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A systematic review of long–term tooth and implant survival rates

Liran Levin, DMD; Michal Halperin-Sternfeld, DMD, MSc

Implant therapy is regarded as a safe and reliable method of treating patients with complete or partial edentulism.[1-5] The use of dental implants as a replacement for "hopeless" or missing teeth has been increasing steadily, probably owing to the high predictability and survival rates, as reported in numerous studies,[1-5] together with supporting technological advances. Given the increasing popularity and clinical success of dental implants, clinicians may tend to believe that they are as good as natural teeth. This could result in the extraction of teeth that are salvageable, on the basis of convenience rather than as a result of a comparative analysis of prognoses.

A critical stage in treatment planning consists of evaluating the tooth's prognosis. During this stage, the clinician integrates and considers various factors to select the treatment with the highest probability of success. To this end, the clinician can use several available classification systems,[5-17] all of which aim to determine the potential fate of the tooth, which leads to its appropriate treatment. We should note that because no criterion standard exists for prognosis classification systems, different methodologies can result in various classifications of the same condition. Therefore, selection of the classification methodology could be critical

ABSTRACT

Background. For the past few decades, dental implants have served as reliable replacements for missing teeth. However, there is an increasing trend toward replacing diseased teeth with dental implants.

Types of Studies Reviewed. The authors conducted a systematic review of long-term survival rates of teeth and implants. They searched the MEDLINE database for relevant publications up to March 2013. They considered studies in which investigators assessed the long-term effectiveness of dental implants or that of tooth preservation. They included only studies that had follow-up periods of 15 years or longer.

Results. The authors selected 19 articles for inclusion. Investigators in nine studies assessed the tooth survival rate, whereas investigators in 10 studies assessed the implant survival rate. When comparing the overall long-term (that is, 15 years or more) tooth loss rate with that of implants, the authors observed rates ranging between 3.6 and 13.4 percent and 0 and 33 percent for teeth and implants, respectively. They could not perform a meta-analysis because of the substantial differences between the studies.

Practical Implications. The results of this systematic review show that implant survival rates do not exceed those of compromised but adequately treated and maintained teeth, supporting the notion that the decision to extract a tooth and place a dental implant should be made cautiously. Even when a tooth seems to be compromised and requires treatment to be maintained, implant treatment also might require additional surgical procedures that might pose some risks as well. Furthermore, a tooth can be extracted and replaced at any time; however, extraction is a definitive and irreversible treatment.

Key Words. Hopeless teeth; periodontal disease; periodontitis; tooth loss; tooth extraction; implant placement; implant loss; implant survival.

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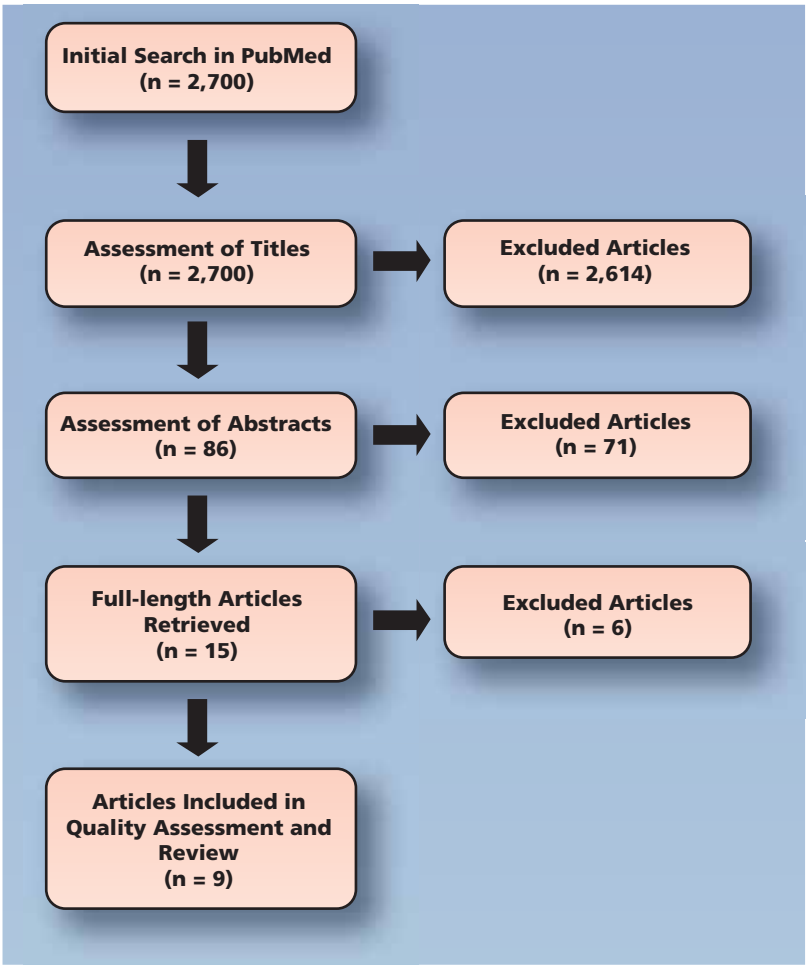

Figure 1. Flowchart of the literature search for tooth survival.

for the tooth's future, because of the large variations between the systems.[17]

Faced with the option of retaining a compromised tooth or extracting the tooth and placing a dental implant, the clinician should make an evidence-based decision.[18-20] This decision should account for the predictability of both treatment options over the long term. It is not an easy task to assess treatment alternatives reliably, because the outcome is affected by various factors, not all of which can be accounted for. Among these factors are the patient's compliance, frequency of maintenance visits (that is, supportive periodontal treatment [SPT]), systemic condition and smoking status, as well as the clinician's background and experience. Furthermore, the lack of information in the literature regarding the long-term survival and success of implants in relation to the patient's life expectancy raises doubts about the predictability of this treatment modality for young patients.[21] Because an implant can serve as a replacement for an extracted tooth at any point, clinicians may choose to preserve the natural teeth for as long as possible.

