Review

The Influence of Implant Diameter on Its Survival: A Meta-Analysis Based on Prospective Clinical Trials

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Background: The use of narrow-diameter implants has been proposed to restore small edentulous spans, thus avoiding extensive bone augmentation procedures and reducing the surgical complexity of implant rehabilitations. Although success rates of narrow-diameter implants have already been analyzed in the literature, to the best of the authors' knowledge, no meta-analysis based on prospective and randomized controlled trials has been performed. The aim of this study is to analyze the survival rates of narrow-diameter implants compared with standard or wide-diameter implants.

Methods: An electronic search from three databases and a hand search in implant-related journals of studies published in English before September 1, 2012 were performed. Prospective human clinical studies with at least 10 implants and a follow-up period of 1 year were included in the meta-analysis. Implants were divided into two groups based on their diameters.

Results: The initial search yielded 484 articles, of which 49 were evaluated in full text for eligibility. Finally, 16 studies were chosen and separated into two groups: 1) implants of diameter <3.3 mm (group 1) and 2) implants of diameter ≥3.3 mm (group 2). A meta-analysis performed for groups 1 and 2 showed survival rates of 75% and 87%, respectively.

Conclusions: This meta-analysis showed that narrower implants (<3.3 mm) had significantly lower survival rates compared with wider implants (≥3.3 mm). Other variables, such as type of prosthesis, implant surface, and timing of prosthetic loading, were found to have influenced the implant survival rates. *J Periodontol 2014;85:569-580.*

KEY WORDS

Alveolar process; dental implantation; dental implants, single-tooth; dental prosthesis, implant-supported.

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Dental implants are excellent for replacing missing teeth. Not only do they demonstrate high success rates,[1,2] they improve patients' quality of life by restoring lost function and esthetics. Compared with removable and fixed partial dentures, dental implants offer a fixed reconstruction of edentulous spans with no risk of biologic complications, such as caries, to natural teeth. As such, implant-supported or retained prostheses have indications ranging from replacing a single tooth to restoring full-arch edentulous spans.[3] Despite the benefits of dental implants, their use is confined to areas with adequate bone volume. This serves as a limitation because bone remodeling after tooth loss frequently renders the edentulous site unsuitable for implant placement.[4] Loss of horizontal ridge width occurs more frequently and to a greater extent compared with vertical bone loss after tooth extraction.[5] Several options, such as advanced bone-grafting procedures[6] before or simultaneously with implant placement and use of narrow[7] implants, have been proposed to overcome this limitation.

Multiple studies in the literature attempted to classify small implants by their diameter.[8-10] Saadoun and Le Gall[9] considered 3.8 mm as standard diameter and narrow implants as ≤3.7 mm. In contrast, Degidi et al.[10] classified

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≤3-mm-diameter implants as narrow-diameter implants, whereas Davarpanah et al.[6] considered narrow implants as those with diameters from 3.0 to 3.4 mm.

Similarly, Romeo et al.[11] classified small-diameter implants as 3.3-mm implants, with 4.1 mm being the standard-diameter implants. Quek et al.[8] attempted to classify implants into mini (<2.9 mm), small or narrow (3 to 3.4 mm), regular (3.75 to 4 mm), and wide (5 to 6 mm). Therefore, implant diameters ranging from 1.8 to 3.3 mm[12-15] have been categorized as narrow implants. In addition, huge variability existed among the studies, making it even more difficult to establish the definition of small- and standard-diameter implants. This research showed that there is no universal classification of implant diameters.

Multiple studies found that narrow implants shared similar success and survival rates as regular and wide implants.[11,16] A recent review reported that small-diameter implants have survival rates of >90%.[16] However, there is no meta-analysis evaluating the success and survival rates of narrow implants. Therefore, this meta-analysis aimed to explore the success and survival rates of narrow implants based only on prospective studies. To obtain statistically significant results, implant diameter is grouped as <3.3 and ≥3.3 mm for this analysis.

