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REVIEW ARTICLE

WILEY CLINICAL ORAL IMPLANTS RESEARCH

Survival rates of short dental implants (≤6 mm) compared with implants longer than 6 mm in posterior jaw areas: A meta-analysis

Panos Papaspyridakos[1] | **Andre De Souza**[1] | **Konstantinos Vazouras**[1] | **Hadi Gholami**[1] | **Sarah Pagni**[2] | **Hans-Peter Weber**[1]

[1]Department of Prosthodontics, Tufts University School of Dental Medicine, Boston, MA, USA

[2]Department of Public Health and Community Service, Tufts University School of Dental Medicine, Boston, MA, USA

Correspondence
Panos Papaspyridakos, Department of Prosthodontics, Tufts University School of Dental Medicine, 1 Kneeland Street, Boston, 02111, MA, USA.
Email: panpapaspyridakos@gmail.com

Abstract

Purpose: To systematically review randomized controlled clinical trials (RCTs) reporting on the long-term survival and failure rates, as well as the complications of short implants (≤6 mm) versus longer implants (>6 mm) in posterior jaw areas.

Materials and Methods: Electronic and manual searches were conducted to identify studies, specifically RCTs, reporting on short dental implants (≤6 mm) and their survival and complication rates compared with implants longer than 6 mm. Secondary outcomes analyzed were marginal bone loss and prosthesis survival rates.

Results: Ten RCTs fulfilled the inclusion criteria and featured a total of 637 short (≤6 mm) implants placed in 392 patients, while 653 standard implants (>6 mm) were inserted in 383 patients. The short implant survival rate ranged from 86.7% to 100%, whereas standard implant survival rate ranged from 95% to 100% with a follow-up from 1 to 5 years. The risk ratio (RR) for short implant failure compared to standard implants was 1.29 (95% CI: 0.67, 2.50, $p = 0.45$), demonstrating that overall, short implants presented higher risk of failure compared to longer implants. The heterogeneity test did not reach statistical significance ($p = 0.67$), suggesting low between-study heterogeneity. The prosthesis survival rates from the short implant groups ranged from 90% to 100% and from 95% to 100% for longer implant groups, respectively.

Conclusion: Short implants (≤6 mm) were found to have *higher variability* and *lower predictability* in survival rates compared to longer implants (>6 mm) after periods of 1–5 years in function. The mean survival rate was 96% (range: 86.7%–100%) for short implants, and 98% (range 95%–100%) for longer implants. Based on the quantity and quality of the evidence provided by 10 RCTs, short implants with ≤6 mm length should be carefully selected because they may present a greater risk for failure compared to implants longer than 6 mm.

KEYWORDS
dental implants, short dental implants

1 | INTRODUCTION

Implants are broadly used for oral rehabilitation in patients who are partially or completely edentulous (Gallucci et al., 2014). There are factors such as presence or absence of sufficient bone volume, keratinized mucosa, smoking habits, periodontal disease, and systemic conditions such as diabetes that can contribute to the long-term success and survival of dental implants.

Presence of adequate bone quality and quantity needs to be evaluated prior to surgical interventions for placing implants. Various procedures such as maxillary sinus floor elevation, bone grafting, guided bone regeneration, distraction osteogenesis, and vertical bone augmentation are being used to enhance bone width and height in atrophied ridges (Gulje et al., 2013). However, there are problems associated with these augmentation techniques such as high cost and treatment time, increased postoperative morbidity, and increased risk of complications (Esposito et al., 2010; Heitz-Mayfield, Needleman, Salvi & Pjetursson, 2014). Therefore, short implants (Atieh, Zadeh, Stanford, & Cooper, 2012), tilted implants (Maló, de Araújo Nobre, Lopes, Ferro, & Gravito, 2015; Maló, de Araujo Nobre, Lopes, Francischone, & Rigolizzo, 2012; Queridinha, Almeida, Felino, de Araújo Nobre, & Maló, 2016), zygoma, or pterygoid implants (Esposito & Worthington, 2013) have been proposed as alternatives to avoid bone augmentation for the accommodation of standard implants, which tends to have greater morbidity and requires longer healing times.

In the implant literature, various authors have defined "short dental implants" differently. Some consider 10 mm or less as being short, while others propose <8, <7, or <6 mm as truly short (Friberg, Jemt, & Lechkolm, 1991; Renouard & Nisand, 2006; Rossi et al., 2016). The survival of short dental implants has been a controversial topic. There have been studies where a lower survival rate has been associated with the use of short implants versus longer implants (Bahat, 1993). On the contrary, a number of systematic reviews and consensus documents have reported that the survival rates of short implants are comparable to those of conventional implants placed in pristine or grafted bone (Atieh et al., 2012; Fan, Li, Deng, Wu, & Zhang, 2017; Lemos, Ferro-Alves, Okamoto, Mendonça, & Pellizzer, 2016; Nisand, Picard, & Rocchietta, 2015; Sanz et al., 2015; Thoma, Zeltner, Hüsler, Hämmerle, & Jung, 2015; Thoma, Haas et al., 2015).

The aim of this study was to systematically review the long-term survival and failure rates, as well as complications of ≤6 mm short implants versus implants longer than 6 mm in posterior jaw areas based on evidence from randomized controlled clinical trials (RCTs).

2 | MATERIAL AND METHODS

A detailed protocol was followed according to the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) statement (Moher et al. 2009). The focused question of the search was in a PICO (Population, Intervention, Comparison, Outcomes) format as follows: "In patient with posterior dental implant restorations, do short implants (≤6 mm) compared to longer implants (>6 mm) demonstrate similar clinical and patient-based outcomes?" The project was registered with PROSPERO (CRD42016049610).

