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Clinical outcomes of short implants (≤ 6 mm) placed between two adjacent teeth/implants or in the most distal position: A systematic review and meta-analysis

KEY WORDS
dental implants, occlusal loading, short implants, single crown

ABSTRACT

Purpose: To investigate whether implant position (adjacent to teeth/implants vs most distal position in the arch) influences the clinical outcomes of short (≤ 6 mm) non-splinted implants.

Materials and methods: A systematic electronic search of human randomised clinical trials and prospective cohort studies was performed using the PubMed, Embase and Cochrane Central Register of Controlled Trials (Central) databases. A manual search of implant-related journals was also performed. A meta-analysis was conducted to compare survival rate, marginal bone loss and prosthetic complications based on implant position.

Results: Overall, 11 studies were included to give a total of 388 non-splinted short implants (269 adjacent, 119 distal) followed up over a period ranging from 12 to 120 months. No significant differences in survival were found when comparing adjacent and distal positioning for both arches, and no significant differences were found for marginal bone loss or prosthetic complications between groups regardless of position.

Conclusions: Short implants supporting single crowns presented similar outcomes when placed in the most distal position in the arch or between adjacent teeth or other implants.

Conflict-of-interest statement: *The authors do not have any financial interests, either direct or indirect, in the products mentioned in the present study.*

Introduction

Rehabilitation of one or more missing teeth utilising dental implants has been demonstrated to be a predictable surgical modality in the treatment of partially and completely edentulous patients[1]. Two studies of patients who received standard dental implants (≥ 10 mm) with a long-term follow-up demonstrated satisfactory results and high survival rates[2,3]. Other recent studies have defined standard length as ≥ 8 mm, highlighting a shift in clinical philosophy regarding the definition of standard implant length[4,5]. Substantial alveolar bone atrophy is, however, a common consequence of long-term edentulism that may impede the placement of standard length implants due to anatomical limitations. In such situations, practitioners often perform more advanced and invasive procedures such as guided bone regeneration (GBR), block grafting or sinus elevation[6,7]. To prevent the need for such procedures, several recent studies have evaluated the performance of short implants for rehabilitation of atrophic alveolar ridges[8-10]. Short implants can be used as an alternative to advanced grafting procedures, as the latter may be associated with increased cost and a higher risk of complications and postoperative morbidity[11,12].

Advancements in the design of micro- and macroimplant topography have seen shorter implants be introduced to the market, and the definition of a 'short implant' has changed over time. In 2007, Strietzel and Reichard[13] considered implants with a length ≤ 11 mm as short. Other authors defined short as < 10 mm or < 8 mm, and extra-short as < 6 mm[14-16]. A 2018 meta-analysis published after the International Team of Implantology (ITI) workshop in Amsterdam reduced the threshold for short implants to ≤ 6 mm[17].

Short (≤ 6 mm) implants are a viable treatment alternative in atrophic ridges, demonstrating a satisfactory survival rate (94.0%) and a relatively low rate of biological and prosthetic complications over a 5-year follow-up[8]. Furthermore, splinting two or more short implants has been shown to reduce the risk of prosthetic complications (such as screw loosening) and implant failure compared to non-splinted short implants[8,18]. A biomechanical explanation for these results is that splinting implant-supported crowns reduces the level of stress concentrated at the implant–crown interface and increases resistance to rotational movements[19,20]. On the other hand, non-splinted implant-supported crowns often offer greater access for maintenance, can more easily attain a passively fitting framework, and are typically associated with better aesthetic outcomes[20]. Regarding the increased risk of implant failure associated with non-splinted short implants, an important clinical question is whether the occlusal loading associated with different implant positioning plays a significant role in determining clinical outcomes. Photoelastic stress analysis has demonstrated that the presence or absence of two interproximal contacts (mesial and distal) as well as the tightness of interproximal contacts has a substantial influence on load distribution around non-splinted implants[19,21-23]. Moreover, previous studies have characterised short implant location based on positioning between adjacent teeth/implants or in the most distal position in the arch[24,25]. To the best of the present authors' knowledge, however, no study has investigated whether placing short non-splinted implants between two adjacent teeth/implants (with two interproximal contacts) relative to a free-end distal position in the arch (one mesial interproximal contact) has an impact on clinical outcomes of implants. As such, the present systematic review and meta-analysis aimed to investigate whether implant positioning (between two adjacent contacts vs free-end distal positioning) influences survival rate, marginal bone loss (MBL) and prosthetic complications with short non-splinted implants.

Materials and methods

Reporting format and study registration

The 27-item Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement[26] was used to describe the search for articles meeting the eligibility criteria. The Assessment of Multiple Systematic Reviews guidelines (AMSTAR)[27] were utilised to evaluate methodological quality. The protocol was registered in the Prospective Register of Systematic Reviews (PROSPERO; no. CRD42020187656).

Patient, intervention, comparison and outcome framework

The focused question was elaborated according to the patient, intervention, comparison and outcome (PICO) framework[28]:

- Patient: Patients receiving non-splinted short (≤ 6 mm) dental implants.
- Intervention: Placement of short implants in the most distal free-end position of the arch (only a mesial interproximal contact is present, at the second molar, first molar or second premolar position) (Dis group).
- Comparison: Placement of short implants between two adjacent teeth/implants (mesial and distal interproximal contacts are present) (Adj group).
- Outcome: Implant survival rate, MBL and prosthetic complications.

The focused question was as follows: 'In patients receiving short dental implants, do implants placed in the most distal position in the arch perform as well as short implants placed between two adjacent teeth/implants?'

Information sources and search strategy

Manual and electronic searches were performed by two independent reviewers (MB and EP), with no language or date restrictions applied. A systematic search of the literature was completed using MEDLINE (via PubMed), Embase and the Cochrane Central Register of Controlled Trials (Central) up to January 2020, with the following search strategy: ((short AND single) implant*) AND (single crown*)). A broad manual search of periodontal and implant-related journals was also conducted to guarantee a complete screening process. Finally, the New York Academy of Medicine Grey Literature Report was explored to identify any ongoing or unpublished trials. A kappa coefficient was utilised to assess the inter-examiner agreement throughout the search process.

Inclusion and exclusion criteria

Trials were considered suitable if they met the following inclusion criteria:

- cohort prospective studies or randomised clinical trials (RCTs) including human subjects receiving non-splinted short implants (≤ 6 mm);
- studies with follow-up ≥ 1 year;
- studies presenting information on at least one of the following variables: survival rate, MBL and prosthetic complications.

The exclusion criteria were as follows:

- studies with follow-up < 1 year;
- case series, case reports, retrospective studies, systematic reviews, in vitro studies and preclinical animal studies;
- studies including human subjects only receiving splinted short (≤ 6 mm) implants;
- studies including human subjects only receiving implants > 6 mm in length.

Implants from included articles that failed before prosthetic loading, with splinted restorations and with a length > 6 mm were excluded from the analysis.

Outcomes and variables

Implant failure referred to the removal of an implant for any reason. MBL was calculated from prosthetic loading (baseline) until the final follow-up. Prosthetic complications encountered during the follow-up period were also assessed, and were defined as any mechanical complications involving the implant-supported restoration that occurred after occlusal loading, such as screw loosening or chipping of the restoration.

Data extraction and statistical analysis

Two independent reviews (MB and EP) screened the titles and abstracts of the articles obtained. The full texts were then read to confirm that they adhered to the aforementioned inclusion and exclusion criteria. Any disagreements between the reviewers were discussed with a third expert author (AR). The corresponding authors of the included studies were contacted by email to request the data, such as patient characteristics, clinical outcomes and implant position (adjacent or distal). Statistical analysis was performed by an expert biostatistician. With regard to implant survival, the raw rate was estimated using a random effects model with corresponding Z statistics, *P* values and 95% confidence intervals (CIs), and a restricted maximum likelihood estimator was employed. Due to several authors reporting survival rates of 100.0%, a Wilson correction was used to estimate standard errors (SEs) using an exact binomial formula to evaluate heterogeneity.

To assess the effect of the duration of follow-up on the estimation of survival rate, a meta-regression was considered with follow-up as a moderator variable. Additionally, the raw incidence failure rate per year was calculated to neutralise the undesirable effect of different follow-up intervals, as follows: incidence failure rate per year = (n failures)/(n implants × years follow-up).

Provided that each article included implants in adjacent and distal positions, a comparative analysis of the incidence of implant failure between both positions was conducted. The same strategy was applied to assess the effect of positional variables: adjacent vs distal, maxilla vs mandible and premolars vs molars. Regarding MBL, an annual rate was calculated for each implant in the sample as follows: annual MBL = MBL/(years follow-up).