MATERIALS AND METHODS

A search of three electronic databases, including PubMed, Cochrane Central, and Ovid (MEDLINE), for studies published until September 2012 in the English language was conducted by two examiners (I-OO and FS). The authors used the guidelines of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis)[17] to evaluate the survival rate of narrow dental implants. The PRISMA methodology was developed to ensure a more consistent study outcome. Thus, the reader can be assured that the appropriate amount of due diligence was performed in the literature search and that it was done in a logical manner.[18]

The search terms used were "Jaw, edentulous"[mh] OR "Alveolar process"[mh] OR "Dental implants, single-tooth"[mh] OR "Dental implantation"[mh] OR "Dental implants"[mh] OR "Dental prosthesis design"[mh] OR "Dental prosthesis, implant-supported"[mh] OR "anterior implant rehabilitations"[tiab] AND ("narrow"[tiab] OR "small diameter"[tiab] OR "mini"[tiab]) AND ("Provisionalization"[tiab] OR "Restoration"[tiab] OR "Loading"[tiab]), in which mh indicated a MeSH term, and tiab represented a title or abstract.

Hand search of relevant studies published in dental journals from January 2000 to September 2012 was performed. The dental journals included were as follows: 1) *Journal of Clinical Periodontology*; 2) *Clinical Oral Implants Research*; 3) *Journal of Oral and Maxillofacial Implants*; 4) *Implant Dentistry*; 5) *Journal of Oral Implantology*; 6) *Journal of Oral and Maxillofacial Surgery*; 7) *Journal of Dental Research*; 8) *Journal of Prosthetic Dentistry*; 9) *Journal of Periodontology*; 10) *International Journal of Periodontics & Restorative Dentistry*; 11) *International Journal of Oral & Maxillofacial Surgery*; 12) *Clinical Implant Dentistry and Related Research*; and 13) *European Journal of Oral Implantology*.

Articles were included if the following criteria were fulfilled: prospective human clinical trials that analyzed success or survival rates of small-diameter implants with at least 10 implants placed in either the maxilla or mandible and a minimum follow-up of 12 months. The implants were restored as single crowns, fixed partial bridges, or overdentures. Articles were excluded if they had one or more of the following characteristics: 1) case reports/series; 2) review articles or clinical trials with <10 implants; 3) insufficient follow-up (<1 year); or 4) implants with smooth surfaces. Retrospective studies were also excluded as well as finite element analysis and animal studies. Potential articles were independently reviewed in full text by two examiners (I-OO and FS). When disagreement occurred between the two examiners, discussion was used to resolve them. The final decision on the included articles was made with mutual agreement of the two examiners.

Quality of the Included Studies

All studies included in the present meta-analysis were prospective human trials, and the Newcastle-Ottawa scale (NOS) was used to assess the quality of such studies for a proper understanding of nonrandomized studies.[19]

Statistical Analyses

Failure rates by year were computed by dividing the number of failures by the total exposure time (TET) of implants. TET was computed as the product of the number of implants by the length of the follow-up period in years. No data were available on the timing of implants lost during the follow-up period or on study attrition by death, refusal to participate, other illnesses, or causes. A Poisson distribution was assumed for a total of implant exposure years. For the Poisson regression, a logarithmic link function was used, and the TET per study was the exposure variable.[20-22]

The Pearson goodness-of-fit statistic was used to evaluate heterogeneity of the event rates for each specific study. A P value <0.05 was assumed to indicate heterogeneity and non-combinability of the studies. Under the random-effects model, summary estimates and standard errors were computed to obtain 95% confidence interval (95% CI) of the combined event rates. Moreover, gamma-distributed random-effects Poisson regression was developed to test the effects of implant diameter on failure rates. Survival rates after 5 years were computed using the survival function S: $S(T) = e^{-T \times \text{Event Rate}}$.[21,22] Event rate was assumed constant across time but not across studies. Random-effects Poisson regression was used to test whether event rates were a function of implant diameter. Implant diameters <3.3 mm were coded as narrow. Implants ≥3.3 mm were coded as regular or standard.

RESULTS

The mean NOS score of the non-randomized included studies was 7.06 ± 1.94 (ranging from 6 to 9), ensuring a more consistent quality outcome of the selected studies. Figure 1 presents the screening process. A total of 484 articles were found in the initial screening. After reading titles and abstracts, 49 articles were further evaluated. From these, 16 studies met inclusion and exclusion criteria.[3,7,9-15,23-29] Interexaminer agreement in selecting the articles was 0.9.