Indeed, even when a clinician classifies a tooth as hopeless, extraction is not the only viable solution. The effectiveness of periodontal treatment and long-term SPT in preventing tooth loss in patients with severe periodontal disease has been reported by investigators in many studies.[6,7,9,11,13,22] One might contemplate whether the possibility of retaining the tooth under enhanced maintenance and treatment is overruled by the availability of dental implants as an attractive alternative. Moreover, the inherent difficulties in determining the predictability of both treatment alternatives, as mentioned earlier, also might be a significant factor in deciding to extract compromised teeth and replace them with dental implants.

To provide insight into this important issue, we conducted a systematic review to assess the long-term survival rates and treatment outcomes for retained compromised teeth in comparison with the long-term survival rates for dental implants. Our focused question was this: Is the long-term survival rate of dental implants comparable to that of natural teeth that are adequately treated and maintained?

METHODS

To identify studies for this review, we searched MEDLINE's electronic database (via PubMed) from its earliest records until March 2013. The search was restricted to English-language publications. The search strategy included only studies with a follow-up period of at least 15 years. We included prospective longitudinal studies and retrospective studies in our search. The main outcomes sought were long-term survival of teeth and implants. Inclusion criteria con-

ABBREVIATION KEY. AgP: Aggressive periodontitis. **APT:** Active periodontal treatment. **CP:** Chronic periodontitis. **DM:** Diabetes mellitus. **NA:** Not available. **NR:** Not relevant. **SPT:** Supportive periodontal treatment.

sisted of follow-up of 15 years or more, a report on survival rates and more than five cases included in the study. Exclusion criteria included case reports and small case series, as well as a short follow-up period or an unclear description of survival rates for the follow-up period. In the first phase of study selection, we screened the titles and abstracts of all identified publications. We then obtained the full-text articles for all potentially relevant studies, and we independently performed an assessment of each article. In addition, we conducted a manual search of bibliographies of published review articles and of the selected studies for additional relevant reports. We resolved disagreements through discussion.

Data extraction. We extracted the following data from the selected studies: author or authors; year of publication; follow-up period; number of patients; mean age and age range of patients; periodontal disease classification; number of teeth or implants at baseline and follow-up; implant system; type of prostheses (single crown, fixed partial denture, complete denture); SPT; tooth or implant survival rate; number of patients exhibiting tooth or implant loss; reasons for tooth or implant loss; timing regarding implant loss.

Owing to the large variation in study design, a statistical meta-analysis was not feasible.

Risk of bias. We performed an assessment of risk of bias in the selected studies by using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[23] We excluded one of the criteria regarding study methodology (concealment of the allocation sequence), because it was not relevant to our study. We included an additional criterion—examining whether external funding was provided for the research.

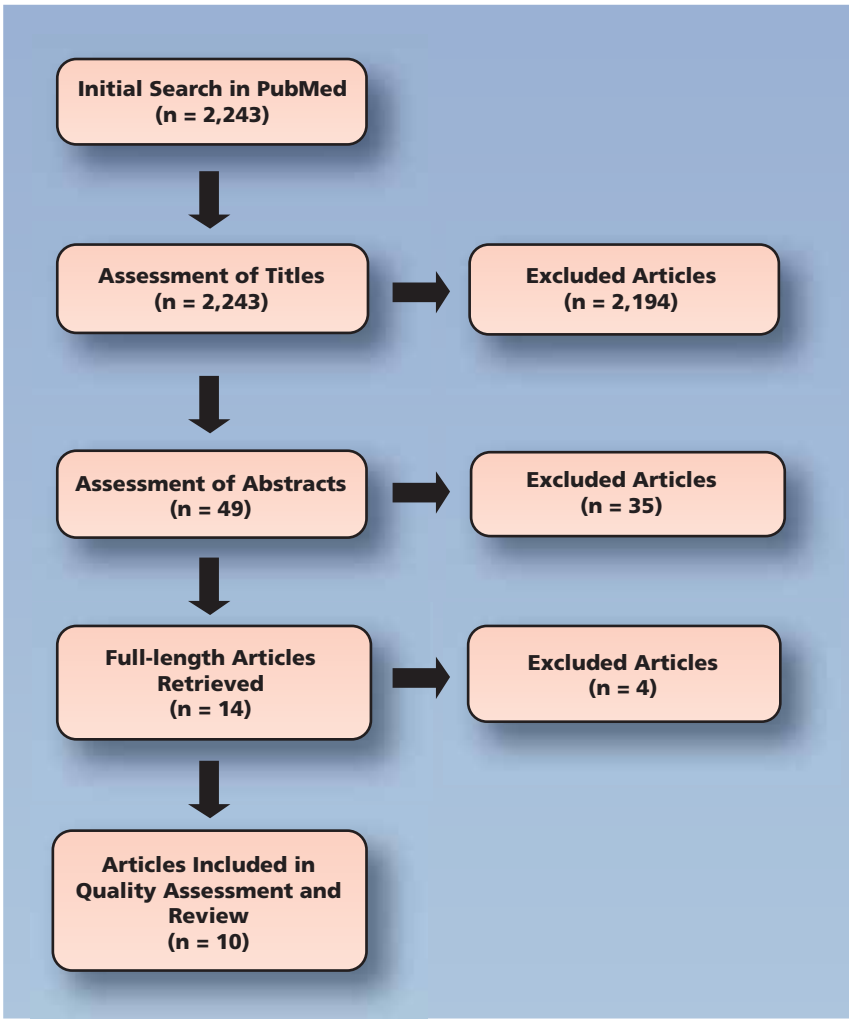

Figure 2. Flowchart of the literature search for implant survival.