Weighted means were obtained from the meta-analysis to characterise MBL in the population with random effects models and comparative analysis between the subgroups. Complication analysis was conducted to compare adjacent and distal implants, and a heterogeneity analysis was also carried out. A Cochran Q test was performed and the I^2 index was calculated to evaluate the inter-study variability compared to the total variability. Cut-off points of 25%, 50% and 75% were associated with low, medium and high levels of heterogeneity, respectively. A funnel graph was constructed to assess potential publication bias. An Egger test was conducted to contrast the hypothesis. The level of significance was set at 5% ($\alpha = 0.05$) and R statistical software (version 3.5.1, R Core Team, Vienna, Austria) was used for analysis.

Risk of bias and qualitative assessment

Full-text screening of articles was performed by the investigators (AR and MG) to assess the quality of the included articles. The Cochrane risk-of-bias tool for randomised controlled trials[29] was used to assess the quality of all randomised controlled trials, and the Newcastle-Ottawa scale[30] was utilised to assess the quality of non-RCT prospective clinical studies.

Results

Study selection

The initial search yielded 303 articles (PubMed, n = 105; Embase, n = 145; Central, n = 53), then an additional five articles were found through manual screening of other sources, giving a total of 308. After removal of duplicates, 162 articles were selected after title and abstract review, and 25 were potentially eligible after full-text screening. Four further studies were excluded after full-text reading, leaving 21 studies that were eligible for inclusion. After the authors were contacted to request information, 10 studies were excluded: three due to data not being available, six due to a

Table 1 Excluded articles and reasons for exclusion

Stage	Study	Reason
After full-text reading	Pohl et al[31]	Recent publication with longer follow-up available
	Sahrmann et al[32]	
	Schincaglia et al[33]	
	De Santis et al[34]	Short > 7 mm
After contacting authors	Thoma et al[35]	Data not available
	Bechara et al[36]	
	Bernardi et al[37]	
	Al-Hashedi et al[38]	No response received from authors
	Ayna et al[39]	
	Shah et al[40]	
	Hadzik et al[41]	
	Weerapong et al[42]	
	Mendoza-Azpur et al[43]	
	Perelli et al[44]	Limited sample size of implants ≤ 6 mm length

lack of response, and one due to the limited number of patients. A complete list of articles excluded after full-text reading and after contacting the authors is presented in Table 1. After the screening process, 11 articles were included in the present systematic review and meta-analysis (Fig 1). Kappa scores for inter-examiner agreement for title and abstract review and full-text screening were 0.93 and 0.84, respectively.

Quality assessment of included studies

The results from the risk of bias assessments for included RCTs and prospective clinical trials are summarised in Tables 2 and 3, respectively. Three RCTs[25,45,46] were included in the present systematic review and meta-analysis and were assessed using the Cochrane risk-of-bias tool. One study was judged to be at low risk of bias[45], whereas two were considered to be at unclear risk of bias[25,46]. None of the included RCTs were randomised with regard to the parameters explored in the present meta-analysis (adjacent vs distal positioning). Eight of the included studies were prospective clinical trials[24,44,47-52] and were assessed using the Newcastle-Ottawa scale. Of these, one was given eight stars[51] and three received seven stars each[47-49], and were thus judged to be at low risk of bias. The remaining studies were given six stars and were considered to be at moderate risk of bias[24,44,50,52].

Characteristics of the included studies

A total of 11 studies[24,25,44-52] were included and reported outcomes for 388 non-splinted short implants (Table 4). The total number of included implants placed adjacent to natural teeth/implants was 269, whereas 119 were placed at the most

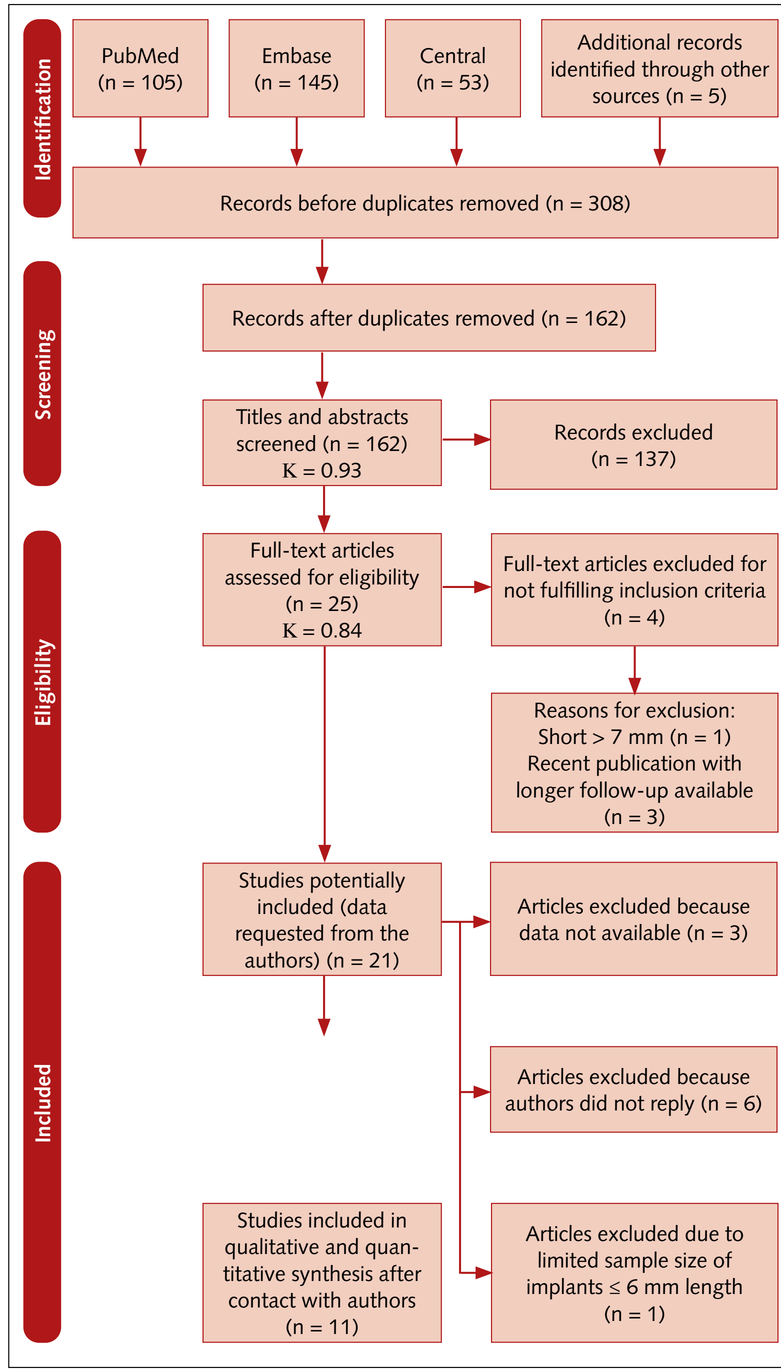


Fig 1 PRISMA flowchart of the screening process for the different databases.

Table 2 Risk of bias assessment for included RCTs according to Cochrane guidelines

Study	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias
Shi et al[45]	Low	Low	Low	Unclear	Low	Low	Low
Naenni et al[46]	Low	Unclear	Unclear	Unclear	Low	Low	Low
Guljé et al[25]	Low	Unclear	Unclear	Unclear	Low	Low	Low

Table 3 Risk of bias assessment for included non-RCTs according to the Newcastle-Ottawa Scale

Study	Domain								
	Representativeness of the exposed cohort	Selection of the non-exposed cohort	Ascertainment of exposure	Outcome of interest not present at start of study	Comparability of cohorts on the basis of the design or analysis	Assessment of outcome	Sufficient follow-up for outcome to occur	Adequacy of follow-up	Total
Villarinho et al[47]	*	*	*	*	*	–	*	*	7
Malchiodi et al[48]	–	*	*	*	*	*	*	*	7
Guarnieri et al[49]	*	*	*	*	*	–	*	*	7
Nizam et al[50]	*	*	*	*	*	–	–	*	6
Svezia and Casotto[51]	*	*	*	*	*	*	*	*	8
Guljé et al[24]	–	*	*	*	*	–	*	*	6
Perelli et al[44]	–	*	*	*	*	–	*	*	6
Rossi et al[52]	–	*	*	*	*	–	*	*	6