After the full-text evaluation, the following criteria were used to exclude studies: 1) if they were animal studies,[30] case reports/series,[31-33] or retrospective studies;[34-53] 2) if they were published in languages other than English;[54] 3) if they had data combined with wider implants;[55,56] 4) if they included orthodontic implants[57] and smooth surface implants;[58,59] and 5) if they did not report success or survival rates.[60-62]

A total of 16 studies were included in this analysis. Tables 1 and 2 are summaries of the selected studies published from 1996 to 2012 with an observation period of 1 to 8 years. A total of 3,291 implants were placed in 1,470 patients, aged 18 to 85 years. Given that neither the elapsed time until implant failure nor the study attrition was reported in these studies, the TET for each study were computed based on the assumption that all implant failures were observed at the end of the follow-up times.

Implant Failure

Seven of the studies used narrow implants (<3.3 mm), and the remaining used standard implants (≥3.3 mm), with an average follow-up time of 3.26 and 4.04 years, respectively. The estimated failure rates per 100 implants year ranged from 0% to 4.12%, and the summary estimate obtained by Poisson regression was 0.68% (99.32% survival), with 95% CI ranging from 0.43% to 1.07% (dispersion parameter = 1.29; P <0.01) (Fig. 2). The estimated survival rate at 5 years after loading was 0.92, with 95% CI ranging from 0.60 to 1.41 (Table 3).

The random-effects Poisson regression estimates of failure rates were 1.21% and 0.34%, respectively, for narrow and standard implants (z = –4.51; P <0.001; 95% CI ranging from 0.62% to 1.24%). The difference between the two diameter conditions remained significant when restoration delivery, implant surface, location (mandible, maxilla, or both), and restoration type (single crowns, overdentures of fixed partial bridges) were included in the prediction equation (0.35% and 0.99% for regular and narrow, respectively; z = –7.34; P <0.001). Two studies were excluded from this analysis because information on the implant surface could not be extracted.

The Poisson regression estimates of the 5-year failure rates were 0.51% and 1.64%, respectively, for standard and narrow implants (z = –3.49; P <0.001; 95% CI ranging from 0.69% to 1.86%). The difference between the failure rates

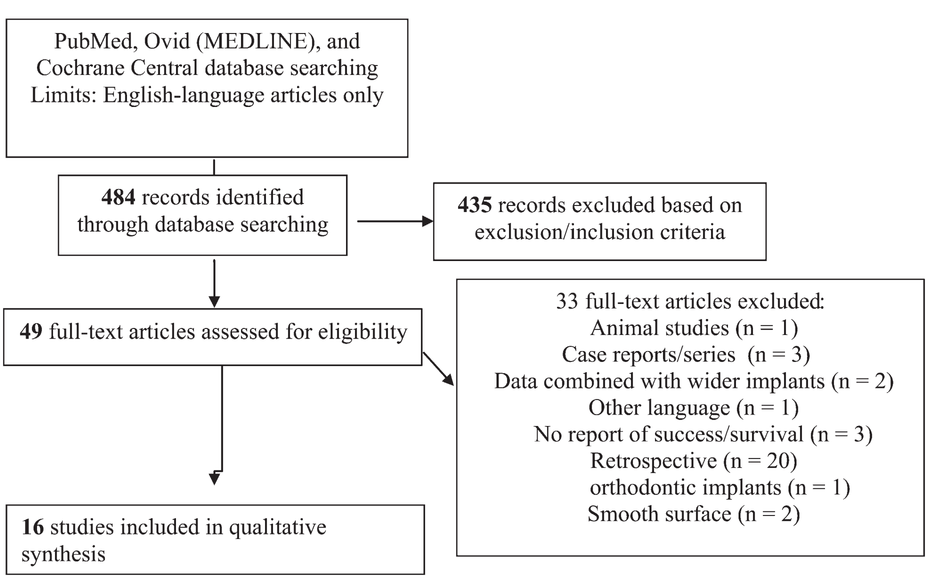

Figure 1.
Flowchart of the screening process.

