Review

Do Implant Length and Width Matter for Short Dental Implants (<10 mm)? A Meta-Analysis of Prospective Studies

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Background: This meta-analysis of prospective clinical trials was conducted to determine the effects of dental implant length and width on implant survival rate of short (<10 mm) implants.

Methods: An electronic search of the PubMed database for relevant studies published in English from November 1998 to March 2012 was performed. Selected studies were randomized clinical trials, human clinical trials, or prospective trials with a clear aim of investigating the success or survival rate of short (<10 mm) implants.

Results: Eight studies fulfilled the inclusion criteria and were subsequently analyzed. A total of 525 short (<10 mm) dental implants were analyzed, of which 253 were 3.5 mm in diameter (48.19%), 151 were 4.0 mm (28.76%), 90 were 4.1 mm (17.14%), 21 were 4.8 mm (4%), and 10 were 5.1 mm (1.9%). All implants included in this meta-analysis had a follow-up period of 12 to 72 months. The included studies reported on the survival rate and diameter of the implants. Six of the studies used "short implants" (7 to 9 mm), and the remaining were classified as "extra-short implants" (≤6 mm). Five-year estimated failure rates were 1.61% and 2.92%, respectively, for extra-short and short implants ($z = -3.49$, $P < 0.001$, 95% confidence interval = 0.51% to 4.10%). Furthermore, it was found that the wider the implant, the higher the failure rate (estimated failure rate = 2.36%, 95% confidence interval = 1.07% to 5.23%).

Conclusions: Neither implant length nor width seemed to significantly affect the survival rate of short implants (<10 mm). Nonetheless, further well-designed randomized clinical trials are needed to confirm these findings. *J Periodontol 2013;84:1783-1791.*

KEY WORDS

Alveolar bone loss; dental implants; evidence-based dentistry; longitudinal studies; survival rate.

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Owing to bone resorption, the residual ridge is often inadequate for ideal implant placement.[1] Several techniques, such as guided bone regeneration (GBR),[2] block grafts,[3] sinus augmentation,[4] and distraction osteogenesis,[5] have been proposed to augment the deficient residual ridge before or simultaneously with implant placement.[6,7] These bone augmentation techniques have been found to successfully increase residual ridge height and width for implant placement.[2] However, these procedures may not be widely adopted by clinicians because they are technically challenging and may not produce predictable treatment outcomes. In addition, patients may not accept these procedures because of the risks involved, for example, donor site morbidity, pain, and additional cost and treatment time.[8,9] Consequently, alternative treatment options such as placing short (<10 mm)[10,11] or tilted[12,13] implants have been suggested in attempts to overcome the limitations posed by having a deficient residual ridge. The advantages of the alternative options are avoidance of vital structures, reduced surgical complications, and increased patient satisfaction.[9,11,12,14]

Placement of a suitably sized dental implant is essential for achieving a

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successful treatment outcome.[15] However, advances in implant microdesign have enabled short implants to be successfully used for oral rehabilitation.[16] Formation and preservation of osseointegration depend on multiple biologic and prosthetic factors.[17] Bone density, smoking habits, implant surface, crown-to-implant ratio, splinting, size of occlusal table, cantilever length, type of implant system, and opposing dentition were found to influence the success of short implants.[17,18] In addition, implant width has been reported to be an important factor affecting treatment success.[19] It was demonstrated that wider implants, irrespective of their lengths, were able to withstand large loads, and increasing their contact surfaces could reduce the tensile force exerted on the peri-implant bone.[20] However, in terms of clinical outcomes, it was uncertain whether short implants were influenced by their widths.[21] Hence, this meta-analysis sets out to investigate the effect of implant length and width on the implant survival rate of short implants (<10 mm).