Table 4 Characteristics of included studies at patient and implant levels

Study	Study design and participants	Follow-up	Implant location	
Villarinho et al[47]	Prospective study. 20 patients (46 implants; 8 men and 12 women; mean age 52 ± 10 y, age range 25–76 y)	45.0 ± 9.0 mo	Maxilla 23, mandible 23; premolars 12, molars 34; 35 adjacent, 11 distal*	
Shi et al[45]	Randomised controlled clinical trial. 217 patients total (96 men, 121 women), 74 included in review (66 implants; 29 men, 45 women; mean age 38.1 y)	12 mo	Maxilla 74, mandible 0; premolars 2, molars 72; 52 adjacent, 14 distal*	
Malchiodi et al[48]	Prospective study. 47 patients (13 implants; 31 men, 16 women; mean age 60 ± 9 y, age range 39–81 y)	48.5 ± 19.1 mo	Maxilla NR, mandible NA; premolars NR, molars NR; 5 adjacent, 8 distal*	
Naenni et al[46]	Randomised controlled clinical trial. 86 patients total (47 men, 39 women), 40 included in review (50 implants; number of men and women NR, median age 56 y)	60 mo	Maxilla 14, mandible 36; premolars NR, molars NR, 40 adjacent, 10 distal*	
Guarnieri et al[49]	Prospective study. 28 patients (6 implants; 14 men, 14 women; mean age 51.0 ± 19.8 y, age range 21–82 y)	36 mo	Maxilla NR, mandible NR; premolars NR, molars NR; 3 adjacent, 3 distal*	
Nizam et al[50]	Prospective study. 30 patients (35 implants; 15 men, 15 women; mean age 53.0 ± 10.6 y Group 1 and 50.4 ± 8.4 y Group 2, age range 30–73 y)	18 mo	Maxilla 35, mandible 0; premolars 16, molars 19; 19 adjacent, 16 distal*	
Svezia and Casotto[51]	Prospective study. 110 patients total (49 men, 61 women), 59 included in review (59 implants; number of men and women NR, mean age 58.4 y, age range 35–78 y	24 mo	Maxilla 40, mandible 19, premolars NR, molars NR, 34 adjacent, 25 distal*	
Guljé et al[25]	Randomised controlled clinical trial. 41 patients total (20 men, 21 women), 21 included in review (21 implants; 7 men, 14 women; mean age 50.0 ± 10.1 y, age range 30–71 y)	60 mo	Maxilla 21, mandible 0; premolars 5, molars 16; 18 adjacent, 3 distal	
Guljé et al[24]	Prospective study. 21 patients (31 implants; 7 men, 14 women; mean age 57.0 ± 9.1 y, age range 44–70 y)	60 mo	Maxilla 0, mandible 31; premolars 12, molars 19; 21 adjacent, 10 distal	
Rossi et al[52]	Prospective study. 45 patients (38 implants; 24 men, 21 women; mean age 48.4 y, age range 30–74 y)	120 mo	Maxilla 14, mandible 24; premolars 12, molars 26; 28 adjacent, 10 distal*	
Perelli et al[44]	Prospective study. 87 patients (23 implants; 52 men, 35 women; aged > 18 y	60 mo	Maxilla 23, mandible 0; premolars 0, molars 23; 14 adjacent, 9 distal*	

*Data gathered after contacting the authors. NR, not reported.

distal position in the arch. The patients in the included studies were followed up for a period ranging from 12 to 120 months. Six studies treated partially edentulous patients with single or multiple edentulous sites[24,25,45,47,49,50], three treated single edentulous sites exclusively[46,51,52], and two treated partially or completely edentulous patients[44,48]. Regarding implant location, four studies reported implant placement exclusively in the maxilla[25,44,45,50], one examined implant placement in the mandible only[24], and six studied placement in both arches[46-49,51,52] to give a total of 173 maxillary and 116 mandibular implants. With regard to implant length, 6-mm implants were placed in 10 studies[24,25,45-52] and 5-mm implants were placed in two studies[44,50], giving a total of 350 implants with a length of 6 mm and 38 with a length of 5 mm. Most of the studies utilised bone-level fixtures[24,25,44,46,48-51], whereas three involved placement of tissue-level implants[45,47,52]. The only included study that did not use an implant system with an internal connection was Malchiodi et al[48], who used a system with an external hexagon connection.

	Implant characteristics	Implant length, mm	Implant diameter, mm (number of implants)	MBL landmarks	Prosthetic information
	Standard Plus Regular Neck SLActive (Straumann, Basel, Switzerland); airborne-particle–abraded large grit acid-etched surface with hydrophilic surface treatment	6.0	4.1 (46)	Coronal: Implant platform Apical: Most coronal bone–implant contact	Metal-ceramic restorative material, screw-retained mechanism
	Standard Plus (Straumann); airborne-particle–abraded large grit acid-etched surface	6.0	4.1 (30) .8 (42)	Coronal: Implant shoulder Apical: Most coronal bone–implant contact	Restorative material unknown; cement-retained mechanism
	K implants (WINSIX, BioSAFin, Ancona, Italy) and TTx implants (WINSIX, BioSAFin); airborne-particle–abraded and acid-etched surface for both	6.0	3.8 (NR) 4.5 (NR) 5.2 (NR)	Coronal: Implant shoulder Apical: Most coronal bone–implant contact	Zirconium-ceramic or metal-ceramic restorative material; cement-retained mechanism
	Standard Plus Tissue Level (Straumann); airborne-particle–abraded and large grit acid-etched with hydrophilic surface treatment	6.0	4.1 (50)	NR	Restorative material unknown; screw-retained mechanism
	Tapered Short Laser-Lok (BioHorizons, Birmingham, AL, USA); laser-ablated surface	6.0	4.6 (6)	Coronal: Implant collar Apical: Crestal bone margin	Restorative material unknown; mechanism unknown
	i-system (Novodent, Yverdon-les-Bains, Switzerland); surface NR	6.0	NR	Coronal: Implant–abutment interface Apical: Most coronal bone–implant contact	Metal-ceramic restorative material; mechanism unknown
	JDIcon and JDEvolution systems (JDentalCare, Modena, Italy); airborne-particle–abraded and acid-etched surface	6.0	NR	Coronal: Most coronal margin of implant collar Apical: Most coronal bone–implant contact	Restorative material unknown; cement- and screw-retained mechanism
	OsseoSpeed 4.0 S (Astra Tech Implant System, Astra Tech, Mölndal, Sweden); titanium oxide–blasted and acid-etched surface with fluoride surface modification	6.0	4.0 (21)	Coronal: Implant neck Apical: Unclear	Zirconia-ceramic restorative material; cement-retained mechanism
	OsseoSpeed 4.0 S (Astra Tech); titanium oxide–blasted and acid-etched surface with fluoride surface modification	6.0	4.0 (31)	Coronal: Junction between machined bevel and microthreads Apical: Crestal bone margin	Zirconia-ceramic restorative material; cement-retained mechanism
	Straumann implant systems; airborne-particle–abraded large grit and acid-etched surface with hydrophilic surface treatment	6.0	4.1 (38)	Coronal: Implant shoulder Apical: Most coronal bone–implant contact	Metal-ceramic restorative material; cement-retained mechanism
	Endopore (INNOVA, Toronto, ON, Canada); porous sintered bead surface	5.0	4.1 and 5.0 (NR)	Coronal: Coronal margin of smooth collar Apical: Crestal bone margin	Metal-ceramic restorative material; cement and screw-retained mechanism

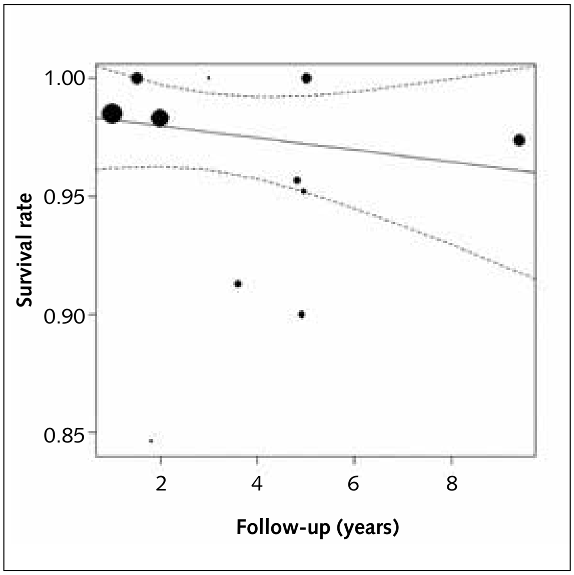


Fig 2 Short implant survival throughout the follow-up period.

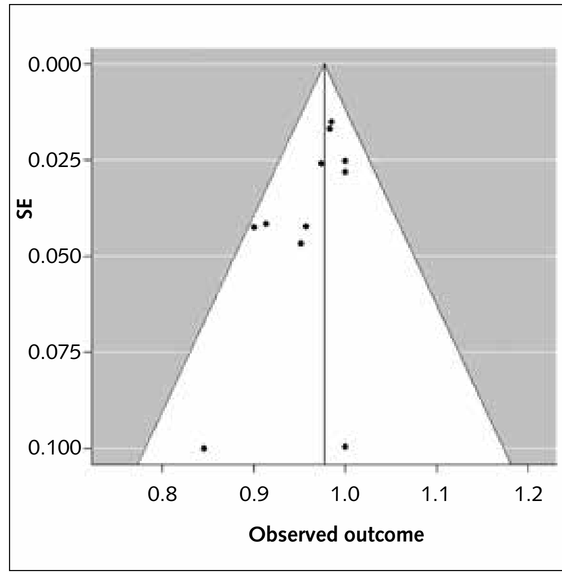


Fig 3 Funnel plot of studies included in meta-analysis of survival rates.