RESULTS

Literature search. Figure 1 and Figure 2, respectively, present the flowcharts of the literature search for tooth survival and implant survival.

Teeth. The search strategy identified 2,700 studies. Screening of titles from the database search resulted in the identification of 86 publications that were potentially relevant for this review. Evaluation of abstracts yielded nine studies eligible for full-text analysis.

Implants. The search strategy identified 2,243 studies. We excluded 2,194 of these after reviewing the publication titles. Of the 49 remaining studies, 35 were excluded after we reviewed the article abstracts. We then screened the full texts of the remaining articles considered potentially relevant. Of these reports, four were excluded owing to missing information regarding implant survival rates or mean follow-up periods of less than 15 years. We included 10 studies in our review.

Long-term tooth survival. Tooth-loss rates after periodontal treatment and during the maintenance phase are well documented in the

TABLE 1

Characteristics of studies of tooth loss.

STUDY, YEAR	FOLLOW-UP, IN YEARS	STUDY DESIGN	NO. OF PATIENTS	PATIENT SAMPLE	SPT*
Hirschfeld and Wasserman,[7] 1978	22	Survey	600	Early to advanced periodontal disease	Yes (4-6–month intervals)
			499/600	Well maintained‡	Yes (4-6–month intervals)
			76/600	Downhill§	Yes (4-6–month intervals)
			25/600	Extreme downhill¶	Yes (4-6–month intervals)
McFall,[9] 1982	19	Retrospective	100	White, middle economic levels	Yes (4-6–month intervals)
			77/100	Well maintained	Yes (4-6–month intervals)
			15/100	Downhill	Yes (4-6–month intervals)
			8/100	Extreme downhill	Yes (4-6–month intervals)
Goldman and Colleagues,[24] 1986	22.2	Retrospective	211	White, middle economic levels	Yes (4-6–month intervals)
			131/211	Well maintained	Yes (4-6–month intervals)
			59/211	Downhill	Yes (4-6–month intervals)
			21/211	Extreme downhill	Yes (4-6–month intervals)
Norderyd and Colleagues,[25] 1999	17	Longitudinal	574	Swedish adult population	No
Matthews and Colleagues,[26] 2001	16.1	Retrospective	335	NA	Yes
Axelsson and Colleagues,[27] 2004	30	Longitudinal	257	Swedish adult population	Yes (4-6–month intervals)
Chambrone and Chambrone,[28] 2006	17.4	Retrospective	120	Generalized chronic periodontitis: Brazil	Yes (4-6–month intervals)
Jansson and Lagervall,[29] 2008	16.2	Retrospective	60	Generalized chronic periodontitis: Sweden	Yes (< 6 months)
Graetz and Colleagues,[30] 2011	16.3	Retrospective	34	Chronic periodontitis	Yes (3-12 months)
	16.1		34	Aggressive periodontitis	Yes (3-12 months)

* SPT: Supportive periodontal treatment.
† APT: Active periodontal treatment.
‡ Well maintained: Patient lost 0 to three teeth.
§ Downhill: Patient lost four to nine teeth.
¶ Extreme downhill: Patient lost 10 to 23 teeth.

TABLE 1 (CONTINUED)

AGE RANGE, IN YEARS (MEAN)	APT† AND SPT OR SPT	NO. OF TEETH AT BASELINE (MEAN NO. OF TEETH/PATIENT)	% OF TEETH LOST (MEAN NO. OF TEETH/PATIENT)	% OF PATIENTS WITH TOOTH LOSS	TOOTH LOSS CAUSE, IN PERCENTAGE (MEAN NO. OF TEETH/PATIENT)
12-73	SPT	**TOTAL:** 15,666 (26.11) Questionable: 2,141	**TOTAL:** 8.3; questionable: 31.1	Not available	7.1 periodontal (1.8 teeth/patient), 1.2 other causes
		Questionable: 1,592/2,141	(0.68) Questionable: 17.1	Not available	
		Questionable: 385/2,141	(5.7) Questionable: 64.7	Not available	
		Questionable: 164/2,141	(13.3) Questionable: 88.4	Not available	
8-71	SPT	**TOTAL:** 2,627 (26.27) Questionable: 215	**TOTAL:** 11.3 (3) Questionable: 62.3	Not available	9.8 periodontal (2.6 teeth/patient), 1.5 other causes
		Questionable: 83/215	(0.68) Questionable: 27.7	Not available	
		Questionable: 71/215	(6.7) Questionable: 77.5	Not available	
		Questionable: 61/215	(14.4) Questionable: 91.8	Not available	
(41.8)	APT and SPT	**TOTAL:** 5,761 (27.3)	**TOTAL:** 13.4 (3.6)	Not available	Not available
		3,631/5,761	3.6 (1)	Not available	
		1,575/5,761	21.6 (5.8)	Not available	
		555/5,761	53.9 (14.2)	Not available	
15-60	APT and SPT	(23.5)	6 (1.4)	Not available	58 periodontal, 36 caries
16-77	SPT	(21.8)	(1.5)	20.6	Periodontal (0.9 tooth/patient)
20-65	APT and SPT	(24.2)	3.6	Not available	62.4 root fracture, 6.9 root resorption, 6.9 caries, 4.6 trauma, 5.2 periodontal, 13.9 endodontic
20-72 (38.9)	SPT	**TOTAL:** 2,927 (24.3)	3.8 (0.92)	35.8	1.8 periodontal, 0.5 root fracture, 0.2 caries, 0.2 endodontic, 1 third molars
27-55	SPT	(19.8)	(2.3)	Not available	Not available
40-69 (51.6)	APT and SPT	**TOTAL:** 874 (24.9) Questionable: 149; hopeless: 51	Questionable: 26.8; hopeless: 54.9	85.3	36.1 periodontal
	SPT	(22.1)	**TOTAL:** 11.2; questionable: 20.4; hopeless: 34.3; 0.16 teeth/year	79.4	Not available
23-42 (33.3)	APT and SPT	**TOTAL:** 923 (26.8) Questionable: 262; hopeless: 63	Questionable: 20.2; hopeless: 65.1	Not available	78.9 periodontal
	SPT	(25.5)	**TOTAL:** 8.4; questionable: 11.8; hopeless: 40.5; 0.14 teeth/year	Not available	Not available