MATERIALS AND METHODS

An electronic search of the PubMed database for relevant studies published in English from November 1998 to March 2012 was performed by one examiner (AM). The key words used in the search included a combination of "dental implants," "endosseous implants," "oral implants," "short implants," and "short length." A manual search of implant-related journals was also performed, including *Clinical Implant Dentistry and Related Research*, *International Journal of Oral and Maxillofacial Implants*, *Clinical Oral Implants Research*, *Implant Dentistry*, *European Journal of Oral Implantology*, *Journal of Oral Implantology*, *International Journal of Oral and Maxillofacial Surgery*, *Journal of Oral and Maxillofacial Surgery*, *Journal of Dental Research*, *International Journal of Prosthodontics*, *Journal of Prosthetic Dentistry*, *Journal of Clinical Periodontology*, *Journal of Periodontology*, and *The International Journal of Periodontics & Restorative Dentistry*, from November 1998 to March 2012.

Selected studies were randomized clinical trials and prospective human clinical trials with a clear aim of investigating the survival or success rate of short (<10 mm) implants. Studies had to have a minimum sample size of 10 healthy patients with 10 short implants that were in function for at least 1 year. In addition, the implants were placed in pristine residual ridges that did not receive any bone augmentation procedures such as sinus floor augmentation, onlay bone grafting, or GBR. Excluded were: 1) animal studies; 2) retrospective human trials with insufficient information; 3) studies involving only smooth or smooth and rough surface implants or immediate implant placement and/or

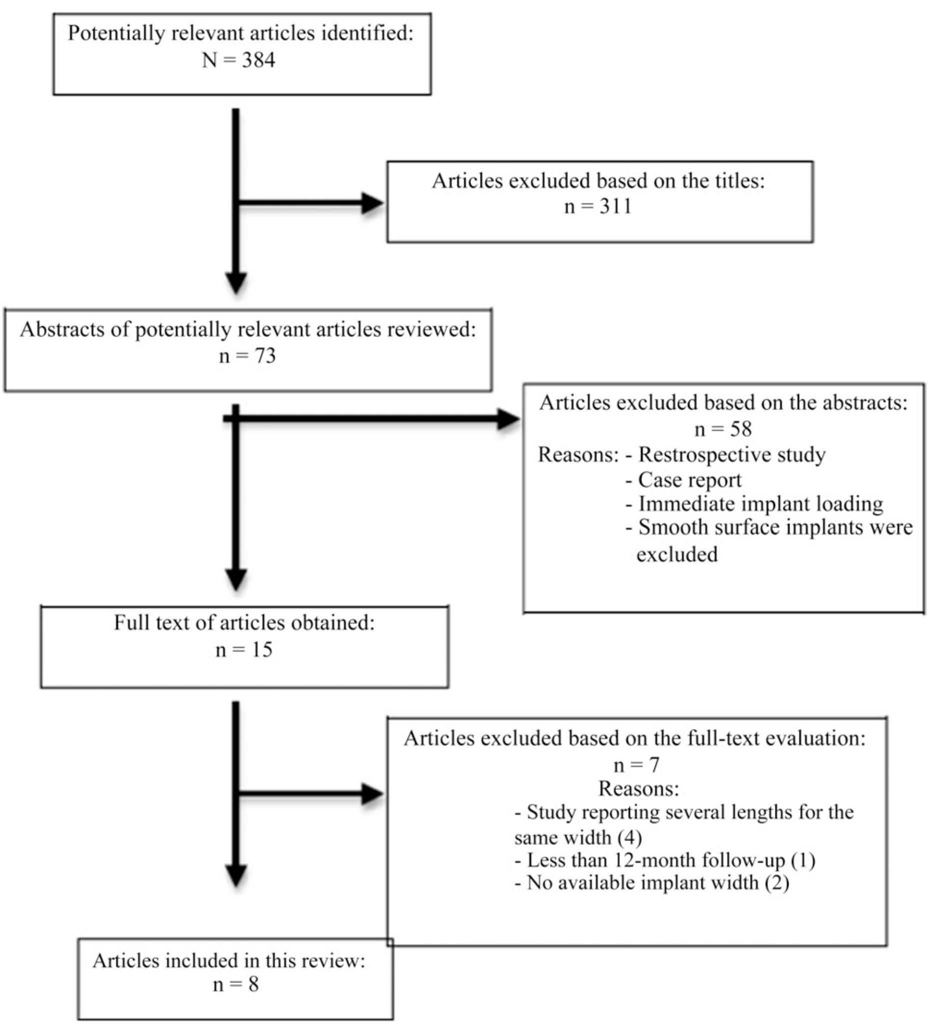

Figure 1.
Flowchart of the screening process.