2.1 | Search strategy

An electronic MEDLINE (PubMed) and EMBASE search was performed for clinical studies, including articles published from January 1, 1990, up to June 30, 2017. The search was limited to the English language. The search strategy included the following word combinations: (partially edentulous patients OR posterior partially edentulous OR posterior partial edentulous OR posterior jaw OR posterior dental implant OR posterior implant OR dental implant) AND (short dental implant OR short implant OR reduced length implant) AND (dental implant OR regular implant OR Long implant OR regular length implant OR longer implant OR sinus floor elevation OR sinus lift OR osteotome OR Summers technique OR vertical augmentation OR vertical ridge augmentation OR nerve lateralization) AND (success OR complication OR survival OR Implant Survival OR implant failure OR implant loss OR implant complication OR prosthetic complication OR patient-centered outcome OR patient-based outcome OR peri-implant bone level OR peri-implant bone loss OR marginal bone level OR crestal bone level).

In addition to the electronic search, the bibliographies of all the full-text articles that were selected after title and abstract selection were manually searched. A reference manager software program (Endnote X7, Thompson Reuters) was used and the duplicates were discarded electronically.

2.2 | Inclusion criteria

- Randomized clinical trials.
- Partially edentulous subjects with implant restorations in the posterior mandible or maxilla.
- Implants with rough surfaces and ≤6 mm in length compared to implants ≥7 mm.
- The studies included were at least 10 patients.
- There was a follow-up of at least 1-year post loading.
- The studies included implant rehabilitation of partially edentulous posterior mandible or maxilla.

2.3 | Exclusion criteria

In vitro and preclinical studies, case reports or case series, prospective cohort or retrospective studies were not included. Studies were also not included in the review in case of insufficient information regarding number of patients, follow-up and/or criteria for "short implants." Multiple publications on the same patient population were discarded and only the one with the longest follow-up period included.

2.4 | Selection of studies

Two authors (HG and KV) independently screened the titles derived from this extensive search based on the inclusion criteria. In a subsequent manner, abstracts of all titles agreed on by both authors were obtained and screened for satisfying the inclusion criteria. If title and abstract did not provide sufficient information with regards to the inclusion criteria, the full text was obtained as well. Any disagreements at the above stages of the search were resolved by discussion. At last, the selection based on inclusion/exclusion criteria was made for the full-text articles. The finally selected studies were screened by the two reviewers (HG and KV) and double-checked. Any questions that came up were discussed within the group to achieve consensus.

2.5 | Data extraction and method of analysis

The two reviewers independently extracted the data of all included studies using data extraction tables. The total of extracted data was double-checked, and any questions that came up during the screening and the data extraction were discussed within the group.

The following information was extracted from the selected articles: author(s), study design, year of publication, study setting (university/private practice), number of patients, mean age, age range, drop-out/lost to follow-up, type of comparison (groups), implant design, length, diameter and surface, number of implants placed, number of implants per patient, area of placement, type of prosthesis, loading protocol, prosthesis retention system (screw-retained/cement-retained), follow-up, implant and prosthesis survival rates, marginal bone level, biologic, technical/mechanical complications and patient-centered outcomes.

The primary outcomes included survival rates of dental implants. Secondary outcomes were survival rates of prostheses, complication rates for implants and prostheses as well as radiographic bone levels.

2.6 | Quality assessment

The quality of the included studies was assessed by both reviewers (HG and KV) using the Cochrane Collaboration's tool for assessing risk of bias in randomized trials. Any disagreement was discussed until consensus was achieved.

2.7 | Statistical analysis

Implant survival was evaluated using a risk ratio (RR) with a 95% confidence interval. For studies in which neither the short nor the