literature. The included studies are presented in Table 1.[7,9,24-30] Researchers in several studies assessed the rate of tooth loss over various follow-up periods ranging from 16 to 30 years, and they examined tooth loss with or without specifying the prognosis at the initial examination.[7,24,25,27-30]

Researchers in four studies[24,25,27,30] reported the mean number of teeth per patient at baseline, which ranged between 23.5[25] and 27.3.[24] Researchers in six studies[7,9,26,28-30] reported the number of teeth present—ranging between 19.8[29] and 26.27[9] per patient—after the initial active periodontal treatment (APT). Among these studies, Graetz and colleagues[30] provided information regarding both tooth loss rates after APT and during maintenance therapy, as well as information regarding patients with chronic and aggressive periodontal disease. Tooth loss from baseline to the final examination varied between 3.6 percent[27] and 13.4 percent[24] over a follow-up period of 16 to 30 years (Table 1[7,9,24-30]). Overall, between 1.4 and 3.6 teeth per patient were lost. Researchers observed a similar incidence of tooth loss during SPT, ranging from 3.8 percent[28] to 11.3 percent[9] (0.92 to 2.6 teeth lost per patient) after 16 to 22 years of follow-up. The proportion of participants who experienced tooth loss ranged from 14.7 percent to 64.2 percent.[26,28,30] Although Norderyd and colleagues[25] did not report any information regarding maintenance programs, the tooth loss rates reported in their study are in the range reported by investigators in other studies in which patients underwent SPT. Norderyd and colleagues[25] examined tooth loss rates over a 17-year follow-up period in a Swedish population.

We should note, however, that the tooth loss rates in the included studies (3.6-13.4 percent)[7,9,24-30] also reflect tooth extraction resulting from a clinician's subjective decision. However, the clinician's decision to extract a tooth is not always indicative of the tooth's ability to survive in the long term. The results of a study by Becker and colleagues[8] showed that patients who did not undergo maintenance therapy exhibited a tooth loss rate of only 6 percent over a mean follow-up period of 5.25 years. Norderyd and colleagues[25] observed the same 6 percent rate of tooth loss in a study in which they did not report any periodontal maintenance therapy. Therefore, even this relatively low rate of tooth loss might be an underestimation of the actual potential for tooth survival.

In addition to examining the overall tooth loss rate, we examined the specific reasons for tooth loss in studies in which this information was available.[7,9,25,27,28,30] When addressing tooth loss due to periodontal disease, we observed substantial variability (Table 1[7,9,24-30]). These differences arose, in part, from the methodologies used in the various studies. Specifically, Hirschfeld and Wasserman,[7] in a 22-year follow-up study among periodontal patients, reported that 7.1 percent of all teeth were lost as a result of periodontal causes and 1.2 percent were lost for other reasons. Yet, in this retrospective study, the authors attributed tooth loss to a periodontal reason if no information was available in the patient's record. This might have led to an overestimation of the periodontal disease–related tooth loss rate. McFall[9] provided a similar assessment of the causes of tooth loss; he reported that 9.8 percent of teeth were lost as a result of periodontal disease and that 1.5 percent were lost as a result of other causes, with a similar possibility of overestimation of periodontal disease–related tooth loss.

The studies that specified the prognosis for the teeth at the initial examination provide a means to focus on the survival of teeth classified as "hopeless" or "questionable," as these teeth often are the main candidates for replacement by dental implants. Hirschfeld and Wasserman,[7] McFall[9] and Graetz and colleagues[30] reported loss rates for questionable teeth that ranged between 11.3 and 31.1 percent (Table 1[7,9,24-30]). With regard to hopeless teeth, Graetz and colleagues[30] reported a long-term loss rate of 34.3 percent for patients with chronic periodontitis (CP) and 40.5 percent for those with aggressive periodontitis (AgP). As expected, these results show a significantly higher tooth loss rate for teeth classified as hopeless.

Graetz and colleagues[30] reported similar mean numbers of teeth per patient before APT (24.9 and 26.8 teeth for CP and AgP, respectively). However, patients with AgP exhibited more questionable (n = 262) and hopeless (n = 63) teeth than did patients with CP (n = 149 and n = 51 for questionable and hopeless teeth, respectively). The study results showed that tooth loss rates were 11.2 percent and 8.4 percent for patients with CP and AgP, respectively. Specifically, in patients with AgP, 11.8 percent of questionable teeth and 40.5 percent of hopeless teeth were lost. In patients with CP, 20.4 percent of questionable teeth and 34.3 percent of hopeless teeth were lost.[30] The results of this study indicate that the overall tooth loss rate and the tooth loss rate for compromised teeth (on the basis of the initial prognosis) were not affected by aggressive disease when the teeth were properly treated and maintained.