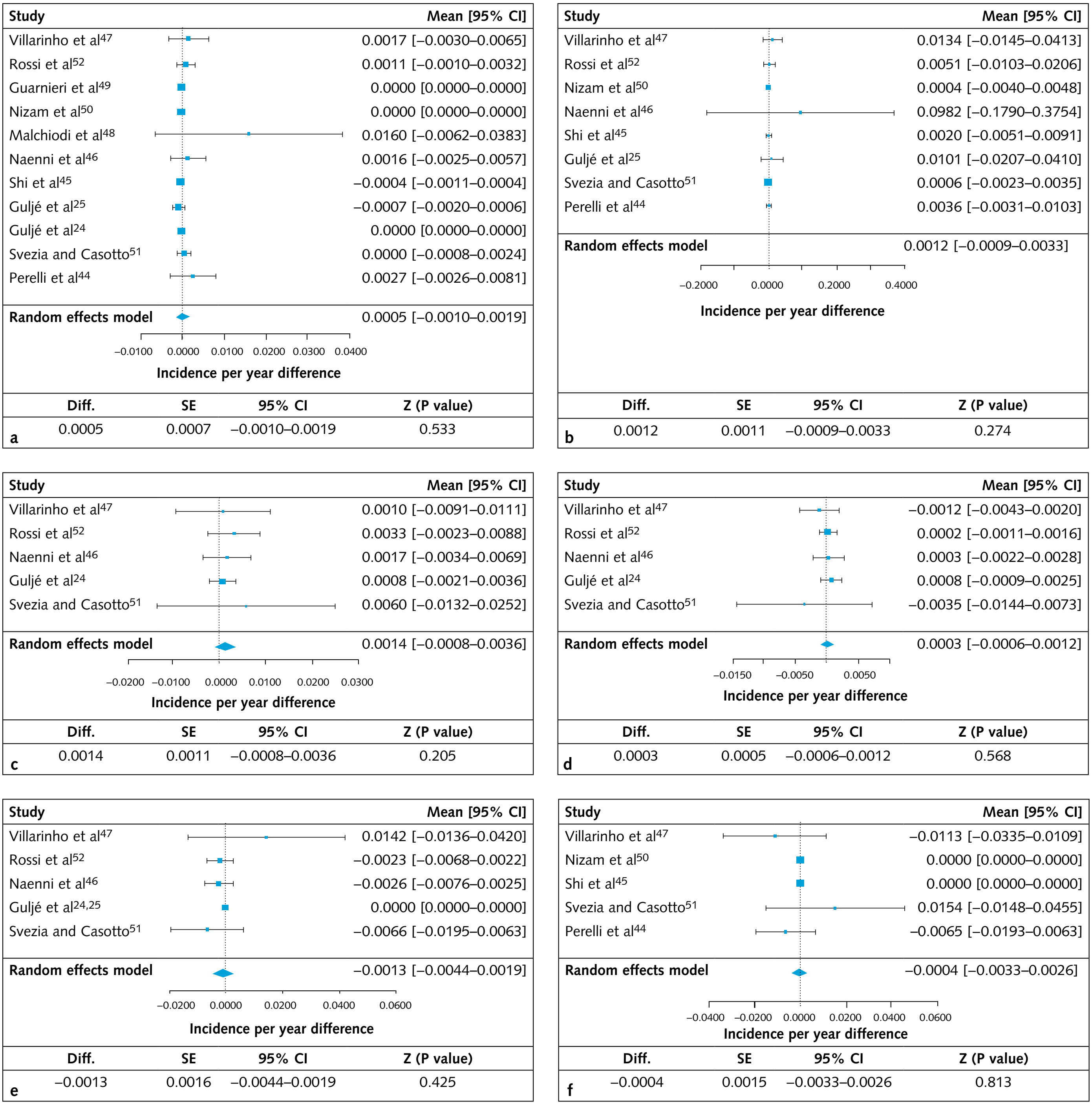
Five studies placed cement-retained restorations exclusively[24,25,45,48,52], three implemented screw-retained restorations exclusively[46,47,51], one placed both cement- and screw-retained restorations[44], and the remaining two did not report the mechanism of restoration retention used[49,50]. Most studies included smokers within a certain threshold of cigarettes smoked per day. In four studies, a limit of 10 cigarettes per day was applied[44,45,49,51], whereas for Naenni et al[46] and Malchiodi et al[48] it was 19 and 20 cigarettes per day, respectively. In contrast, Rossi et al[52] included all smokers regardless of smoking intensity, Nizam et al[50] excluded smokers, and three studies did not report the smoking status of the included patients[24,25,47]. Information on short implant survival was collected for adjacent and distal implants from all the included studies. With the exception of Naenni et al[46], all the included studies provided information on MBL and prosthetic complications.

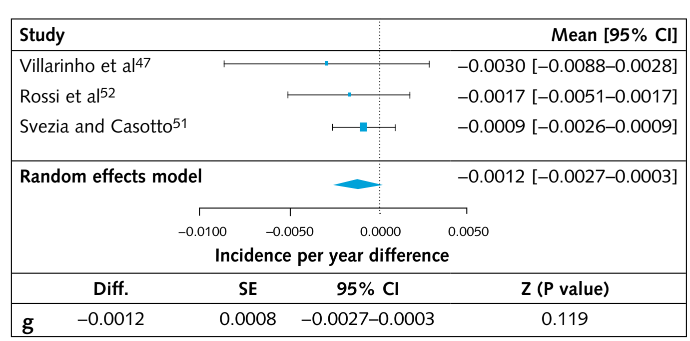
Survival analysis

Overall, 16 out of 388 implants (4%) failed over the full follow-up period (Fig 2). The possibility of publication bias was assessed using an Egger test and is presented in a funnel plot (Fig 3). The funnel plot demonstrates a high level of asymmetry ($P = 0.055$) due to the fact that the studies with the lowest SEs reported the highest survival rates.

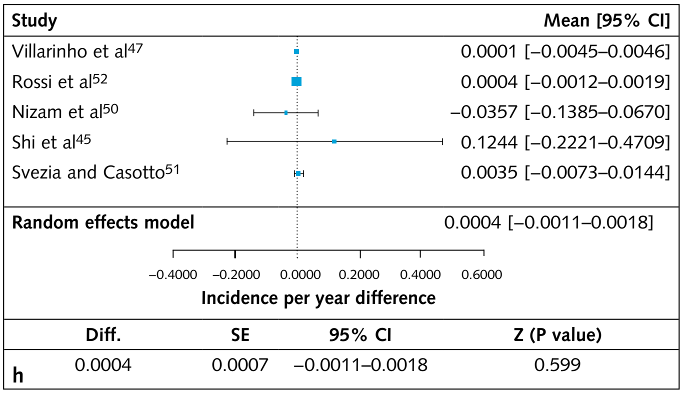
Survival rate based on implant position

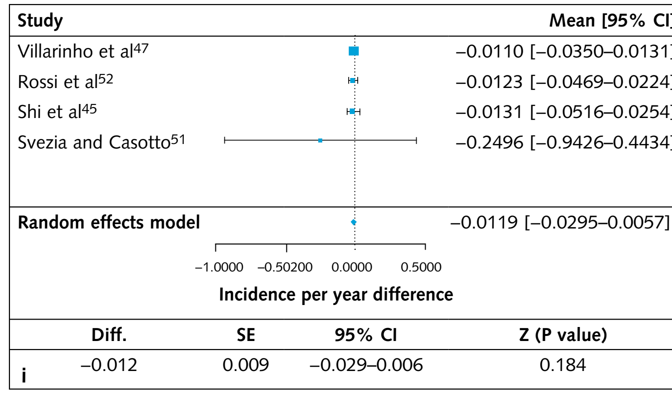
A meta-analysis of failure rates between adjacent and distal implants from all the included studies found no statistically significant difference ($P = 0.533$) (Fig 4a). Considering adjacent or distal positioning within each arch, no statistically significant differences in survival rate were found for maxillary ($P = 0.274$) (Fig 4b) or mandibular implants ($P = 0.205$) (Fig 4c). Interarch comparisons showed no statistically significant differences when comparing only adjacent ($P = 0.568$) (Fig 4d) or only distal implants ($P = 0.425$) (Fig 4e). None of the articles included any distal implants in the first premolar position. There were no statistically significant differences in survival rate when comparing short implants in first and second molar positions ($P = 0.813$) (Fig 4f) or implants placed between premolar and molar positions ($P = 0.119$) (Fig 4 g) when considering implants placed at the most distal position in the arch only. The same trends ($P > 0.050$) were found when comparing adjacently placed first and second molar implants (Fig 4 h) and those placed between premolar and molar sites (Fig 4i).