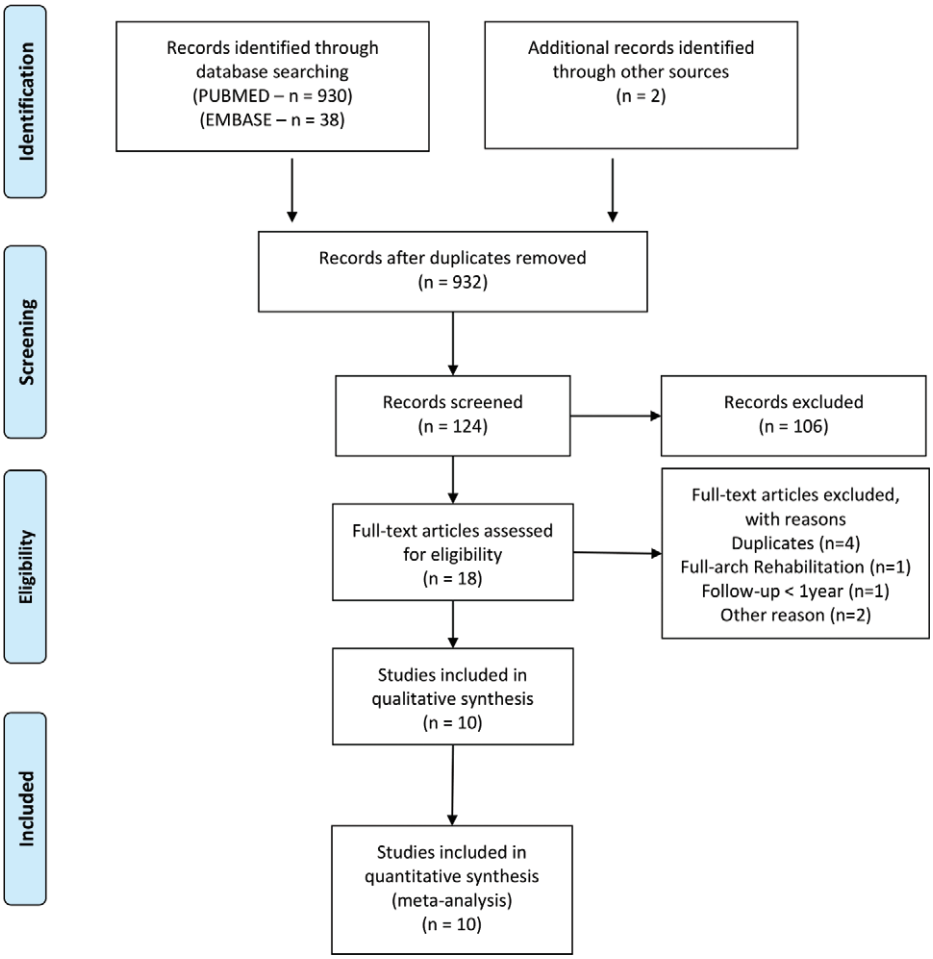

FIGURE 1 Search strategy flow chart

longer implants experienced any failures, a continuity correction was applied. A meta-analysis was performed using a fixed effects model with Mantel-Hansel methods. Mean bone loss was expressed as a weighted mean difference (WMD) and a 95% confidence interval. A meta-analysis was performed using a fixed effects model with inverse-variance methods. Heterogeneity was examined using Cochran's *Q*-statistic and the I^2 statistic. *p*-values < 0.05 were considered statistically significant. The analysis was performed with Stata version 13.1 (StataCorp LLC, College Station, TX).

3 | RESULTS

3.1 | Study characteristics

The electronic search identified 932 titles (Figure 1). After discussion, 808 titles were excluded and the number of finally obtained abstracts was 124. In a subsequent manner, 18 full-text articles were obtained, of which eight were excluded. At last, ten articles representing RCTs met the inclusion criteria and were included in the meta-analysis.

3.2 | Excluded studies

The reasons for excluding studies after the full text was obtained were as follows: four duplicate studies (Esposito, Pellegrino, Pistilli, & Felice, 2011; Esposito et al., 2015; Schincaglia et al., 2015; Thoma, Zeltner et al., 2015; Thoma, Haas et al., 2015), one study with a follow-up of <1 year (Zhang et al., 2017), one study not involving partially edentulous patients (Cannizzaro et al., 2015),one study including less than ten patients (Romeo, Storelli, Casano, Scanferla, & Botticelli, 2014) and one study with an insufficient number of ≤6 mm implants (Al-Hashedi, Taiyeb-Ali, & Yunus, 2016).

3.3 | Included studies

The ten studies that satisfied the inclusion criteria are presented in Table 1. Quality assessment of the included studies is summarized in Table 2. All studies were RCTs published between 2012 and 2017 and conducted at specialty clinics or/and in a university environment. Two studies had a split-mouth design (Esposito, Pistilli, Barausse, & Felice, 2014; Pistilli, Felice, Piattelli et al., 2013; Pistilli, Felice, Cannizzaro et al., 2013) where both treatment modalities were performed in all patients, while seven studies only had one treatment modality being performed in the involved patients in a random way. In one study (Rossi et al., 2016), one-third of the patients were treated with both treatment modalities, while the other two-thirds of patients only received one of the two options in a randomized assignment.

A total of 637 short implants (≤6 mm) were placed in 392 patients, while 653 implants with >6 mm length were inserted in 383 patients. In three studies (Bechara et al.,2016; Felice et al.,2015; Pohl et al.,2017) implants were placed only in the maxilla, whereas in the remaining six studies implants were placed in both jaws. Five studies had a 1-year follow-up (Felice et al., 2015, 2016; Gulje et al., 2013; Pistilli, Felice, Piattelli et al., 2013; Pistilli, Felice, Cannizzaro et al., 2013), four studies presented a 3-year follow-up (Bechara et al., 2016; Esposito et al., 2014; Pohl et al., 2017; Sahrmann et al., 2016), and only one study had a 5-year follow-up (Rossi et al., 2016). With regards to implant length, the short implant group included implant lengths of 4–6 mm with only one study reporting on 4 mm implants (Felice et al., 2016). All other studies included implants of 5 or 6 mm length or both. On the other hand, the control groups in all studies had a variety of implant lengths ranging from 8.5 to 15 mm. Two RCTs reported immediate implant placement as part of their studies (Bechara et al., 2016; Felice et al., 2016), one of them (Bechara et al., 2016) in both groups, the other only in the test group (Felice et al., 2016). Seven of 10 of the included studies reported one or more adjacent implants placed in each patient depending on the span of the edentulous site. When the edentulous area represented more than a single missing tooth, the restoration on multiple adjacent implants was always splinted. Only three studies (Pohl et al., 2017; Rossi et al., 2016; Sahrmann et al., 2016) reported exclusively on implant supported single crowns as the only treatment modality. At last, with regards to retention of restorations, four studies (Bechara et al., 2016; Felice et al., 2015; Pistilli, Felice, Piattelli et al.,2013; Pohl et al., 2017) mentioned combinations of screw- or cement-retained restorations. Three studies (Felice et al., 2016; Gulje et al., 2013; Sahrmann et al., 2016) included only screw-retained restorations while in the remaining three studies only cement-retained restorations were used (Esposito et al., 2014; Pistilli, Felice, Cannizzaro et al., 2013; Rossi et al., 2016).