Long-term implant survival. Table 2[31-40] presents characteristics of studies of implants included in this review. Follow-up periods varied between 15 and 23 years. When examining the implant loss (or survival) rate over a long-term follow-up period, we focused on two parameters: the rate of implant loss over time and peri-implant marginal bone loss. Researchers rarely reported the causes of implant loss, whereas they frequently reported the timing of implant loss. In addition, we describe the different implant types, various surface characteristics and different implantation sites reported by the researchers. Because these factors might affect implant survival, we also compare and contrast the study results below.

The majority of study investigators reported data on Brånemark system (Nobel Biocare, Zurich) implants. Several reported data on implants placed in edentulous jaws to support an overdenture,[32,39] whereas other investigators reported data on implants placed in edentulous or partially edentulous jaws to support fixed prosthetic reconstructions.[31,33-38,40] Of the latter studies, four pertained to placement of single implants.[31,34,38,40]

The percentage of implant losses during the follow-up period varied between 0 and 33.6 percent.[31-40] The cumulative survival rate ranged between 69.6 and 100 percent. Investigators in four of these studies presented information regarding the number of patients who had experienced implant loss.[35,38-40] The calculated proportion of such participants in this group of studies ranged between 0 and 35 percent, indicating that implant loss often occurred within a subset of the patient group.

We retrieved data from seven studies regarding the amount of bone loss over a follow-up period ranging between 15 and 20 years.[33-38,40] The bone loss varied between 0.05 and 2.1 millimeters.

Tomasi and colleagues[4] reviewed studies with shorter follow-up periods (up to 10 years) and reported an implant loss rate of 1 to 18 percent and marginal bone loss of 0.7 to 1.3 mm. In contrast, investigators in studies with longer follow-up periods[33-38,40] (up to 23 years) reported an implant loss rate and a marginal bone loss that were almost twice as large as those in the study by Tomasi and colleagues.[4] These findings might imply that greater bone and implant loss occur over longer follow-up periods.

Factors affecting implant survival rates. Various factors might affect implant survival rates, including different implant types, implant surface texture (machined or textured), heterogeneity among the preimplantation sites (that is, pristine versus augmented bone and different bone characteristics) and patient-related factors. Long-term studies in which researchers assess the influence of these factors still are lacking.

Bone augmentation techniques sometimes are performed before or in conjunction with dental implant placement. Such procedures might affect implant survival rates. For example, in cases of deficient alveolar ridges, reconstruction sometimes is required first or simultaneously with implant placement. Several techniques might be used, consisting of application of autogenic bone graft, allogenic bone grafts or synthetic materials. Clementini and colleagues[41] recently conducted a review, the results of which showed success rates of 61.5 to 100 percent over a follow-up period of one to 11 years for dental implants placed in augmented bone; the authors also reported that the success rate decreased over time. Hämmerle and colleagues[42] reported a survival rate of 79.4 to 100 percent after a five-year follow-up period for implants placed after guided bone regeneration procedures.

Similarly, in cases of reduced maxillary bone height, a sinus augmentation procedure may be required before dental implants can be placed. Several investigators compared implant survival after sinus augmentation procedures in the posterior maxilla with implant survival after conventional implant placement.[43-47] Graziani and colleagues[43] reported greater variability with regard to survival in grafted sinuses. Indeed, the results of some studies showed that this procedure might decrease the survival rate of dental implants.[44-46] Del Fabbro and colleagues[45] conducted a systematic review of implant survival rates in grafted sinuses and evaluated such factors as implant surface type and graft material. They reported implant survival rates of between 61.2 and 100 percent, with a maximum mean follow-up of 75 months. Tong and colleagues[47] conducted a meta-analysis, the results of which showed implant survival rates of 87 to 98 percent in augmented sinuses over a follow-up period of six to 60 months.

Implant morphology and surface modifications, as well as the type of connection between the implant and the abutment also may influence implant survival and marginal bone loss.[48] Different implant shapes resulted in variations in stress distributions in the bone.[48-53] More specifically, conical implants displayed higher stresses than did cylindrical and screw-shaped implants. Furthermore, Siegele and Soltesz[49] found that a fixed bond between the bone and implant in the medullary region produced a

TABLE 2

Characteristics of studies of implant loss.

STUDY, YEAR	FOLLOW-UP, IN YEARS	STUDY DESIGN	NO. OF PATIENTS OR IMPLANTS	AGE RANGE, IN YEARS (MEAN)	INDICATION/TYPE OF PROSTHESIS	IMPLANT SYSTEM
Noack and Colleagues,[31] 1999	16	Retrospective	**TOTAL:** 883 patients 1,964 implants	15-86	Single implant, intermediate space, distal extension, edentulous patients	All types
			144/883 patients 349/1,964 implants			Brånemark†
			83/883 patients 146/1,964 implants			Frialit-1‡
			68/883 patients 140/1,964 implants			Frialit-2‡
			527/883 patients 1,250/1,964 implants			IMZ§
			61/883 patients 79/1,964 implants			Linkow blade¶
Attard and Zarb,[32] 2004	15.53	Prospective	45 patients	(70)	Edentulous patients (implant overdenture)	Brånemark
Attard and Zarb,[33] 2004	20.67	Prospective	45 patients 265 implants	30-66 (49.45)	Edentulous patients (implant-supported fixed prosthesis)	Brånemark
Jemt and Johansson,[34] 2006	15	Retrospective	76 patients 450 implants	32-75 (60.1)	Edentulous maxillae	Turned Brånemark
Jemt,[35] 2008	15	Retrospective	Test group: 38 patients 47 implants	(25.4)	Single implant	Turned Brånemark
			Control group: 76 patients 76 implants	32-75 (60.1)	Edentulous patients	
Åstrand and Colleagues,[36] 2008	20	Retrospective	48 patients	40-74 (54.3)	Edentulous patients	Modum Brånemark
Örtorp and Jemt,[37] 2009	15	Retrospective	**TOTAL:** 208 patients 1,099 implants	35-87	Edentulous mandible	Turned Brånemark
			Test group: 155 patients 821 implants	35-87 (64)	Titanium framework	
			Control group: 53 patients 278 implants	39-86 (67)	Gold alloy framework	
Bergenblock and Colleagues,[38] 2012	18.4	Prospective (5 years), retrospective (~15 years)	57 patients 65 implants	15-57 (31.9)	Single implant	83% turned Brånemark, 17% Brånemark implants with conical head
Vercruyssen and Quirynen,[39] 2010	23	Retrospective	495 patients 1,051 implants	(60.8)	Implant-retained overdenture in mandible	95.5% turned Brånemark, 4.6% TiUnite#
Dierens and Colleagues,[40] 2012	18.4	Retrospective	Control group: 134 patients	14-57 (23.9)	Single implant	Turned external hex Brånemark
			Investigation group: 50 patients			