Table 1.

Studies With Implant Diameter <3.3 mm

Reference	Restoration Delivery	Design	Technique	Diameter (mm)	Length (mm)	Surface Characteristics	Number of Patients	Number of Implants	Location	Restoration Type	Follow-Up (Months)	Survival/ Success
Andersen et al., 2001[26]	6 months	Prospec	FR	3.25	13 to 16	Dual acid-etched	28	32	Maxillary lateral or central incisor	SC	36	100% sur/ 93.8% suc
Elsyad et al., 2011[12]	1 stage	Prospec	FL	1.8	12 and 18	Sandblasted acid-etched	28	112	Mandible	OV	36	96.4% sur/ 92.9%suc
Galindo-Moreno et al., 2012[7]	2.5 months	Prospec	FR	3	11 to 13 to 15	Fluoride-modified nanostructure implant surface*	69	97	Anterior region in the maxilla and mandible	SC	12	95.9% sur
Griffitts et al., 2005[13]	1 stage	Prospec	FL	1.8	10 to 18	Etched self-tapping thread	24	116	Maxilla and mandible	OV	13	97.40% suc
Oyama et al., 2012[28]	3 months	Prospec	FR and FL	3	≥11	Grit-blasted thermal acid-etched	13	17	Maxillary lateral incisor and mandibular incisor	SC	12	100% suc
Morneburg and Pröschel, 2008[23]	2 stage	Prospec	NA	2.5	9, 12, 15	Sandblasted and acid-etched	67	134	Mandible	OV	72	95.50% sur
Saadoun and Le Gall, 1996[9]	3 to 8 months	Prospec	NA	3.25	8 to 10 to 12 to 14 to 16	Titanium screw	NA	330	Maxilla and mandible	SP or PP	96	88.5% suc

N/A = not available; Prospec = prospective; FR= flap reflection; FL= flapless; NA = not available; SC = single crowns; OV = overdentures; SP = single prosthesis; PP = partial prosthesis; sur = survival; suc = success.
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Table 2.

Studies With Implants ≥3.3 mm

Reference	Restoration Delivery	Design	Technique	Diameter (mm)	Length (mm)	Surface Characteristics	Number of Patients	Number of Implants	Location	Restoration Type	Follow-Up (Months)	Survival/ Success
Andersen et al., 2001[26]	6 months	Prospec	FR	3.75	13 to 15	Dual acid-etched	27	28	Maxillary lateral or central incisors	SC	36	100% sur and suc
Chiapasco et al., 2012[15]	3 to 12 months	Prospec	FR	3.3	8 to 10 to 12 to 14	Titanium zirconium alloy	18	51	Maxilla and mandible	FP or RP	24	100% sur and suc
Degidi et al., 2009[10]	30 immediate, 30 one stage	Randomized clinical trial	FR	3	15 to 18	Grit-blasted and acid-etched	60	60	Maxillary lateral incisors	SC	36	100% sur
El-Sheikh et al., 2012[29]	2.5 months	Prospec	FR	3.3	10 to 12 to 14	NA	20	50	Mandible	OV	24	98% sur
Hallman, 2001[24]	3 to 6 months	Prospec	NA	3.3	8 to 12	Sandblasted and acid-etched	40	182	Maxilla	FP/SC	12	99.4% sur
Al-Nawas et al., 2012[25]	NA	Prospec	NA	3.3	8 to 10 to 12 to 14	Chemically active implant surface*	87	174	Mandible	OV	12	98.1% sur/ 95.% suc
Romeo et al., 2006[11]	3 to 6 months	Prospec	FR	3.3	10 to 12	Titanium plasma sprayed	68	122	Maxilla and mandible	45 PFP and 23 ST	84	97.5% sur/ 94% suc
			FR	4.1	10 to 12	Titanium plasma sprayed	120	208	Maxilla and mandible	70 PFP and 50 ST		97% sur/ 96% suc

Table 2. (continued)