Figs 4a-i Comparison of failure rates based on short implant position in the maxilla and mandible.





Figs 4a-i (cont.) Comparison of failure rates based on short implant position in the maxilla and mandible.

MBL based on implant position

Nine articles provided data for meta-analysis of annual MBL[24,25,45,47-52]. A funnel plot (Fig 5) was constructed and demonstrated an overall level of symmetry using an Egger test ($P = 0.563$). Although adjacent implants showed slightly higher annual MBL (0.021 mm/year), no clinically or statistically significant differences were found between adjacent and distal implants ($P = 0.078$) (Fig 6a). No significant differences were found for the following comparisons of annual MBL: adjacent vs distal in the maxilla (Fig 6b), adjacent vs distal in the mandible (Fig 6c), maxilla vs mandible (adjacent only) (Fig 6d), and maxilla vs mandible (distal only) (Fig 6e). In addition, there were no significant differences in annual MBL when comparing implants in the following sites: first and second molars in a distal position (Fig 6f), first and second molars in an adjacent position (Fig 6 g), and premolars vs. molars in an adjacent position (Fig 6 h). None of the included studies reported MBL at both premolar and molar sites for implants placed in a distal position.

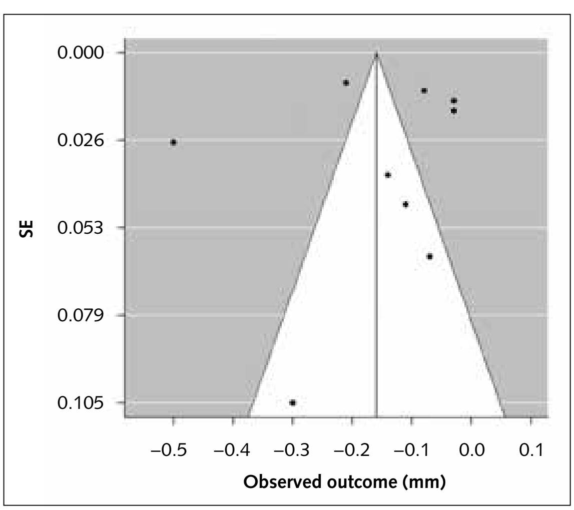
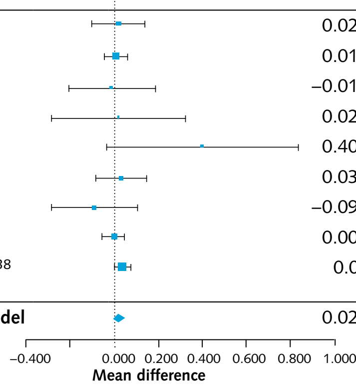


Fig 5 Funnel plot of studies included in meta-analysis of MBL.

Prosthetic complications

Nine articles reported on prosthetic complications[24,25,44,45,47-50,52], yielding a total of 20 complications. A funnel plot was constructed and demonstrated a high level of asymmetry using an Egger test ($P < 0.001$) (Fig 7). The Galbraith plot showed that Villarinho et al[47] were outside of the 95% CI due to a high rate of prosthetic complications (Fig 8). Screw loosening was the most common prosthetic complication (n = 16), followed by restoration chipping (n = 4). Only one case of restoration chipping (distal site) resulted in prosthetic failure. No significant differences in prosthetic complications were found between implants placed in adjacent and distal positions ($P = 0.211$) (Fig 9).

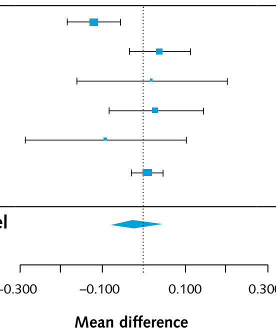
Study	Mean [95% CI]
Villarinho et al[47]	0.020 [−0.100–0.140]
Rossi et al[52]	0.010 [−0.041–0.061]
Guarnieri et al[49]	−0.010 [−0.202–0.182]
Nizam et al[50]	0.020 [−0.283–0.323]
Malchiodi et al[48]	0.400 [−0.033–0.833]
Shi et al[45]	0.030 [−0.083–0.143]
Guljé et al[25]	−0.090 [−0.284–0.104]
Guljé et al[24]	0.000 [−0.049–0.049]
Svezia and Casotto[38]	0.040 [0.004–0.075]
Random effects model	0.021 [−0.002–0.045]



Weighted mean difference	SE	95% CI	Z (P value)	I^2	QH (P value)	Egger (P value)
0.021	0.012	0.078	0.533	0.0%	0.618	0.944

a

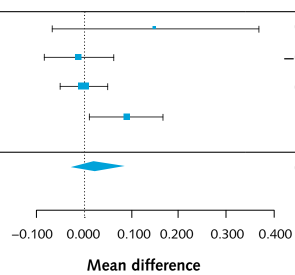
Study	Mean [95% CI]
Villarinho et al[47]	−0.120 [−0.184–−0.056]
Rossi et al[52]	0.040 [−0.032–0.112]
Nizam et al[50]	0.020 [−0.162–0.202]
Shi et al[45]	0.030 [−0.083–0.143]
Guljé et al[25]	−0.090 [−0.284–0.104]
Svezia and Casotto[51]	0.010 [−0.026–0.046]
Random effects model	−0.016 [−0.078–0.045]



Weighted mean difference	SE	95% CI	Z (P value)	I^2	QH (P value)	Egger (P value)
−0.016	0.032	−0.078–0.045	0.602	68.2%	0.008	0.936

b

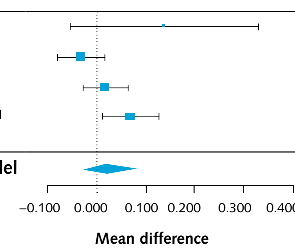
Study	Mean [95% CI]
Villarinho et al[47]	0.150 [−0.067–0.367]
Rossi et al[52]	−0.010 [−0.083–0.063]
Guljé et al[24]	0.000 [−0.049–0.049]
Svezia and Casotto[51]	0.090 [0.014–0.166]
Random effects model	0.031 [−0.026–0.087]



Weighted mean difference	SE	95% CI	Z (P value)	I^2	QH (P value)	Egger (P value)
0.031	0.029	−0.026–0.087	0.285	49.1%	0.117	0.184

c

Study	Mean [95% CI]
Villarinho et al[47]	0.140 [−0.051–0.331]
Rossi et al[52]	−0.030 [−0.079–0.019]
Guljé et al[24,25]	0.020 [−0.025–0.065]
Svezia and Casotto[51]	0.070 [0.015–0.125]
Random effects model	0.027 [−0.026–0.080]

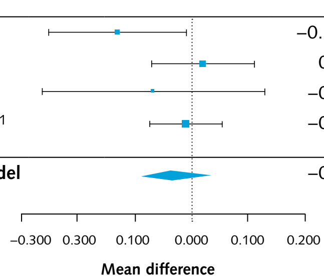


Weighted mean difference	SE	95% CI	Z (P value)	I^2	QH (P value)	Egger (P value)
0.027	0.027	−0.027–0.080	0.324	65.3%	0.034*	0.219

*$P < 0.05$.

d

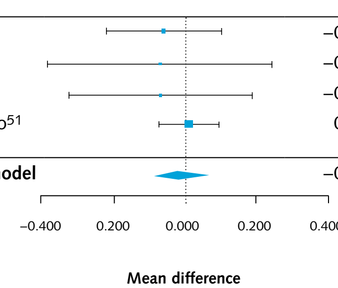
Study	Mean [95% CI]
Villarinho et al[47]	−0.130 [−0.250–−0.010]
Rossi et al[52]	0.020 [−0.070–0.110]
Guljé et al[24,25]	−0.070 [−0.265–0.125]
Svezia and Casotto[51]	−0.010 [−0.074–0.054]
Random effects model	−0.030 [−0.090–0.031]



Weighted mean difference	SE	95% CI	Z (P value)	I^2	QH (P value)	Egger (P value)
−0.030	0.031	−0.090–0.031	0.337	30.2%	0.231	0.309

e

Study	Mean [95% CI]
Villarinho et al[47]	−0.060 [−0.221–0.101]
Nizam et al[50]	−0.070 [−0.381–0.241]
Shi et al[45]	−0.070 [−0.326–0.186]
Svezia and Casotto[51]	0.010 [−0.075–0.095]
Random effects model	−0.013 [−0.083–0.057]



Weighted mean difference	SE	95% CI	Z (P value)	I^2	QH (P value)	Egger (P value)
−0.013	0.036	−0.083–0.057	0.708	0.0%	0.818	0.387

f

Figs 6a-h Comparison of MBL based on short implant position in the maxilla and mandible.