* NA: Not available.
† Brånemark implants are manufactured by Nobel Biocare, Zurich.
‡ Frialit-1 and Frialit-2 implants are manufactured by Dentsply Implants, Mölndal, Sweden, and Mannheim, Germany.
§ IMZ implants were manufactured by Interpore International, Irvine, Calif.
¶ Linkow implants were manufactured by Linkow, New York City.
# TiUnite implants are manufactured by Nobel Biocare.

TABLE 2 (CONTINUED)

NO. (%) OF PATIENTS OR IMPLANTS FOLLOWED UP	% OF IMPLANTS LOST	CUMULATIVE SURVIVAL RATE, IN PERCENTAGE	NO. (%) OF PATIENTS WITH IMPLANT LOSS	MEAN (STANDARD DEVIATION) BONE LOSS, IN MILLIMETERS	TIME OF IMPLANT LOSS
809 patients	6.2	NA*	NA	NA	4.3% during postprosthetic phase; 1.9% before prosthetic phase
132 patients	0.86	96.2 for 1 year			
77 patients	33.6	82.1 for 1 year; 69.6 after 10 years			
63 patients	5.7	92.7 for 1 year			
482 patients	3.7	98.2 for 1 year; 81 after 10 years			
55 patients	20.3	90.1 for 1 year; 81.4 after 10 years			
30 patients	NA	90	NA	NA	NA
32 patients, 67 implants	NA	86.76 after 20 years	NA	0.05 (0.018)	NA
33 patients, 203 implants	NA	90.9	27 (35)	2.1 (0.58)	3.3% before prosthesis placement; 4.8% after prosthesis placement
72.1% of patients, 68.1% of implants	0	100	0	0.66 (0.78)	NA
76 patients, 76 implants	4	95.4	3 (4)	0.5 (0.47)	
21 patients, 123 implants	0.8	99.2	NA	0.53	2 years, 4 months after loading
72 patients (34.6%)	1.1	98.7	NA	NA	NA
52 patients (44.4%) 282 implants	2.2	98.7		0.59 (0.56)	
13 patients (24.5%) 65 implants	2.2	98.9		0.98 (0.64)	
48 patients (84.2%) 53 implants (81.5%)	3.77	96.8	2 (4)	Turned Brånemark: 0.3 (0.92); conical: 0.2 (1.11)	1 lost during first year in function; 1 lost owing to fracture after 9 years in function
369 patients	3.9	95.5	31 (3)	NA	0.4% before abutment connection; 2.3% soon after abutment connection; 1.2% after loading
118 patients	9.7	91.5	(10.2)	NA	NA
50 patients 62 implants	4.8	NA	(4)	1.7 (0.88); range, −0.8 to 5	1 failed within 1 month after surgery before abutment connection; 2 failed when crown was in place (after 5 and 15 months)

more uniform stress distribution than did a pure contact. The platform-switching concept, in which the diameter of the abutment is reduced with respect to the diameter of the implant, may decrease peri-implant bone resorption.[50] The results of several studies[45,51,52] showed that textured implants (rough-surfaced implants) achieved superior outcomes to those of machined surfaces,[45,51,52] exhibiting a mean survival rate of 94.2 to 96.7 percent versus 81.6 to 86.3 percent during a mean follow-up period of 12 to 75 months.

Although researchers have documented the high survival rate of dental implants, biological complications and mechanical overload also may lead to implant loss or related complications.[1,2,54] Dental implants are exposed to the same periopathogenic environment as are teeth; therefore, the prevalence of peri-implant infections rises with the number of implants and with extended exposure periods in the oral cavity.[55] Mombelli and colleagues[56] reported that periodontal pathogens identified in residual pockets at the time of implant placement were adjacent to the implant three and six months later, indicating the spread of pathogens.

Zitzmann and Berglundh[57] studied the incidence of peri-implant infections. They reported that peri-implant mucositis occurred in 80 percent of participants and in 50 percent of implant sites, whereas peri-implantitis was diagnosed surrounding 7 to 43 percent of implants and among 16 to 56 percent of patients.[57] The different criteria used by researchers to define peri-implant diseases[58] might result in an underestimation of the reported incidence of peri-implant disease. Underestimation of peri-implant disease incidence also might result from the fact that many of the studies were performed in university or specialized clinics that might not reflect the general population. We can conclude from the above data that many of the implants placed (about one of five) will result in peri-implant disease—a disease with no apparent criterion standard treatment—at some point.[57-61]

Treatment planning for dental implants involves the clinician's assessment of patient-related factors.[62] A range of conditions are associated with an increased risk of experiencing implant failure, either early if the condition occurs before the procedure or late if the condition arises subsequent to implant loading. The clinician must be aware of and understand the many risk factors in order to advise patients and to consider when planning and providing treatment.