Studies With Implants ≥3.3 mm

Reference	Restoration Delivery	Design	Technique	Diameter (mm)	Length (mm)	Surface Characteristics	Number of Patients	Number of Implants	Location	Restoration Type	Follow-Up (Months)	Survival/ Success
Saadoun and Le Gall, 1996[9]	3 to 8 months	Prospec	NA for all three groups in this study	3.8	8 to 10 to 12 to 14 to 17	HA-coated cylinder		826				98% suc
				3.8	8 to 10 to 12 to 14 to 18	Titanium plasma sprayed cylinder	605 (total of three groups)	133	Maxilla and mandible for all three groups in this study	SP or PP for all three groups in this study	96	99.2% suc
				4.5	8 to 10 to 12 to 14 to 19	HA-coated screw		214				97.6% suc
Veltri et al., 2008[27]	6 months	Prospec	FR	3.5	9 to 13 to 15 to 17	Titanium dioxide-blasted	12	73	Maxilla	FP	12	100% sur
Zarone et al., 2006[14]	4 months	Prospec	FR	3.3	10 to 12 to 14	Sandblasted and acid-etched	30	34	Maxillary lateral incisors	SC	39	97.06% sur/ 94.12% suc
Zinsli et al., 2004[3]	3 to 6 months	Prospec	NA	3.3	8 to 10 to 12	NA	154	298	Maxilla and mandible	SC/PFP or CFP/OV	72	96.6% sur

NA = not available; Prospec = prospective; FR = flap reflection; HA = hydroxyapatite; SC = single crowns; OV = overdentures; SP = single prosthesis; PP = partial prosthesis; FP = fixed prostheses; RP = removable prostheses; PFP = partial fixed prostheses; CFP = complete fixed prostheses; ST = single-tooth; sur = survival; suc = success.
* SLActive, Institute Straumann, Crawley, West Sussex, U.K.

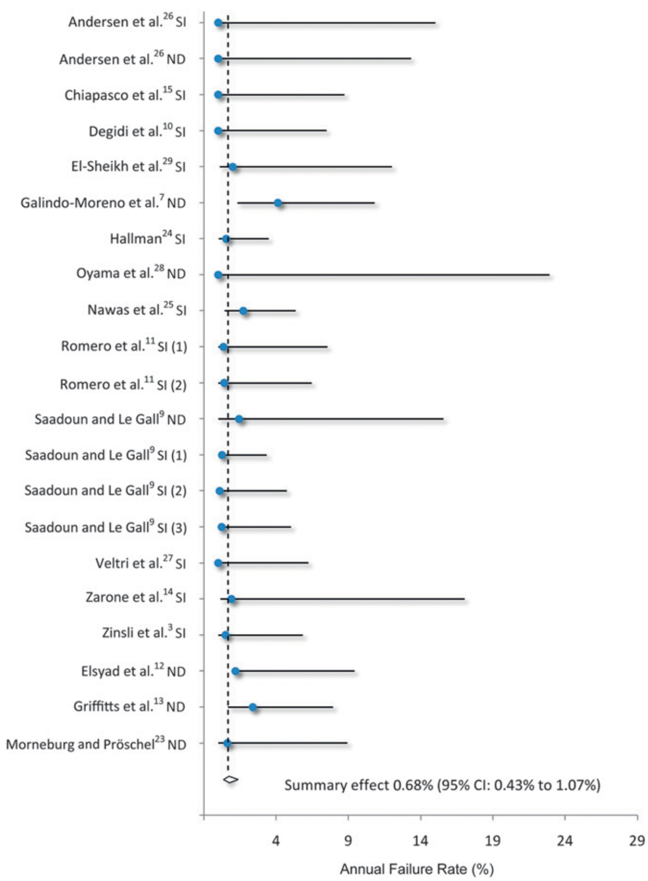

Figure 2.
Failure rates per 100 implants per year. ND = narrow-diameter; SI = standard implant.

of the diameters at 5 years (1.15%) remained significant after introducing the other predictors (0.40% and 1.55% for standard and narrow, respectively; $z = -4.19$; $P < 0.001$).