Table 1.
Summary of Articles Included in the Present Study

Reference	Implants (n)	Implant System	Width (mm)	Length (mm)	Follow-Up (months)	Healing Time (months)	Location	Type of Prosthesis	Implant Survival Rate (%)	Implant Failure Rate (%)
ten Bruggenkate et al. (1998)[22]	253	*	3.5	6	72	4	MX/MD	ST/FPD/FFA	94	6
Polizzi et al. (2000)[23]	10	†	5.1	7 to 8.5	36	6	MX/MD	ST	90	10
McGlumphy et al. (2003)[25]	20	‡	4	8	60	3 to 6	MX/MD	FPD	80	20
Rossi et al. (2010)[24]	19	*	4.1	6	24	1 to 2	MD	ST	89.5	10.5
	21		4.8	6	24	1 to 2	MD	ST	100	0
Guljé et al. (2012)[26]	60	§	4	6	12	3	MD	OD	96.7	3.3
Van Assche et al. (2012)[27]	24	*	4.1	6	24	6	MX	OD	97.9	2.1
Perelli et al. (2011)[28]	47	‖	4.1	7	60	4	MD	ST/FPD/OD	85.1	14.9
Pieri et al. (2012)[30]	71	§	4	6	36	4	MX	FPD	98.6	1.4

MX = maxilla; MD = mandible; ST = single tooth; FPD = fixed partial denture; FFA = full fixed arch; OD = overdenture.
* Straumann, Basel, Switzerland.
† Nobel Biocare, Gothenburg, Sweden.
‡ Omniloc, Carlsbad, CA.
§ Astra Tech, Gothenburg, Sweden.
‖ Endopore, Toronto, ON, Canada.

loading; and 4) studies not discriminating implant survival rate for different implant widths.

Several factors were extracted from the selected studies and analyzed: 1) implant length; 2) implant manufacturer; 3) total number of implants placed; 4) healing time; 5) location; 6) type of prosthesis; 7) follow-up period; and 8) implant survival and failure rates.

Statistical Analyses

Failure rates by year were computed by dividing the number of failures by the total exposure time (TET) of the implants. TET was computed as the product of the number of implants by the length of the follow-up period in years because no data can be obtained regarding the time the implants were lost. Implants were lost to follow-up because of study attrition, death of patient, refusal to participate, or other illnesses or causes. Poisson distribution was assumed for the number of events in each study for a total of implant exposure years. A logarithmic link function was used to calculate Poisson regression, and the TET per study was the exposure variable.

Heterogeneity of the event rates was computed using the Pearson goodness-of-fit statistical test and its associated *P* value. A *P* value <0.05 was assumed to indicate heterogeneity and overdispersion of the studies. Under the random-effects model, summary estimates and standard errors were computed to obtain the 95% confidence interval (CI) of the combined event rates. Moreover, γ-distributed random-effects Poisson regression was developed to test the effects of implant length on failure rates per 100 implants at 1 and 5 years. Survival rates after 5 years were computed using the survival function *S*, $S(T) = e^{-T \times \text{Event Rate}}$. Event rate was assumed constant across time but not across studies. Multivariate random-effects Poisson regression was used to test whether event rates were a function of implant length. Implant lengths ≤6 mm were coded as "extra-short." Implant lengths of 7 to 9 mm were coded as "short." Given that neither the elapsed time until implant failure or study attrition

Table 2.

Percentages of Studies and Implants Reporting Location and Prosthesis

	Studies (%)	Implants (%)
Location		
MX/MD	33.33	53.90
MD	44.44	28.00
MX	22.22	18.10
Prosthesis design		
FPD	22.22	17.3
OD	22.22	16.0
ST	33.33	9.5
ST/FPD/FFA	11.11	48.2
ST/FPD/OD	11.11	9.0

MX = maxilla; MD = mandible; FPD = fixed partial denture; OD = overdenture; ST = single tooth; FFA = full fixed arch.

Table 3.