Study	Mean [95% CI]
Villarinho et al[47]	−0.050 [−0.242–0.142]
Rossi et al[52]	0.110 [0.018–0.202]
Shi et al[45]	0.030 [−0.175–0.235]
Random effects model	0.064 [−0.027–0.155]

Mean difference (axis: −0.300, 0.100, 0.100, 0.300)

	Weighted mean difference	SE	95% CI	Z (P value)	I²	QH (P value)	Egger (P value)
g	0.064	0.046	−0.027–0.155	0.167	15.8%	0.305	0.164

Study	Mean [95% CI]
Villarinho et al[47]	0.100 [−0.039–0.239]
Rossi et al[51]	0.020 [−0.028–0.068]
Nizam et al[50]	−0.080 [−0.243–0.083]
Shi et al[45]	0.120 [−0.178–0.418]
Svezia and Casotto[51]	−0.070 [−0.132–0.008]
Random effects model	−0.004 [−0.072–0.064]

Mean difference (axis: −0.400, −0.200, 0.000, 0.200, 0.400, 0.600)

	Weighted mean difference	SE	95% CI	Z (P value)	I²	QH (P value)	Egger (P value)
h	−0.004	0.035	−0.072–0.064	0.902	55.3%	0.063	0.489

Figs 6a-h Comparison of MBL based on short implant position in the maxilla and mandible.

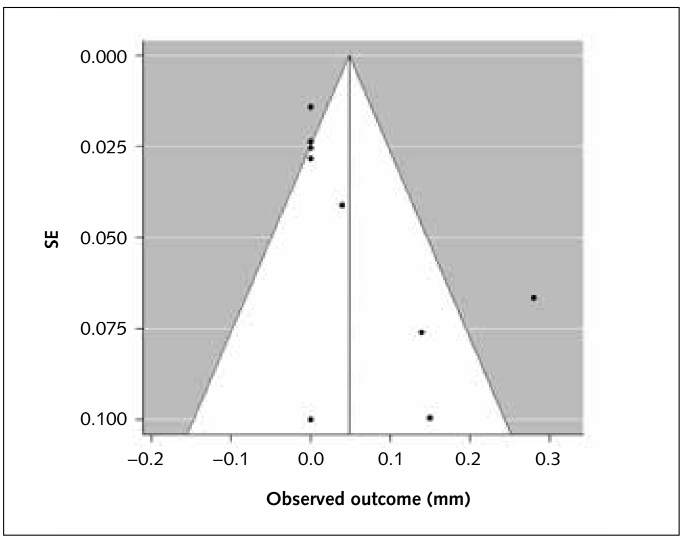


Fig 7 Funnel plot of studies included in meta-analysis of prosthetic complications.

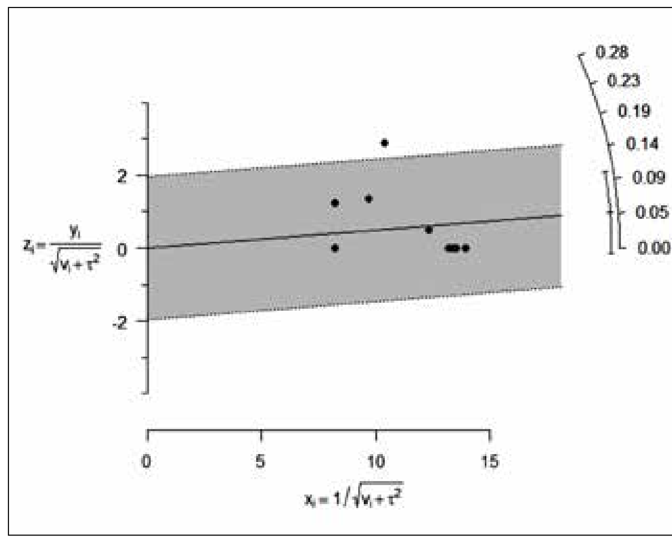


Fig 8 Galbraith plot of studies included in meta-analysis of prosthetic complications.

Study	Mean [95% CI]
Villarinho et al[47]	0.280 [0.150–0.410]
Rossi et al[52]	0.000 [0.000–0.046]
Guarnieri et al[49]	0.000 [0.000–0.195]
Nizam et al[50]	0.000 [0.000–0.049]
Malchiodi et al[48]	0.150 [0.000–0.344]
Shi et al[45]	0.000 [0.000–0.028]
Guljé et al[25]	0.140 [0.000–0.288]
Guljé et al[24]	0.000 [0.000–0.055]
Perelli et al[44]	0.040 [0.000–0.120]
Random effects model	0.049 [0.000–0.105]

Observed outcome (axis: 0.000, 0.200, 0.400)

Weighted mean difference	SE	95% CI	Z (P value)	I²	QH (P value)	Egger (P value)
0.049	0.029	0.000–0.105	0.089	82.9%	0.003**	< 0.001***

**P < 0.01; ***P < 0.001

Fig 9 Comparison of prosthetic complications between adjacent and distal implant positions.

Discussion

The present systematic review and meta-analysis is the first to explore whether the position of short implants (≤ 6 mm length with 3.8 to 5.2 mm diameter) influences their survival rate, MBL and prosthetic complications. The results demonstrated that short implants are a predictable treatment option even when placed in the most distal free-end position in the arch, as no significant differences in any of the studied outcomes were found between the two groups.

The influence of functional loading is a crucial factor to consider when analysing long-term clinical outcomes of implants placed in posterior sites. Although implant length has been shown to have a limited effect on improving occlusal load distribution[53], the influence of occlusal loading has always been an important consideration during treatment planning for short implants. In order study the potential influence of occlusal factors on short implant treatment outcomes more precisely, only implants restored with single crowns were included in the present study. Research suggests that splinting two or more restorations aids in the distribution of masticatory forces, diminishing the stress transmitted to the fixture[19,20]. Higher survival rates have been found for splinted short implants than for non-splinted short implants[8]. In addition, early implant failures were excluded from the analysis because it is essential to consider prosthetic loading in order to accurately compare adjacent and distal positioning.

The presence of two adjacent interproximal contacts could be speculated to reduce undesirable forces on implant-supported single crowns, especially in posterior locations, when compared to a free-end distal implant position in the arch. This notion has rarely been addressed in the literature. Aguiar Júnior et al[23] performed a photoelastic stress analysis to study whether stress distribution at non-splinted first molar screw-retained metal–ceramic crowns was affected by the absence of a second molar distal contact. Their results suggested that the presence of an effective interproximal contact distal to an edentulous site restored with an implant decreased the stress pattern and the load distribution around the implant when an off-axis load was applied[23]. However, despite several finite element analyses concluding that higher stress occurred around short implants than longer implants[54-56], results from in vivo studies did not show an association with increased MBL[20,57]. Increased mechanical stress around dental implants did not lead to increased MBL but was instead related to higher bone density due to increased peri-implant bone turnover[58-60]. The functional adaptation of bone to biomechanical stimuli supporting short implants has been confirmed by the results of an RCT with 3- and 5-year follow-ups[32,61].

With regard to prosthetic complications, the lack of a significant difference between groups suggests that other parameters might play a more important role than implant position. Indeed, the elimination of eccentric contacts, the size of the occlusal table and cuspal inclination are all critical factors to consider at the time of short implant restoration. Furthermore, the height and dimensions of the crown are likely to be more relevant than the crown–implant ratio, the latter of which has been demonstrated to have no significant association with increased prosthetic complications[62]. Accordingly, stress distribution has been shown to be more dependent on implant diameter than length, with increased diameter corresponding to decreased stress at the bone–implant interface[53]. Although increased short implant diameter appears unlikely to influence implant survival[15,63], there is more compelling evidence to suggest that narrower diameters may be associated with increased incidence of prosthetic complications[64-66]. Implant diameter must be considered in conjunction with the dimensions and emergence profile of the implant crown, as a large mismatch (i.e., a wide crown with a narrow-diameter implant) may contribute to the development of prosthetic complications including component fracture or screw loosening due to an increased moment arm[67]. In addition, short implants are often restored with taller crowns to compensate for vertical bone loss. Crown height is another important variable that must be considered regarding technical complications[68], as taller implant crowns produce a greater vertical cantilever effect in response to off-axis forces, increasing the probability of technical complications[67]. In terms of the severity of prosthetic complications encountered, it is important to note that the vast majority were of minor importance (i.e., screw loosening and minor chipping); however, one instance of prosthetic failure was recorded in a distal site. A biomechanical explanation for the high prevalence of screw loosening might be the use of non-splinted crowns, which are more prone to experiencing rotational movement in response to eccentric forces. This result is in line with a previous review that found screw loosening to be the most frequent complication in short implants, and 16 times more frequent for non-splinted implants than splinted implants[8]. A similar result was recorded by Pjetursson et al[69] who reported this complication in 12.7% of implants restored with single crowns compared to 5.6% in splinted restorations.