3.4 | Implant survival rates

Overall, survival rates of short implants (≤6 mm) ranged from 86.7% to 100%, whereas the survival rates for longer implants (>6 mm) ranged from 95% to 100% with a follow-up from 1 to 5 years (Table 3). Two studies reported no implant failures for both groups (Felice et al., 2015; Pohl et al., 2017) during their respective follow-up periods. The study of Guljé et al. (2013) reported a 97% survival rate for the short implants group with two implant failures before and one failure after loading yet prior to the 1-year follow-up. The group with longer implants had a 99% survival rate with one implant lost after loading and prior to the one-year follow-up. In a split-mouth study design, Esposito et al. (2014) found a 92% survival rate for short implants and 97% for longer implants placed in areas previously submitted to vertical augmentation, either with interpositional block grafts or maxillary sinus augmentation depending on indication and anatomic location. Similar to that, Rossi et al. (2016) in a 5-year follow-up study reported lower survival rates for short implants (86.7%) compared to longer implants (96.7%). Some studies reported a minimal difference or an even superior survival rate of short implants compared to longer implants (Bechara et al., 2016; Felice et al., 2016; Pistilli, Felice, Piattelli et al., 2013; Pistilli, Felice, Cannizzaro et al., 2013). In a 3-year follow-up study, Sahrmann et al. (2016) reported 98% survival

TABLE 1 Study and patient characteristics of the included studies [In PDF format, this table is best viewed in two-page mode]

Author/Year	Study design	Number of patients	Number of implants	Number of prostheses	Jaw	Follow-up
Gulje et al. (2013)	RCT	Short: 49 Long: 46	Short: 107 Long: 101	Short: 47 Long: 46	Max/Mand	1 year
Pistilli, Felice, Piattelli et al. (2013)	RCT	Short: 40 Long: 40	Short: 68 Long: 68	Short: 40 Long: 40	Max/Mand	1 year
Pistilli, Felice, Cannizzaro et al. (2013)	RCT Split-mouth	Short: 20 Long: 20	Short: 80 Long: 91	Short: 40 Long: 40	Max/Mand	1 year
Esposito et al. (2014)	RCT Split-mouth	Short: 30 Long: 30	Short: 60 Long: 68	Short: 30 Long: 30	Max/Mand	3 years
Rossi et al. (2016)	RCT	Short/ Long: 45	Short: 30 Long: 30	Short: 29 Long: 30	Max/Mand	5 years
Felice et al. (2015)	RCT	Short: 10 Long: 10	Short: 16 Long: 18	Short: 16 Long: 18	Max	1 year
Felice et al. (2016)	RCT	Short: 75 Long: 75	Short: 124 Long: 116	Short: 75 Long: 73	Max/Mand	1 year
Bechara et al. (2016)	RCT	Short: 33 Long: 20	Short: 45 Long: 45	Short: 35 Long: 33	Max	3 years
Sahrmann et al. (2016)	RCT	Short: 40 Long: 38	Short: 40 Long: 38	Short: 40 Long: 38	Max/Mand	3 years
Pohl et al. (2017)	RCT	Short: 50 Long: 51	Short: 67 Long: 70	Short: 61 Long: 68	Max	3 years

RCT, randomized clinical trial; SC, single crown; FDP, fixed dental prosthesis, SR, screw-retained; CR, cemented-retained; N/A, not applicable.

rate for short and 100% longer implants placed in pristine bone. Our meta-analysis revealed a risk ratio (RR) of 1.29 (95% CI: 0.67, 2.50, $p = 0.45$), for short implant failure compared to longer implants. This means that short implants (≤6 mm) would present a 29% higher risk of failure compared to longer implants. The forest plot with included studies is shown in Figure 2. The heterogeneity test did not reach statistical significance ($p = 0.67$), suggesting low between-study heterogeneity.

3.5 | Marginal bone levels

All studies included in the systematic review reported mean marginal bone levels (MBL) for both implant groups. One study did not report the standard deviation, and instead listed the confidence interval. A meta-analysis for MBL was not performed due the high heterogeneity of MBL between the studies. The mean MBL values of the short implant group ranged from +0.06 to −1.22 mm at the respective follow-up examination. The correspondent values for the longer implants varied from +0.02 to −1.54 mm. Most of the studies reported no statistically significant differences between groups regarding MBL (Felice et al., 2015, 2016; Gulje et al., 2013; Pohl et al., 2017; Sahrmann et al., 2016). On the contrary, four studies found statistically significant differences between groups. However, these differences ranged only from 0.02 to 0.32 mm (Bechara et al., 2016; Esposito et al., 2014; Pistilli, Felice, Piattelli et al., 2013; Rossi et al., 2016).

3.6 | Biologic complications

Most of the studies reported biologic complications related to intra-surgical and post-surgical events (Bechara et al., 2016; Esposito et al., 2014; Felice et al., 2016; Pistilli, Felice, Piattelli et al., 2013; Pistilli, Felice, Cannizzaro et al., 2013; Pohl et al., 2017). Overall, the percentage of patients that experienced biologic complications ranged from 0% to 26% in the short implant group and from 0% to 90% in the longer implant group. Two studies reported that there were no biologic complications (Felice et al., 2016; Sahrmann et al., 2016), while two studies did not clearly assess this variable (Gulje et al., 2013; Rossi et al., 2016). Most of the complications were related to the immediate post-operative period, and included transient paresthesia of the lower lip, Schneiderian membrane perforation, and mandibular graft infection.