Rejected Articles and Reasons for Exclusion

Reference	Reason for Exclusion
Deporter et al. (1999)[31] Ferrigno et al. (2006)[32]	No implant width available
Esposito et al. (2012)[9]	Results at <1 year
Nedir et al. (2004)[33] Willer et al. (2003)[34] Testori et al. (2002)[35] Romeo et al. (2006)[36]	No specific survival rate for each width of short implant

was available for these studies, the TET for each study was computed with the assumption that all implant failures were observed at the end of the follow-up times.

RESULTS

An initial screening yielded a total of 384 articles, of which 42 potentially relevant articles were selected after an evaluation of their titles and abstracts. Full text of these articles was obtained, and eight articles[22-30] fulfilled the inclusion criteria and were subsequently analyzed in this meta-analysis (Fig. 1). Details of all included studies are summarized in Tables 1 and 2, whereas Table 3 illustrates studies that were rejected[9,31-36] and the reasons for exclusion.

A total of 525 short (<10 mm) dental implants were analyzed, of which 253 were 3.5 mm in diameter (48.19%), 151 were 4.0 mm (28.76%), 90 were 4.1 mm (17.14%), 21 were 4.8 mm (4%), and 10 were 5.1 mm (1.9%). All the implants included in the present study had a follow-up of 1 to 6 years.

All the included studies reported on the survival rate and diameter of the implants. Six of the studies used short implants (7 to 9 mm), and the rest were classified as extra-short implants (≤6 mm), with an average follow-up time of 4.33 and 2.67 years, respectively. The estimated failure rates per 100 implants/year ranged from 0% to 5.25%, and the summary estimate obtained by random-effects Poisson regression was 2.04% (97.96% survival), with robust 95% CI ranging from 1.11% to 3.76% (Fig. 2). The estimated failure rate at 5 years after loading was 4.33%, with 95% CI ranging from 2.11% to 8.89%.

Given that overdispersion was present in the study sample ($P = 0.016$), random-effects Poisson models were used in the analysis. The effect of implant length on the implant failure rate was assessed. It was found that random-effects Poisson regression estimates of failure rates were 1.09% and 3.29%, respectively, for extra-short and short implants ($z = 3.04$, $P < 0.002$, 95% CI = 1.15% to 4.11%). Multivariate Poisson regression, including average healing time, location (maxilla, mandible, both), implant diameter, and type of prosthesis, indicated that none of these predictors significantly influenced the failure rates (all $P > 0.341$). Five-year estimated failure rates of extra-short and short implants were 1.61% and 2.92%, respectively ($z = -3.49$, $P < 0.001$, 95% CI = 0.51% to 4.10%).

An analysis of implant width and failure rates showed that the wider the implant, the higher the failure rate (estimated failure rate = 2.36%, 95% CI = 1.07% to 5.23%). Figure 3 shows that the relationship between annual failure rates and implant widths appears to be best described by a potential function. Having in mind the lengths of the implants included in this study, this result indicates that a change of 1 mm in diameter could have a weak effect on failure rates when looking at the lower part of the diameter scale (1.7% increment when moving from 3.5 to 4.5 mm), but a larger effect when moving in the upper part of the diameter scale (3.1% increment moving from 4.5 to 5.5 mm).

DISCUSSION

Advanced bone grafting procedures such as sinus augmentation or GBR with simultaneous implant placement have shown increased intra- and postoperative complications compared with their predecessors.[9] Therefore, placing short implants might provide higher patient satisfaction in terms of a less invasive surgical procedure and better treatment outcomes.[30]