The present article has some limitations. First, the sample size for certain sub-analyses was not ideal. Ten potential additional articles were excluded due to unavailability of data or a lack of response from the authors. Second, the included articles were not designed with the intention of studying the influence of implant position (adjacent vs distal) on the clinical outcomes of short implants. This led to an unequal sample distribution in favour of adjacent implants, which could have influenced data analysis; however, it should be noted that 119 distal implants were analysed. Further RCTs directly comparing adjacent and distal short implants over a long-term follow-up period are required to confirm the present results.

Conclusion

For non-splinted short implants (≤ 6 mm with 3.8 to 5.2 mm diameter), implant positioning between two adjacent contacts compared to a free-end distal location did not influence survival rate, MBL or prosthetic complications. This finding is relevant for clinical decision-making during rehabilitation of posterior edentulism, especially in cases where short implants are indicated and where clinicians would prefer to place non-splinted restorations.

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References

1. Naert I, Quirynen M, van Steenberghe D, Darius P. A six-year prosthodontic study of 509 consecutively inserted implants for the treatment of partial edentulism. J Prosthet Dent 1992;67:236–245.
2. Horikawa T, Odatsu T, Itoh T, et al. Retrospective cohort study of rough-surface titanium implants with at least 25 years' function. Int J Implant Dent 2017;3:1–8.
3. Dierens M, Vandeweghe S, Kisch J, Nilner K, De Bruyn H. Long-term follow-up of turned single implants placed in periodontally healthy patients after 16-22 years: Radiographic and peri-implant outcome. Clin Oral Implants Res 2012;23:197–204.
4. Martinolli M, Bortolini S, Natali A, et al. Long-term survival analysis of standard-length and short implants with multi-functional abutments. J Oral Rehabil 2019;46:640–646.
5. Rameh S, Menhall A, Younes R. Key factors influencing short implant success. Oral Maxillofac Surg 2020;24: 263–275.
6. Urban IA, Jovanovic SA, Lozada JL. Vertical ridge augmentation using guided bone regeneration (GBR) in three clinical scenarios prior to implant placement: A retrospective study of 35 patients 12 to 72 months after loading. Int J Oral Maxillofac Implants 2009;24:502–510.
7. Carrao V, DeMatteis I. Maxillary sinus bone augmentation techniques. Oral Maxillofac Surg Clin North Am 2015;27:245–253.
8. Ravidà A, Barootchi S, Askar H, Suárez-López Del Amo F, Tavelli L, Wang HL. Long-term effectiveness of extra-short (≤ 6 mm) dental implants: A systematic review. Int J Oral Maxillofac Implants 2019;34:68–84.
9. Thoma DS, Haas R, Tutak M, Garcia A, Schincaglia GP, Hämmerle CH. Randomized controlled multicentre study comparing short dental implants (6 mm) versus longer dental implants (11-15 mm) in combination with sinus floor elevation procedures. Part 1: Demographics and patient-reported outcomes at 1 year of loading. J Clin Periodontol 2015;42:72–80.
10. Ravidà A, Wang IC, Sammartino G, et al. Prosthetic rehabilitation of the posterior atrophic maxilla, short (≤ 6 mm) or long (≥ 10 mm) dental implants? A systematic review, meta-analysis, and trial sequential analysis: Naples Consensus Report Working Group A. Implant Dent 2019;28:590–602.
11. Ravidà A, Wang IC, Barootchi S, et al. Meta-analysis of randomized clinical trials comparing clinical and patient-reported outcomes between extra-short (≤ 6 mm) and longer (≥ 10 mm) implants. J Clin Periodontol 2019;46:118–142.
12. Stacchi C, Spinato S, Lombardi T, et al. Minimally invasive management of implant-supported rehabilitation in the posterior maxilla, part II. Surgical techniques and decision tree. Int J Periodontics Restorative Dent 2020;40:e95–e102.

13. Strietzel FP, Reichart PA. Oral rehabilitation using Camlog screw-cylinder implants with a particle-blasted and acid-etched microstructured surface. Results from a prospective study with special consideration of short implants. Clin Oral Implants Res 2007;18:591–600.
14. Lozano-Carrascal N, Anglada-Bosqued A, Salomó-Coll O, Hernández-Alfaro F, Wang HL, Gargallo-Albiol J. Short implants (< 8 mm) versus longer implants (≥ 8 mm) with lateral sinus floor augmentation in posterior atrophic maxilla: A meta-analysis of RCT's in humans. Med Oral Patol Oral Cir Bucal. 2020;25:e168–e179.
15. Monje A, Fu JH, Chan HL, et al. Do implant length and width matter for short dental implants (< 10 mm)? A meta-analysis of prospective studies. J Periodontol 2013;84:1783–1791.
16. Monje A, Suárez F, Galindo-Moreno P, García-Nogales A, Fu JH, Wang HL. A systematic review on marginal bone loss around short dental implants (< 10 mm) for implant-supported fixed prostheses. Clin Oral Implants Res 2014;25:1119–1124.
17. Papaspyridakos P, De Souza A, Vazouras K, Gholami H, Pagni S, Weber HP. Survival rates of short dental implants (≤ 6 mm) compared with implants longer than 6 mm in posterior jaw areas: A meta-analysis. Clin Oral Implants Res 2018;29(suppl 16):8–20.
18. Ravidà A, Tattan M, Askar H, Barootchi S, Tavelli L, Wang HL. Comparison of three different types of implant-supported fixed dental prostheses: A long-term retrospective study of clinical outcomes and cost-effectiveness. Clin Oral Implants Res 2019;30:295–305.
19. Guichet DL, Yoshinobu D, Caputo AA. Effect of splinting and interproximal contact tightness on load transfer by implant restorations. J Prosthet Dent 2002;87:528–535.
20. Ravidà A, Saleh MHA, Muriel MC, Maska B, Wang HL. Biological and technical complications of splinted or nonsplinted dental implants: A decision tree for selection. Implant Dent 2018;27:89–94.
21. Ng KT, Fan M, Leung MC, Fokas G, Mattheos N. Peri-implant inflammation and marginal bone level changes around dental implants in relation to proximity with and bone level of adjacent teeth. Aust Dent J 2018;63:467–477.
22. Pang NS, Suh CS, Kim KD, Park W, Jung BY. Prevalence of proximal contact loss between implant-supported fixed prostheses and adjacent natural teeth and its associated factors: A 7-year prospective study. Clin Oral Implants Res 2017;28:1501–1508.
23. Aguiar Júnior FA, Tiossi R, Macedo AP, de Mattos MG, Ribeiro RF, Rodrigues RC. Importance of a distal proximal contact on load transfer by implant-supported single adjacent crowns in posterior region of the mandible: A photoelastic study. J Appl Oral Sci 2013;21:397–402.
24. Guljé FL, Raghoebar GM, Vissink A, Meijer HJA. Single crown restorations supported by 6-mm implants in the resorbed posterior mandible: A five-year prospective case series. Clin Implant Dent Relat Res 2019;21:1017–1022.
25. Guljé FL, Raghoebar GM, Vissink A, Meijer HJA. Single crowns in the resorbed posterior maxilla supported by either 11-mm implants combined with sinus floor elevation or 6-mm implants: A 5-year randomised controlled trial. Int J Oral Implantol (Berl) 2019;12:315–326.
26. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. J Clin Epidemiol 2009;62:1006–1012.
27. Shea BJ, Hamel C, Wells GA, et al. AMSTAR is a reliable and valid measurement tool to assess the methodological quality of systematic reviews. J Clin Epidemiol 2009;62:1013–1020.
28. Stone PW. Popping the (PICO) question in research and evidence-based practice. Appl Nurs Res 2002;15: 197–198.
29. Higgins JPT, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 2011;343:d5928.
30. Cook DA, Reed DA. Appraising the quality of medical education research methods: The Medical Education Research Study Quality Instrument and the Newcastle-Ottawa Scale-Education. Acad Med 2015;90: 1067–1076.
31. Pohl V, Thoma DS, Sporniak-Tutak K, et al. Short dental implants (6 mm) versus long dental implants (11-15 mm) in combination with sinus floor elevation procedures: 3-year results from a multicenter, randomized, controlled clinical trial. J Clin Periodontol 2017;44:438–445.
32. Sahrmann P, Schoen P, Naenni N, Jung R, Attin T, Schmidlin PR. Peri-implant bone density around implants of different lengths: A 3-year follow-up of a randomized clinical trial. J Clin Periodontol 2017;44:762–768.
33. Schincaglia GP, Thoma DS, Haas R, et al. Randomized controlled multicenter study comparing short dental implants (6 mm) versus longer dental implants (11-15 mm) in combination with sinus floor elevation procedures. Part 2: Clinical and radiographic outcomes at 1 year of loading. J Clin Periodontol 2015;42:1042–1051.
34. De Santis D, Cucchi A, Rigoni G, Longhi C. Short implants with oxidized surface in posterior areas of atrophic jaws: 3- to 5-year results of a multicenter study. Clin Implant Dent Relat Res 2015;17:442–452.
35. Thoma DS, Haas R, Sporniak-Tutak K, Garcia A, Taylor TD, Hämmerle CHF. Randomized controlled multicenter study comparing short dental implants (6 mm) versus longer dental implants (11-15 mm) in combination with sinus floor elevation procedures: 5-year data. J Clin Periodontol 2018;45:1465–1474.
36. Bechara S, Kubilius R, Veronesi G, Pires JT, Shibli JA, Mangano FG. Short (6-mm) dental implants versus sinus floor elevation and placement of longer (≥10-mm) dental implants: A randomized controlled trial with a 3-year follow-up. Clin Oral Implants Res 2017;28:1097–1107.
37. Bernardi S, Gatto R, Severino M, et al. Short versus longer implants in mandibular alveolar ridge augmented using osteogenic distraction: One-year follow-up of a randomized split-mouth trial. J Oral Implantol 2018;44: 184–191.
38. Al-Hashedi AA, Taiyeb-Ali TB, Yunus N. Outcomes of placing short implants in the posterior mandible: A preliminary randomized controlled trial. Aust Dent J 2016; 61:208–218.
39. Ayna M, Wessing B, Gutwald R, et al. A 5-year prospective clinical trial on short implants (6 mm) for single tooth replacement in the posterior maxilla: Immediate versus delayed loading. Odontology 2019;107:244–253.
40. Shah SN, Chung J, Kim DM, Machtei EE. Can extra-short dental implants serve as alternatives to bone augmentation? A preliminary longitudinal randomized controlled clinical trial. Quintessence Int 2018;49:635–643.
41. Hadzik J, Krawiec M, Kubasiewicz-Ross P, Prylińska-Czyżewska A, Gedrange T, Dominiak M. Short implants and conventional implants in the residual maxillary alveolar ridge: A 36-month follow-up observation. Med Sci Monit 2018;24:5645–5652.
42. Weerapong K, Sirimongkolwattana S, Sastraruji T, Khongkhunthian P. Comparative study of immediate loading on short dental implants and conventional dental implants in the posterior mandible: A randomized clinical trial. Int J Oral Maxillofac Implants 2019;34:141–149.