3.7 | Prosthesis survival rates

Overall, most of the studies reported high prosthesis survival rates. They varied from 90% to 100% for the short implant group, and from 95% to 100% for the longer implant group. Seven studies reported no prosthesis failures for both groups (Bechara et al., 2016; Felice et al., 2015; Gulje et al., 2013; Pistilli, Felice, Cannizzaro et al., 2013; Pohl et al., 2017; Rossi et al., 2016; Sahrmann et al., 2016). In one study the prosthesis survival rate was not clearly reported (Felice et al., 2015).

TABLE 1 (additional columns)

Test and Control Group (mm long × mm wide implants)	Placement protocol	Prosthesis design	Prosthesis retention	Implant system	Setting
Test: 6 × 4 Control: 11 × 4	Healed sites	Splinted	SR	Osseospeed, Astra Tech	Private practice and university clinic
Test: 5 × 5 Control: 10 × 5	Healed sites	SCs or Splinted	SR or CR	MegaGen	University clinic
Test: 6 × 4 Control: (10, 11.5, 13 or 15) × 4	Healed sites/grafted sites	SCs or Splinted	CR	Southern	Private practice and university clinic
Test: 5 × 6 Control: (7, 8.5, 10 or 11.5 or 13) × 4	Healed sites	SC or Splinted	CR	Rescue MegaGen (test), EZ Plus MegaGen (control)	Private practice and university clinic
Test: 6 × 4.1 Control: 10 × 4.1	N/A	SCs	CR	Straumann	Private practice
Test: (5 or 6) × 5 Control: 10 × 5	Healed sites	SCs or Splinted	SR or CR	Osseotite II- Zimmer Biomet (test) Zimmer Biomet (control)	Private practice and university clinic
Test: 4 × 4 Control: (8.5 or longer) × 4	Healed sites or immediate placement	SC or Splinted	SR	Global D (TwinKon Universal SA2)	Private practice and university clinic
Test: 6 × (4–8) Control: (10, 11.5, 13 or 15) × (4–8)	Healed sites or immediate placement	SCs or FDPs	SR or CR	MegaGen	University clinic
Test: 6 × 4.1 Control: 10 × 4.1	Healed sites	SCs	SR	Straumann	University clinic
Test: 6 × 4 Control: (11, 13 or 15) × 4	Healed sites	SCs	SR or CR	Osseospeed, Astra Tech	Private practice and university clinic

4 | DISCUSSION

The purpose of the present systematic review and meta-analysis was to assess the long-term survival and failure rates of short implants (≤6 mm length) versus longer implants (>6 mm length) in augmented or non-augmented bone and reported in RCTs. Secondary outcomes included the assessment of prosthesis survival, clinical complications as well as peri-implant bone level behavior.

The findings of the present study based on the included 10 RCTs indicate that survival rates of short implants (≤6 mm) ranged from 86.7% to 100%, whereas the survival rates for longer implants (>6 mm) were 95% to 100% with a follow-up from 1 to 5 years. The implant survival of short implants was nominally inferior to that of the longer implants. The risk ratio (RR) for short implant failure compared to longer implants (>6 mm) was 1. 29 (95% CI: 0.67, 2.50, $p = 0.45$)), demonstrating that overall, short implants presented a 29% higher risk of failure compared to longer implants. The heterogeneity test did not reach statistical significance ($p = 0.61$), suggesting low between-study heterogeneity. A recently published RCT with 5-year follow-up compared outcomes with 6 mm short vs 10 mm implants for restoration of single tooth gaps (Naenni et al., 2018). The authors reported implant survival rates of 91% (95% confidence interval: 0.836 to 0.998) for the 6-mm group and 100% for the 10-mm group ($p = 0.036$). It has to be highlighted that this RCT was a continuation of an RCT with 3-year results (Sahrmann et al., 2016), which is part of the present meta-analysis. The 5-year study was not included, because it was published after the cut-off date for inclusion of studies in preparation of the systematic reviews for the 2018 ITI Consensus Conference. A time-dependent reduction in the survival rate of single standing 6 mm short implants in the posterior area is clearly demonstrated.

The results of this systematic review are in accordance with previous similar publications. Thoma, Zeltner et al. (2015) and Thoma, Haas et al. (2015) in a systematic review of RCTs reported higher morbidity with longer implants and extensive grafting in the posterior maxilla compared with short implants. Fan et al. (2017), also in a systematic review of RCTs, focused on the posterior maxilla and compared sinus grafting and longer implants vs short implants. The authors reported similar outcomes for both treatment approaches. Lemos et al. (2016) included both posterior maxillae and mandibles in their meta-analysis and found that short implants exhibited at greater risk of failure compared with longer implants. Nisand et al. (2015) reported similar findings when comparing outcomes for the posterior maxilla and mandible and the options of vertical GBR combined with longer implants vs short implants.

All aforementioned reviews defined short implants as 8 mm or less in length. Conversely, the present review defined short implants as implants of 6 mm length or less. The uniqueness of the present review and meta-analysis lies in the fact that only truly short implants of ≤6 mm in length were compared to longer implants. This distinguishes

TABLE 2 Risk of bias assessment for the included studies [In PDF format, this table is best viewed in two-page mode]