Table 4 illustrates the influence of predictors on the failure rate per 100 implants per year. Failure ratio rates (FRRs) have been computed for each variable by dividing each failure rate by the reference, the minimum rate in the corresponding category, so that they indicated how many times the failure rate in the target category overcame the reference. Failures were 3.92 times more frequent in narrow than in regular implants. The evaluation showed that FRR was 1.93 and 1.42 times higher in dual-acid and sandblasted acid-etched implants, respectively. Failures of implants placed in the mandible happened 4.95 times more frequently than failures of those placed in the maxilla. Implants that were restored and loaded at ≤3 months after placement had 4.42 times greater failure rates compared with those loaded at 3 months after placement.

DISCUSSION

Availability of bone in the edentulous ridge determines the implant dimensions that can be used in that site.[11] Narrow implants are indicated in areas with reduced horizontal ridge width or mesio-distal prosthetic space.[6] Some clinical examples include the following: 1) congenitally missing incisors; 2) space collapse in the anterior area; or 3) reduced interdental space after orthodontic therapy.[63] The advantages of using narrow implants include the following: 1) avoidance of advanced bone grafting; 2) reduced bleeding; 3) minimal postoperative discomfort; and 4) less healing time.[13,64,65] Some disadvantages of narrow implants include the following: 1) reduced bone-to-implant contact (BIC) and osseointegration;[3] 2) increased risk of implant fracture attributable to lowered mechanical properties; and 3) an increased risk of implant overloading.[6] Despite the limitations, narrow implants enjoyed relatively high survival rates, for example, 96.4%,[12] 95.5%,[23] and 100%[26] for 1.8-, 2.5-, and 3.25-mm-diameter implants, respectively.

The present meta-analysis shows similar survival rates of narrow implants as that obtained by other studies.[7,16] For implant diameter <3.3 mm, Andersen et al.[26] reported that the survival rates ranged from 93.8% to 100% over a 3-year observation period. Spiekermann et al.[51] reported a 91% to 95% survival rate. Romeo et al.[11] reported survival rates of 92% to 97.7% after a 7-year follow-up. Renouard and Nisand[66] had implant survival rates of 93.3% to 95.3% for 3.0-mm implants and 96% to 99.4% for 3.3-mm implants. However, failure rates were higher for narrow implants. It was found that narrow implants (≤3.3 mm) had failure rates 3.92 times greater than regular implants. Conceptually narrow implants are often placed in compromised clinical scenarios or subjected to higher risks of increased implant body fracture possibility or prosthetic complications.[41,67] Therefore, careful patient selection, optimal biomechanical conditions, and good bone quality are important factors responsible for lowering the failure rates of narrow implants.[66]

According to this analysis, there are several clinical variables other than implant diameter that strongly influenced the survival of narrow implants. Highest survival rates were found when the implant diameter was >3.3 mm, the timing of prosthetic loading was >3 months after implant placement, and the implant surface was roughened by titanium plasma spray.

This study finds that loading narrow implants <3 months after placement increased the failure rate by 4.42 times compared with those loaded at least 3

Table 3.

Annual Failure Rates and Estimated 5-Year Survival Rates

Reference	Number of Implants	Follow-Up (years)	Number of Failures	Total Implant Exposure Years	Estimated Failure Rate per 100 Implants per Year	Estimated Survival After 5 Years
Andersen et al., 2001[26] SI	28	3.00	0	84	0.00	1.00
Andersen et al., 2001[26] ND	32	3.00	0	96	0.00	1.00
Chiapasco et al., 2011[15] SI	51	2.00	0	102	0.00	1.00
Degidi et al., 2009[10] SI	60	3.00	0	180	0.00	1.00
El-Sheikh et al., 2012[29] SI	50	2.00	1	100	1.00	0.95
Galindo-Moreno et al., 2012[7] ND	97	1.00	4	97	4.12	0.81
Hallman, 2001[24] SI	182	1.00	1	182	0.55	0.97
Oyama et al., 2012[28] ND	17	1.00	0	17	0.00	1.00
Al-Nawas et al., 2012[25] SI	174	1.00	3	174	1.72	0.92
Romeo et al., 2006[11] SI (1)	122	7.00	3	854	0.35	0.98
Romeo et al., 2006[11] SI (2)	208	7.00	6	1,456	0.41	0.98
Saadoun and Le Gall, 1996[9] ND	330	8.00	38	2,640	1.44	0.93
Saadoun and Le Gall, 1996[9] SI (1)	826	8.00	17	6,608	0.26	0.99
Saadoun and Le Gall, 1996[9] SI (2)	133	8.00	1	1,064	0.09	1.00
Saadoun and Le Gall, 1996[9] SI (3)	214	8.00	4	1,712	0.23	0.99
Veltri et al., 2008[27] SI	73	1.00	0	73	0.00	1.00
Zarone et al., 2006[14] SI	34	3.25	1	111	0.90	0.96
Zinsli et al., 2004[3] SI	298	6.00	9	1,788	0.50	0.98
Elsyad et al., 2011[12] ND	112	3.00	4	336	1.19	0.94
Griffitts et al., 2005[13] ND	116	1.08	3	126	2.39	0.89
Morneburg and Pröschel, 2008[23] ND	134	6.00	5	804	0.62	0.97
Total	3,291		100	18,603		
Summary estimate and 95% CI					0.68 (0.43 to 1.07)	0.92 (0.6 to 1.41)