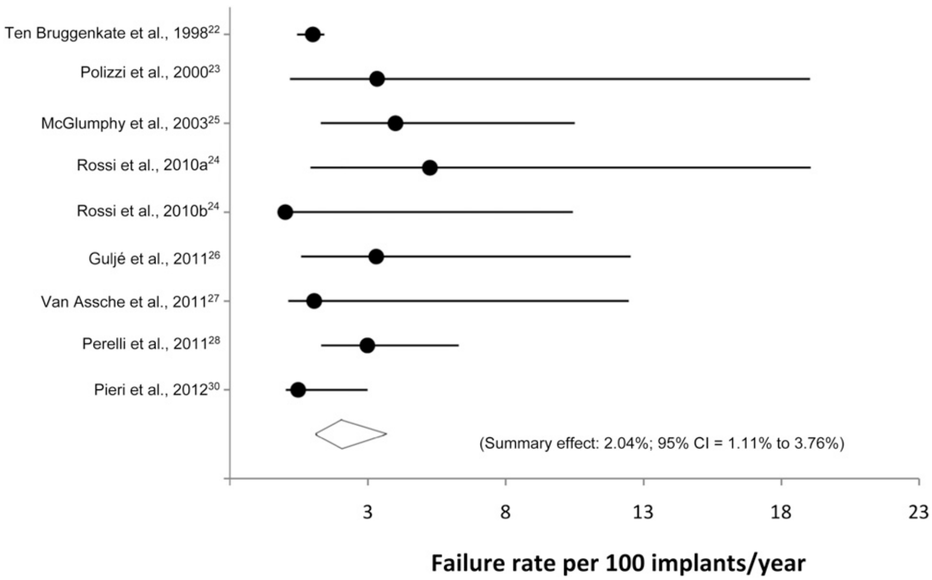

Figure 2.
Annual failure rates of short implants (<10 mm) per 100 implants/year. * *Two different sets of data (a and b) were used to analyze Rossi et al.*[24]

Short implants, defined as <10 mm, have been proven to be a useful and relatively predictable alternative for bone augmentation procedures.[11,17] A recent systematic review reported that short implants had a cumulative survival rate of up to 99.1% after a follow-up period of 3.2 ± 1.7 years.[37] Several retrospective studies demonstrated that shorter implants have significantly lower failure rates compared with longer implants.[38-40] This high survival rate was dependent on several factors such as bone density, patient habits, implant surface, and prosthetic factors.[17,41] For instance, machined-surface implants increased the failure rate of short implants by a maximum of 29%.[17] Furthermore, the diameter of the implant might play a role, since the wider the implant, the greater the contact area between implant surface and surrounding bone,[42] suggesting improved mechanical stability and osseointegration.

To minimize failure of short implants, modifications to the micro- and macrodesigns of the implants have been made to compensate for the reduction in implant length.[35,43,44] Therefore, implant systems have recently developed implants with modified body shapes, new thread designs such as thread pitch or face angle, and implant materials and surface coatings to achieve long-term survival rates.[45]

Regardless of implant length, stress distributed to the apical third was less compared with stress transmitted to the crestal third of the implant fixture.[8] In fact, it was demonstrated that maximum bone stress was almost always constant and independent of implant length and bicortical anchorage.[46,47] Excessive crown-to-implant ratio has been cited in the literature as being detrimental to implant survival.[48,49] However, other authors found that disproportionate crown-to-implant ratio associated with short implants demonstrated high implant survival rates.[50,51] A recent study examining implant prostheses with a mean crown-to-implant ratio of 2.0 concluded that crown-to-implant ratio did not affect the success of these implants, at least for the first 2 years.[52]

Increasing implant diameter resulted in better engagement of the buccal and lingual cortical plates[53] and more bone-to-implant contact,[54] thus improving stress distribution within the surrounding bone.[55] In a three-dimensional finite element analysis, it was demonstrated that increasing the implant diameter resulted in a 3.5-fold reduction in crestal strain. Conversely, increasing the implant length resulted in a 1.65-fold reduction in crestal strain.[56] Other studies showed that increasing implant diameter did not compensate for the reduction in length.[40,57] Therefore, from a biomechanical standpoint, placement of short implants should be a predictable treatment for oral rehabilitation. As a matter of fact, a lower estimated failure rate of shorter (≤6 mm) implants is obtained. However, it is worth mentioning that this difference in survival rates could be attributed to the lack of well-conducted randomized clinical trials that fulfilled the inclusion criteria.

The present study demonstrates that survival of short implants is not significantly influenced by their width. However, failure rates of short implants increased with increasing diameters. This finding was in agreement with a recent systematic review that demonstrated less favorable results of 5-mm-wide implants compared with narrower implants of lengths ≤8 mm.[58] Although studies have demonstrated that narrower implants (≤3 mm) failed earlier and more frequently than wider implants (≥4 mm) at all stages of function,[15,59] Misch[60] claimed that implant diameter was more important than length once a minimum was reached. Winkler et al.,[15] however, believed that the implant width was less important compared with implant length in functional loading.