Author (Year of publication)	Adequate sequence generation (selection bias)	Remark	Allocation concealment (selection bias)	Remark	Blinding of participants and personnel (performance bias)	Remark	Blinding of outcome assessment (detection bias)
Pistilli, Felice, Piattelli et al. (2013)	Low risk	A computer-generated restricted random list was created.	Low risk	The information of treatment allocation was enclosed in a sequentially numbered, identical, opaque sealed envelope.	High risk	1. Patients had the right to know what treatment they were receiving. 2. Surgeons had to know the treatment they would provide.	Low risk
Rossi et al. (2016)	Unclear risk	No information provided	Low risk	Sealed numbered envelopes were prepared from the monitor, patients with two sites were allowed to be included in the study	Low risk	1. Patients had the right to know what treatment they were receiving. 2. Surgeons had to know the treatment they would provide.	High risk
Felice et al. (2015)	Low risk	Two computer-generated restricted randomization lists were created. A blocked randomization was applied to include 10 patients in each treatment group.	Low risk	The randomized codes were enclosed in sequentially numbered, identical, opaque, sealed envelopes. Envelopes were opened sequentially after eligible patients were recruited and signed the consent form.	High risk	1. Patients had the right to know what treatment they were receiving. 2. Surgeons had to know the treatment they would provide.	Low risk
Pistilli, Felice, Cannizzaro et al. (2013)	Low risk	A computer-generated restricted random list was created	Low risk	The information of treatment allocation was enclosed in a sequentially numbered, identical, opaque sealed envelope.	High risk	1. Patients had the right to know what treatment they were receiving. 2. Surgeons had to know the treatment they would provide.	Low risk
Bechara et al. (2016)	Unclear risk	Details of random sequence generation provided. Inconsistencies exit as to selection of patients. Eight immediate implants were placed only on the Test group.	Unclear risk	The information of treatment allocation was enclosed in a sequentially numbered, identical, opaque sealed envelope. Inconsistencies exit as to selection of patients.	High risk	1. Patients had the right to know what treatment they were receiving. 2. Surgeons had to know the treatment they would provide.	Low risk
Esposito et al. (2014)	Low risk	A computer-generated restricted random list was created	Low risk	The information of treatment allocation was enclosed in a sequentially numbered, identical, opaque sealed envelope.	High risk	1. Patients had the right to know what treatment they were receiving. 2. Surgeons had to know the treatment they would provide.	High risk
Felice et al. (2016)	Low risk	A computer-generated restricted randomization list was created.	Low risk	The information of treatment allocation was enclosed in a sequentially numbered, identical, opaque sealed envelope.	High risk	1. Patients had the right to know what treatment they were receiving. 2. Surgeons had to know the treatment they would provide.	High risk
Gulje et al. (2013)	Low risk	Randomization was performed using a block randomization sequence.	Unclear risk	The information of treatment allocation was enclosed in a sealed envelope.	High risk	1. Patients had the right to know what treatment they were receiving. 2. Surgeons had to know the treatment they would provide.	High risk
Pohl et al. (2017)	Low risk	A block randomization sequence was used.	Low risk	The randomization was performed at the day of surgery following flap elevation using a sealed envelope.	High risk	1. Patients had the right to know what treatment they were receiving. 2. Surgeons had to know the treatment they would provide.	High risk

TABLE 2 (additional columns)

Remark	Incomplete outcome data (attrition bias)	Remark	Selective reporting (reporting bias)	Remark	Free of other sources of bias	Remark	Overall risk of bias
Two dentists not involved in the treatment of patients performed all clinical measurements without knowing group allocation. Also one dental student not involved in the treatment of all patients performed all radiographic assessments without knowing group allocation. All data analysis was carried out by a biostatistician without knowing the group codes.	Low risk	Drop-out/ Lost to follow information provided.	Low risk	All pre-specified outcomes were reported.	No	1. Reconstructions would be splinted if more than one implants were placed. 2. No sample size calculation was performed.	Low
No information provided	Low risk	Drop-out/ Lost to follow infirmation provided.	Low risk	All pre-specified outcomes were reported.	Yes	All implants were restored with single crowns.	Unclear
One dentist at each center, not involved in the treatment of the patients assessed implant stability and patient satisfaction. One clinician performed radiographic assessments without knowing group allocation. All data analysis was carried out by a clinician with expertise in biostatistics without knowing the group codes.	Low risk	Drop-out/ Lost to follow infirmation provided.	Low risk	All pre-specified outcomes were reported.	No	1. No information if the clinician who performed radiographic assessments was involved in patient treatment. 2. Sinus lift sites could be identified on radiographs	Low
Two dentists not involved in the treatment of patients performed all clinical measurements without knowing group allocation. Also one dental student not involved in the treatment of all patients performed all radiographic assessments without knowing group allocation. All data analysis was carried out by a biostatistician without knowing the group codes.	Low risk	Drop-out/ Lost to follow infirmation provided.	Low risk	All pre-specified outcomes were reported.	No	1. Reconstructions would be splinted if more than one implants were placed. 2. All clinical measurements and radiographic assessments were performed without knowledge of group allocation, however mandibular augmented sites could be easily identified because of the different implant length.	Low
An experienced, calibrated, independent examiner performed a careful clinical examination of the fixtures, peri-implant tissues, and prostheses.	Low risk	Drop-out/ Lost to follow infirmation provided.	Low risk	All pre-specified outcomes were reported.	No	1. Study reports 0% prosthetic complications in 3 years in both groups. 2. Immediate implants were placed only on test group flaplessly with no information of grafting materials being used.	Unclear
One dentist not involved in treatment performed all measurements without knowing group allocation, BUT augmented sites could be easily identified both clinically (different diameters) and radiographically (different opacity). No blinding was possible.	Low risk	Drop-out/ Lost to follow infirmation provided.	Low risk	All pre-specified outcomes were reported.	No	1. Reason for not including two patients in the study despite fulfilling criteria was not mentioned. 2. Reconstructions would be splinted if more than one implants were placed	Unclear
Two clinicians not involved in patient treatment performed clinical measurements without knowing group allocation. One clinician not involved in patient treatment performed all radiographic assessments but the different implant lengths could be easily identified on radiographs. A clinician analyzed the data, but there is no information as to if she was involved in patient treatment.	Low risk	Drop-out/ Lost to follow infirmation provided.	Low risk	All pre-specified outcomes were reported.	No	1. Reconstructions would be splinted if more than one implants were placed. 2. No sample size calculation was performed.	Unclear
1. At each center, only one clinician performed the surgery and clinical observations. 2. Radiographic measurements were made by an experienced and independent radiologist.	Low risk	Drop-out/ Lost to follow infirmation provided.	Low risk	All pre-specified outcomes were reported.	No	1. No information if the sealed envelope was opaque and sequentially numbered. 2. Two to three implants were placed at each site and restorations were always splinted.	Unclear
The use of independent assessor is not mentioned.	Low risk	Drop-out/ Lost to follow infirmation provided.	Low risk	All pre-specified outcomes were reported.	No	1. The study did not address which clinicians carried out the treatments. 2. Reconstructions were not splinted.	Unclear