ND = narrow-diameter; SI = standard implant.

Table 4.

Estimated Failure Rates Under the Multivariate Poisson Regression Model, 95% CI Limits, and Incident Ratio for Each Predictor

		95% CI		
Implant Features	Failure Rate	LL	UL	FRR
Diameter				
Narrow	1.55	1.00	2.44	3.92
Regular	0.40	0.22	0.71	
Surface				
SLA	0.80	0.43	1.52	1.42
TPS	0.57	0.34	0.93	
Dual-acid	1.09	0.71	1.72	1.93
Location				
Maxilla	0.36	0.17	0.78	
Mandible	1.78	1.14	2.80	4.95
Both	0.93	0.61	1.43	2.58
Timing of delivery of restoration				
≤3 months	1.72	1.12	2.68	4.42
>3 months	0.39	0.22	0.72	

LL = lower limit; UL = upper limit; FRR = failure ratio rate; SLA = sandblasted and acid-etched; TPS = titanium plasma spray.

months after placement. Studies in which implants were loaded at 2.5 months after placement showed an increased risk of failure for narrow implants. It was suggested that factors resulting in this phenomenon were increased biomechanical requirements, reduced BIC, and poorer bone quality at the edentulous sites, and thus longer healing time was necessary.[68] Interestingly, implants placed in the maxilla failed almost five times less than those placed in the mandible. There are two possibilities: 1) mechanisms of contact and distant osteogenesis were different in the maxilla and mandible and 2) the influence of the implant restoration. Normally, in the maxilla, narrow implants are used to replace lateral incisors, using single crowns in areas without a very demanding occlusal function.[14,56] However, in the mandible, these implants are often used as overdenture abutments that are subjected to heavier occlusal forces.[12,13,23,25,29]

One caveat of this meta-analysis is the computation of TET. Most of the studies did not report the timing when implant failure occurred. It was assumed that all failures occurred at the end of the observational period. If the authors did not report these data in their studies, the failure rate per year could not be evaluated. For instance, Galindo-Moreno et al.[7] showed the worst failure rate per year. The authors reported that all their failures occurred before functional loading. This might be because the implants were placed with a one-stage protocol and were loaded 6 weeks after implant placement. Their failure rate after 1 year was 4.12%. Thereafter, there were no more implants that failed at the 3-year follow-up, thus giving rise to a failure rate of 1.37% per year. It is thought that implant failures increased over time, and therefore future studies should include the time the implants failed so that a better understanding of failure patterns could be established. Other types of variables, such as implant length or surgery approach (flap versus flapless), must be more extensively examined. However, those variables cannot be analyzed in this meta-analysis because most of the studies included did not report enough data regarding them. Additional studies are needed to improve the understanding of these factors over the narrow implants.

CONCLUSIONS

According to this meta-analysis, implant survival rates are calculated to be 75% and 87% for <3- and ≥3-mm-diameter implants, respectively. Therefore, only implants with diameter ≥3 mm were suitable for rehabilitation of narrow edentulous spaces. It is also important to bear in mind that, for narrow implants (diameter <3 mm), functional loading at 3 months after implant placement is crucial to obtain higher survival rates.

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