Patient-related factors. Consistent evidence shows an increased implant failure rate among smokers, as well as among patients with diabetes mellitus (DM), a history of radiotherapy, impaired bone quality and quantity, peri-implant disease and a history of periodontitis-related tooth loss.[63-65] Herrmann and colleagues[66] reported early implant failure in 3.7 percent of patients and found that the most significant patient-related factors were jawbone shape (D [some resorption of the basal bone has taken place] and E [extreme resorption of the basal bone has taken place]) and jawbone quality (type 4 [thin layer of cortical bone surrounds a core of low-density trabecular bone]), according to the classification by Lekholm and Zarb.[67]

Smoking might result in compromised wound healing and is associated with early and late implant loss.[68-70] Moy and colleagues[71] conducted a 21-year retrospective study and assessed risk factors associated with implant failure. Of 173 patients with a self-reported history of smoking, 35 (20.23 percent) experienced implant failure (relative risk [RR], 1.56; 95 percent confidence interval [CI], 1.03-2.36; $P < .05$). Levin and Schwartz-Arad[72] found that implant survival rates were lower among smokers than among nonsmokers (87.8 percent and 97.1 percent, respectively). In that review, the authors found higher failure rates in the maxillae of smokers and more implant complications, especially in smokers after bone augmentation procedures.

DM also is a frequently reported risk factor associated with implant failure.[63,64,71] Morris and colleagues[63] reported more implant failures in patients with type 2 diabetes than in patients who did not have diabetes ($P = .020$) over a 36-month follow-up period. Moy and colleagues[71] also found an association between DM and increased rates of implant failure. In their 21-year retrospective study, these authors reported an implant survival rate of 68.75 percent among 48 patients with diabetes (RR = 2.75; 95 percent CI, 1.46-5.18; $P < .05$).

Several study findings show that patients susceptible to periodontal disease are more prone to developing peri-implant infections, including peri-implant mucositis and peri-implantitis.[73-76] In a systematic review, Schou and colleagues[77] found that patients with tooth loss due to periodontitis were affected more significantly by peri-implantitis (RR = 9; 95 percent CI, 3.94-20.57) after 10 years and had significantly increased peri-implant bone loss after five years (95 percent CI, 0.06-0.94) compared with patients who did not have periodontitis-related tooth loss. Moreover, patients receiving SPT who developed reinfections were at greater risk of developing

peri-implantitis and experiencing implant loss.[78] Simonis and colleagues[79] reported a 37.93 percent prevalence of peri-implantitis in patients with a history of periodontitis compared with a 10.53 percent prevalence in patients with no history of periodontitis.

Furthermore, several researchers reported lower success rates for dental implants in such patients.[55,76,80-84] Karoussis and colleagues[76] found that patients who had a history of periodontitis demonstrated lower survival rates (90.5 percent) compared with patients who did not have a history of periodontitis (96.5 percent). Fardal and Linden[85] found more implant failures and complications in a group of patients with refractory periodontal disease; 25 percent of implants were lost during a maintenance period of 13.4 years. Similarly, Levin and colleagues[73] reported a hazard ratio of 8.06 for long-term implant failure in patients with periodontal disease compared with periodontally healthy patients.

As life expectancy increases, clinicians will observe more comorbidity and combined risk factors in their patients, which enhance their risk of experiencing implant failure or associated diseases. For example, a patient who is a current smoker with a history of periodontal disease might need an augmentation procedure before undergoing implant treatment. These risk factors might decrease the implant survival or success rates, although the contribution of each risk factor is unknown, as is the presence or absence of a synergism between the factors.

Risk of bias. Tables 3[7,9,24-30] and 4[31-40] show the results of our assessment of risk of bias in studies of tooth loss and implant loss, respectively. We found that, overall, studies dealing with dental implants tended to present a higher risk of bias. An important issue to consider regarding implant survival is the industry-derived financial support for studies of dental implants. Anecdotal evidence suggests that many of the studies in which investigators report on implant success are supported directly or indirectly by the dental implant industry; however, this information is not always disclosed in the articles. Clinicians should keep this in mind when evaluating these materials.

DISCUSSION

The main purpose of this study was to compare the long-term survival of teeth and dental implants to provide clinicians with tools for evidence-based treatment planning when considering tooth extraction and implant placement.

We should point out that an objective and comprehensive comparison is not easy to accomplish. The available literature consists of data that are heterogenic in many aspects. First, the studies in which investigators assessed tooth and implant survival were designed differently, with tooth studies usually incorporating an epidemiologic approach, whereas most of the implant studies included a distinct group of patients, all of whom received implant therapy (that is, a less heterogenic sample).[4] Although this population typically is less heterogeneous, patients' periodontal status was defined less often than it was in the tooth survival studies. Most studies in which investigators assessed tooth survival were conducted in periodontally compromised patients; however, information regarding the periodontal status of patients in the implant survival studies was seldom reported. We also should note that the cause of tooth loss that led to implant placement could have played a major role in the subsequent loss of the implant. Brägger and colleagues[86] found that periodontal conditions were correlated with the clinical condition diagnosed at implant sites, indicating the possibility of spread of infection from periodontally infected sites to the implant site.[56] Indeed, researchers[73-76] observed higher implant loss rates in periodontally compromised patients than in periodontally healthy patients.

Second, researchers have studied the rate of tooth loss for more years than they have the rate of dental implant loss, because dental implant technology emerged during the 1980s. Third, dental implant systems have improved over time, and some early systems are no longer in use. Yet, the available literature covers a range of systems, not only the most advanced systems that are relevant for treatment planning today. Randomized trials comparing different implant systems still are lacking, and, therefore, clinicians cannot compare the merits of different systems.[87] Fourth, because implant survival and success can change over time, a careful, long-term evaluation is necessary; moreover, these variables might be affected by the above-mentioned factors. However, after taking into consideration these inherent difficulties, we find the attempt to compare tooth survival with dental implant survival to be a worthwhile endeavor.