TABLE 3 Summary of main outcomes of the included studies

Author/year	Implant survival rate, %	Prosthesis survival rate	Mean marginal bone loss (Mean and *SD*)	Biologic complications	Technical complications
Gulje et al. (2013)	Short: 97 Long: 99	Short: 100 Long: 100	Short: 0.06 (0.27) Long: 0.02 (0.6)	N/A	Short: 4 Long: 7
Pistilli, Felice, Piattelli et al. (2013)	Short: 98.5 Long: 97	Short: 97.5 Long: 95	Short: 0.9 Long: 1.08	Short: 20 Long: 56	N/A
Pistilli, Felice, Cannizzaro et al. (2013)	Short: 100 Long: 96.7	Short: 100 Long: 100	Short: 1.05 Long: 1.07	Short: 0 Long: 60	Short: 0 Long: 0
Esposito et al. (2014)	Short: 92 Long: 97	Short: 90 Long: 100	Short: 1.22 (0.49) Long: 1.54 (0.44)	Short: 26 Long: 36	Short: 0 Long: 0
Rossi et al. (2016)	Short: 86.7 Long: 96.7	Short: 100 Long: 100	Short: 0.14 Long: 0.18	N/A	Short: 0 Long: 0
Felice et al. (2015)	Short: 100 Long: 100	Short: 100 Long: 100	Short: 0.70 (0.19) Long: 0.87 (0.21)	Short: 0 Long: 0	Short: 0 Long: 0
Felice et al. (2016)	Short: 96 Long: 97	N/A	Short: 0.53 (0.23) Long: 0.56 (0.33)	Short: 4 Long: 2.6	N/A
Bechara et al. (2016)	Short: 100 Long: 95	Short: 100 Long: 100	Short: 0.20 (0.12) Long: 0.27 (0.14)	Short: 0 Long: 90	Short: 0 Long: 0
Sahrmann et al. (2016)	Short: 98 Long: 100	Short: 100 Long: 100	Short: 0.19 (0.62) Long: 0.33 (0.71)	Short: 0 Long: 0	Short: 3 Long: 0
Pohl et al. (2017)	Short: 100 Long: 100	Short: 100 Long: 100	Short: 0.44 (0.56) Long: 0.43 (0.58)	Short: 4[a] Long: 18[a]	Short: 10 Long: 3

[a]Report from the 1-year follow-up study of Thoma, Zeltner et al. (2015) and Thoma, Haas et al. (2015). N/A, not applicable.

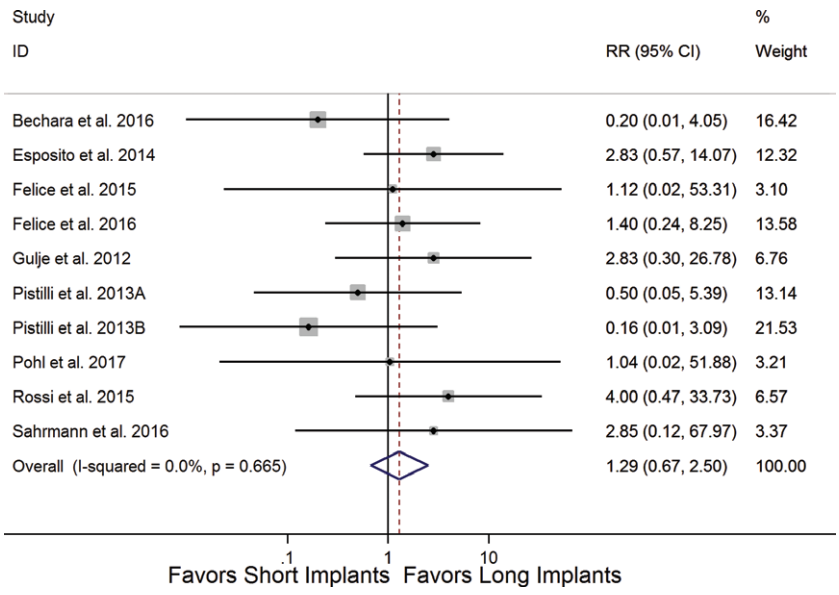

FIGURE 2 Forest plot with included studies. Risk ratios, with continuity correction, by study year

the obtained results from numerous other studies, in which short implants of 8 mm length were assessed and found to perform similarly to those longer than 8 mm (Gallucci et al., 2014; Thoma, Zeltner et al., 2015; Thoma, Haas et al., 2015). To accommodate the highest level of evidence (Moher et al. 2009), only RCTs were included in the present analysis, which adds additional strength to the findings.