43. Mendoza-Azpur G, Lau M, Valdivia E, Rojas J, Muñoz H, Nevins M. Assessment of marginal peri-implant bone level short length implants compared with standard implants supporting single crowns in a controlled clinical trial: 12-month follow-up. Int J Periodontics Restorative Dent 2016;36:791–795.
44. Perelli M, Abundo R, Corrente G, Saccone C. Short (5 and 7 mm long) porous implants in the posterior atrophic maxilla: A 5-year report of a prospective single-cohort study. Eur J Oral Implantol 2012;5:265–272.
45. Shi JY, Li Y, Qiao SC, Gu YX, Xiong YY, Lai HC. Short versus longer implants with osteotome sinus floor elevation for moderately atrophic posterior maxillae: A 1-year randomized clinical trial. J Clin Periodontol 2019;46: 855–862.
46. Naenni N, Sahrmann P, Schmidlin PR, et al. Five-year survival of short single-tooth implants (6 mm): A randomized controlled clinical trial. J Dent Res 2018;97:887–892.
47. Villarinho EA, Triches DF, Alonso FR, Mezzomo LAM, Teixeira ER, Shinkai RSA. Risk factors for single crowns supported by short (6-mm) implants in the posterior region: A prospective clinical and radiographic study. Clin Implant Dent Relat Res 2017;19:671–680.
48. Malchiodi L, Giacomazzi E, Cucchi A, et al. Relationship between crestal bone levels and crown-to-implant ratio of ultra-short implants with a microrough surface: A prospective study with 48 months of follow-up. J Oral Implantol 2019;45:18–28.
49. Guarnieri R, Di Nardo D, Gaimari G, Miccoli G, Testarelli L. Short vs. standard laser-microgrooved implants supporting single and splinted crowns: A prospective study with 3 years follow-up. J Prosthodont 2019;28: e771–e779.
50. Nizam N, Gurlek Ö, Kaval ME. Extra-short implants with osteotome sinus floor elevation: A prospective clinical study. Int J Oral Maxillofac Implants 2020;35:415–422.
51. Svezia L, Casotto F. Short dental implants (6 mm) versus standard dental implants (10 mm) supporting single crowns in the posterior maxilla and/or mandible: 2-year results from a prospective cohort comparative trial. J Oral Maxillofac Res 2018;9:1–8.
52. Rossi F, Lang NP, Ricci E, Ferraioli L, Baldi N, Botticelli D. Long-term follow-up of single crowns supported by short, moderately rough implants–A prospective 10-year cohort study. Clin Oral Implants Res 2018;29:1212–1219.
53. Himmlová L, Dostálová T, Kácovský A, Konvicková S. Influence of implant length and diameter on stress distribution: A finite element analysis. J Prosthet Dent 2004;91: 20–25.
54. Araki H, Nakano T, Ono S, Yatani H. Three-dimensional finite element analysis of extra short implants focusing on implant designs and materials. Int J Implant Dent 2020;6:1–10.
55. Jomjunyong K, Rungsiyakull P, Rungsiyakull C, Aunmeungtong W, Chantaramungkorn M, Khongkhunthian P. Stress distribution of various designs of prostheses on short implants or standard implants in posterior maxilla: A three dimensional finite element analysis. Oral Implantol (Rome) 2017;10:369–380.
56. Toniollo MB, Macedo AP, Rodrigues RC, Ribeiro RF, de Mattos MG. A three-dimensional finite element analysis of the stress distribution generated by splinted and non-splinted prostheses in the rehabilitation of various bony ridges with regular or short morse taper implants. Int J Oral Maxillofac Implants 2017;32:372–376.
57. Vigolo P, Zaccaria M. Clinical evaluation of marginal bone level change of multiple adjacent implants restored with splinted and non-splinted restorations: A 5-year prospective study. Int J Oral Maxillofac Implants 2010;25:1189–1194.
58. Asikainen P, Klemetti E, Vuillemin T, Sutter F, Rainio V, Kotilainen R. Titanium implants and lateral forces. An experimental study with sheep. Clin Oral Implants Res 1997;8:465–468.
59. Roberts WE, Smith RK, Zilberman Y, Mozsary PG, Smith RS. Osseous adaptation to continuous loading of rigid endosseous implants. Am J Orthod 1984;86:95–111.
60. Wehrbein H, Diedrich P. Endosseous titanium implants during and after orthodontic load--An experimental study in the dog. Clin Oral Implants Res 1993;4:76–82.
61. Sluka B, Naenni N, Jung RE, Attin T, Schmidlin PR, Sahrmann P. Changes of radiopacity around implants of different lengths: Five-year follow-up data of a randomized clinical trial. Clin Oral Implants Res 2020;31:488–494.
62. Ravidà A, Barootchi S, Alkanderi A, Tavelli L, Suárez-López Del Amo F. The effect of crown-to-implant ratio on the clinical outcomes of dental implants: A systematic review. Int J Oral Maxillofac Implants 2019;34:1121–1131.
63. Queiroz TP, Aguiar SC, Margonar R, de Souza Faloni AP, Gruber R, Luvizuto ER. Clinical study on survival rate of short implants placed in the posterior mandibular region: Resonance frequency analysis. Clin Oral Implants Res 2015;26:1036–1042.
64. Assaf A, Saad M, Daas M, Abdallah J, Abdallah R. Use of narrow-diameter implants in the posterior jaw: A systematic review. Implant Dent 2015;24:294–306.
65. de Souza AB, Sukekava F, Tolentino L, César-Neto JB, Garcez-Filho J, Araújo MG. Narrow- and regular-diameter implants in the posterior region of the jaws to support single crowns: A 3-year split-mouth randomized clinical trial. Clin Oral Implants Res 2018;29:100–107.
66. Pieri F, Forlivesi C, Caselli E, Corinaldesi G. Narrow- (3.0 mm) versus standard-diameter (4.0 and 4.5 mm) implants for splinted partial fixed restoration of posterior mandibular and maxillary jaws: A 5-year retrospective cohort study. J Periodontol 2017;88:338–347.
67. Nevins M, Wang HL (eds). Implant Therapy: Clinical Approaches and Evidence of Success, ed 2. Batavia: Quintessence, 2019.
68. Nissan J, Gross O, Ghelfan O, Priel I, Gross M, Chaushu G. The effect of splinting implant-supported restorations on stress distribution of different crown-implant ratios and crown height spaces. J Oral Maxillofac Surg 2011;69:2990–2994.
69. Pjetursson BE, Brägger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clin Oral Implants Res. 2007;18(suppl 3):97–113.

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