When assessing the general loss rate of teeth and implants over follow-up periods of at least 15 years, we found a range of 3.6 to 13.4 percent for tooth loss and a range of 0 to 33 percent for implant loss. This might imply a generally higher rate of implant loss than of tooth loss, which supports the conclusion of Holm-Pedersen and colleagues[88] that implant survival will not sur-

TABLE 3

Assessment of risk of bias in studies of tooth loss.

STUDY, YEAR	APPROPRIATE GENERATION OF RANDOM ALLOCATION SEQUENCE	MASKING OF HEALTH CARE PROVIDERS, DATA COLLECTORS, OUTCOME ADJUDICATORS	PERCENTAGE OF PATIENTS LOST TO FOLLOW-UP	TRIALS STOPPED EARLY FOR BENEFIT	ANALYSIS FOLLOWED INTENTION-TO-TREAT PRINCIPLE	INDUSTRY FINANCIAL SUPPORT
Hirschfeld and Wasserman,[7] 1978	Yes	Unknown	NR*	No	Yes	Unknown
McFall,[9] 1982	Yes	Unknown	NR	No	Yes	Unknown
Goldman and Colleagues,[24] 1986	Yes	Unknown	NR	No	Yes	Unknown
Norderyd and Colleagues,[25] 1999	Yes	Unknown	24	No	Yes	No
Matthews and Colleagues,[26] 2001	Yes	Unknown	NR	No	Yes	Unknown
Axelsson and Colleagues,[27] 2004	Yes	Unknown	30	No	Yes	Unknown
Chambrone and Chambrone,[28] 2006	Yes	Unknown	NR	No	Yes	Unknown
Jansson and Lagervall,[29] 2008	Yes	Unknown	NR	No	Yes	Unknown
Graetz and Colleagues,[30] 2011	Yes	Unknown	NR	No	Yes	No

* NR: Not relevant.

TABLE 4

Assessment of risk of bias in studies of implant loss.

STUDY, YEAR	APPROPRIATE GENERATION OF RANDOM ALLOCATION SEQUENCE	MASKING OF HEALTH CARE PROVIDERS, DATA COLLECTORS, OUTCOME ADJUDICATORS	PERCENTAGE OF PATIENTS LOST TO FOLLOW-UP	TRIALS STOPPED EARLY FOR BENEFIT	ANALYSIS FOLLOWED INTENTION-TO-TREAT PRINCIPLE	INDUSTRY FINANCIAL SUPPORT
Noack and Colleagues,[31] 1999	Yes	No	8.4	No	Yes	Unknown
Attard and Zarb,[32] 2004	Yes	Yes	33.3	No	Yes	Unknown
Attard and Zarb,[33] 2004	Yes	Yes	29	No	Yes	Unknown
Jemt and Johansson,[34] 2006	Yes	No	56.6	No	Yes	Unknown
Jemt,[35] 2008	Yes	Unknown	31.9 (treatment), 59.2 (control)	No	Yes	Unknown
Åstrand and Colleagues,[36] 2008	Yes	No	43.7	No	Yes	Yes
Örtorp and Jemt,[37] 2009	Yes	No	66.4 (treatment), 75.5 (control)	No	Yes	Unknown
Bergenblock and Colleagues,[38] 2012	Yes	Yes	18	No	Yes	Unknown
Vercruyssen and Quirynen,[39] 2010	Yes	No	50	No	Yes	No
Dierens and Colleagues,[40] 2012	Yes	Yes	19.4	No	Yes	No

pass tooth survival over the long term. In addition, an implant can serve as a replacement for an extracted tooth at any point, regardless of the length of time the tooth had been maintained. This enables the clinician to preserve the tooth for as long as possible. However, tooth extraction is a definitive and irreversible treatment. The decision to extract a tooth is subjective, requiring the clinician to conduct an extensive observation of all the factors involved.

With regard to hopeless or questionable teeth only, the tooth loss rate was much higher, rang-

ing between 20 and 62.3 percent (Table 1[7,9,24-30]). Still, one should keep in mind that the survival of an implant does not necessarily mean the treatment has been successful, because a surviving implant may be nonfunctional, or significant bone loss may have occurred. In the field of implant dentistry, the common outcome measures to assess performance are survival and success rates. Implant survival is relatively straightforward, whereas success is determined by investigators who use differing criteria. According to the National Institutes of Health Consensus Development Conference Statement,[89] an implant is considered successful when it provides functional service for five years in 75 percent of the cases. That report includes objective and subjective criteria for success.[89] In their 1986 review, Albrektsson and colleagues[90] proposed other criteria for success. In addition to the variability in criteria for success among different studies, the criteria may vary with different implant systems.[87] Because a consensus regarding the success of dental implants still is lacking, we assessed survival rates in this review, as have most investigators in previous review articles. With regard to teeth, there is no definition of a successful tooth; however, it is possible to define a tooth as stable, without active disease.

After an implant has failed, the next step essentially is placing another implant. However, researchers have reported significantly lower success rates for re-implantation than for the original implants.[91,92] Dental implants are not the reference standard for replacing compromised teeth because they will not survive forever. Even when a tooth might seem to be compromised and requires treatment to be maintained, we should keep in mind that implant treatment also requires surgery, sometimes including bone augmentation and additional procedures that are not free of risk.

CONCLUSION

The clinician's ultimate goal when planning treatment is to enhance the probability of success by accounting for the risks implicated in each treatment path. In light of the above review, the decision to retain properly treated and maintained teeth for as long as possible seems to provide an overall solution that can reduce the treatment risks over the long term. ■

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