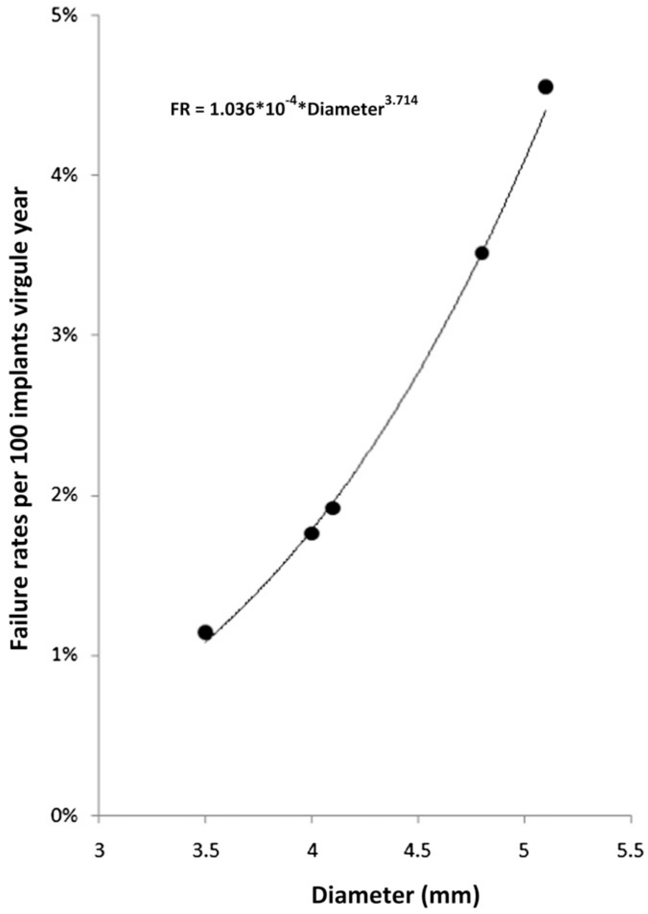

Figure 3.
Annual failure rates per 100 implants/year of short implants (<10 mm) as a function of implant widths. Note that relationships among failure rates and implant widths appear to be best described by a potential function. FR = failure rate.

Moreover, geometry and surface topography are crucial for the short- and long-term success of short dental implants. Short implants with a roughened surface demonstrated significantly lower failure rates compared with machined-surface ones (odds ratio = 3.6).[57] Nonetheless, a systematic review did not find superiority of any particular implant surface in terms of survival.[61] Because smooth-surface implants are rarely available in the current market, only implants with roughened surfaces were analyzed, showing no significant difference in the estimated cumulative survival rate between wider and narrower implants (P = 0.341). Nonetheless, the implant diameter should closely relate to not only implant length but also surface conditions.

Bone quality is thought to be a strong predictor of treatment outcome,[62,63] since short implants demonstrated lower implant survival rates in the maxilla.[32,57,59,64-67] This phenomenon could be attributed to the increase in bone density of the mandible, improved mechanical properties of the implant-bone interface, and reduced stress concentration in bone,[68-70] which facilitate primary stability and early osseointegration, compensating for the reduction in implant lengths.[66] As such, lower bone density might lead to the earlier loss of these implants due to the peri-implant strains.[56] Consequently, implants of length >9 mm and diameter >4 mm would have better success rates in type IV bone.[71] This study shows that there is no difference in survival rate for short implants placed in maxilla or mandible or both (P = 0.34).

CONCLUSIONS

Neither implant length nor width affect survival rate of short implants (<10 mm) significantly. Since longer implants (7 to 9 mm) had higher failure rates than shorter implants (≤6 mm), the latter (i.e., extra-short implants) represent a predictable approach to avoid bone-grafting surgery in the maxilla and mandible. Nonetheless, more well-designed randomized clinical trials are needed to confirm these findings.

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