3% (3.4–11.5)
Total number of complications, FDPs	10.46%(10.2–10.73)	40.1% (39.9–41.5)	8.10% (3.50–18.74)	33.3% (16.1–60.8)

*Published before 2000 vs published 2000–2005.
†Published before 2000 vs published after 2005.

CONCLUSIONS

Despite of high survival rate of implant-supported prostheses and substantial improvements within implant dentistry over time, esthetic, biologic, and technical complications are still frequent. This, in turn, means that a substantial amount of chair time has to be accepted by the patient and dental services. The present systematic review demonstrated in many aspects a positive learning curve in implant dentistry, represented by lower failure and complication rates reported in more recent clinical studies.

It is, however, of outmost importance that the industry, the scientific community, and clinicians worldwide work together to identify failures, complications, and weaknesses in implant dentistry and develop solutions that make implant treatment an even more predictable and safe therapeutic option.

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Annual failure/ complication rate 95% CI) (Published after 2005)	5-year survival/ complication rate (95% CI) (Published after 2005)	*P* value
0.55% (0.36–0.84)	97.3% (95.9–98.2)	.636*, .839†
0.78% (0.51–1.20)	96.2% (94.2–97.5)	.021, .007
0.53% (0.28–1.03)	97.4% (95.0–98.6)	.040, .006
0.83% (0.40–1.70)	95.9% (91.9–98.0)	.008, .166
1.23% (0.66–2.28)	5.9% (3.2–10.8)	.289, .196
1.09% (0.61–1.94)	5.3% (3.0–9.3)	.166, .083
0.01% (0.001–0.09)	0.05% (0.006–0.5)	.467, .172
0.78% (0.51–1.20)	3.8% (2.5–5.8)	.021, .007
1.19% (0.61–2.35)	5.8% (3.0–11.1)	.020, .026
0.68% (0.44–1.05)	3.3% (2.2–5.1)	.025, .084
2.08% (0.59–7.32)	9.9% (2.9–30.7)	.0001, .170
5.85% (3.90–8.78)	25.4% (17.7–35.5)	.441, .0001

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