Nevertheless, caution is advised when interpreting the results due to a variety of reasons. Two studies (Bechara et al., 2016; Felice et al., 2016) included immediate implant placement in their protocol, differently than the other included studies that performed implant placement only in healed sites. The implants in these two studies, however, were loaded 4 months after surgery, at which stage bone-graft healing was already advanced and the different placement protocols (grafted vs. non-grafted sites) most likely did not negatively affect the implant or prosthesis survival. Limitations also include that even though RCTs were included in the analysis, the risk of bias was difficult to assess in several studies. One study (Esposito et al., 2014) reported that one dentist not involved in the

treatment performed all measurements without knowing group allocation. However, augmented sites could easily be identified both clinically (different diameters) and radiographically (different opacity), possibly indicating a higher risk of reporting bias. Another study (Bechara et al.,2016) featured inconsistencies with regards to patient selection and procedure standardization. For instance, a total of eight implants were immediately placed. However, this modality was only used in the test group (short implant group) without any information about bone grafting procedures in these sites involving immediate implant placement. This may have increased the risk of selection bias. In two studies (Gulje et al., 2013; Pohl et al., 2017) blinding was unclear, whereas in another study (Esposito et al.,2014) different implant diameters were used in the two groups, making blinding impossible and introducing the risk of bias. It also has to be considered that a greater implant diameter combined with a given implant length will increase the overall implant surface available for osseointegration making a true comparison of the performance of short and longer implants difficult. However, eight of the 10 RCTs included in this systematic review compared short and long implants with the same diameters.

Most of the included RCTs were conducted in university settings by the same two research groups and not in private practices. A previous study showed that implant success rates for single crowns and FDPs in general dental practices may be lower than those achieved in well-controlled university or specialty settings (Papaspyridakos, 2015).In addition, most of the included studies revealed limited or no information on the restorative aspects and protocols followed during the planning and prosthodontic treatment phases. The risk of bias assessment with the Cochrane's collaboration tool led to an unclear risk of bias with inadequate reporting of restorative outcomes and/or encountered complications.

Another essential component of the success of dental implant treatment is the reporting of complications and patient satisfaction, along with the implant, peri-implant and prosthodontic outcomes (Papaspyridakos, Chen, Singh, Weber, & Gallucci, 2012). These aspects were not reported in most included studies.

At last, the available evidence in the present review should further be interpreted with caution as four RCTs had a limited sample size ranging from 15 to 40 implants per group, had a limited follow-up time, and represented treatments that were performed predominantly by only two research groups.

Regarding the question about true clinical indications for short implants, posterior partial edentulism in the mandible and maxilla will be the most frequently mentioned ones. While bone augmentation via sinus floor elevation can be predictably achieved in the atrophic posterior maxilla allowing the placement of longer implants. Nevertheless, short dental implants may still be considered a valid alternative with less morbidity and fewer biologic complications based on the findings of this systematic review and meta-analysis.

In the atrophic posterior mandible, vertical bone augmentation procedures are more challenging and less predictable (Kuchler & von Arx, 2014). In such cases, the use of short implants may present the preferable alternative based on the results of this review. The survival rate of short implants in the posterior edentulous mandible is high, based on the included studies.

Even though crown-to-implant ratio seems not to be correlated with crestal bone loss or risk of failure of short implants (Garaicoa-Pazmiño et al., 2014), a comment must be made about the advantage of splinting short dental implants via the final fixed prosthesis. Splinting of short implants in indications where two or more adjacent implants are present, combined with providing the patient with a mutually protected or canine guided occlusion will reduce the mechanical forces on the individual implants and components (Kinsel & Lin, 2009; Taylor, Wiens, & Carr, 2005). Splinting may also reduce the incidence of screw loosening/fracture, porcelain chipping, and implant overload.

Technical/mechanical complications were only reported in three studies (Gulje et al., 2013; Pohl et al., 2017; Sahrmann et al., 2016). Gulje et al. (2013), reported a total of 11 complications: four in the short implant group (three abutment screw loosening and one provisional prosthesis fracture), and seven in the longer implant group (three abutment screw loosening, one provisional prosthesis fracture, and three FDP loosening). Pohl et al. (2017) reported 10 complications in the short implant group (eight events of abutment screw loosening and two incidences of crown de-cementation,) and three complications in the group with longer implants (two incidences with loosening of abutment screws and one crown de-cementation). Sahrmann et al. (2016) reported a 3.8% rate of technical complication (all screw loosening) in the short implant group and no such complications in the longer implant group. Other studies did not find any technical complications (Bechara et al., 2016; Esposito et al., 2014; Felice et al., 2015; Pistilli, Felice, Cannizzaro et al., 2013; Rossi et al., 2016) or did not report this outcome (Felice et al., 2016; Pistilli, Felice, Piattelli et al., 2013).

5 | CLINICAL IMPLICATIONS

Clinical implications from the findings of this meta-analysis include the possibility of using short implants as a valid alternative in selected cases where bone quantity precludes the use of longer implants, which would require potentially extensive bone grafting that increases invasiveness as well as morbidity of the treatment and treatment time. Especially for the posterior mandible where vertical ridge augmentation tends to be a challenging procedure with guarded predictability, the use of short implants seems to offer an excellent alternative. Splinting of multiple short implants appears to be recommended based on the information retrieved from most of the included studies for a better distribution of occlusal forces on the entire implant-prosthodontic complex.

6 | FUTURE RESEARCH

Suggestions for further research include the demand for more longitudinal studies with longer follow-up times on short implants and better standardization of study protocols, especially, important would be the comparison of long-term performance of single versus

splinted implants in posterior jaw areas. In addition, studies would be desirable that compare financial impact, treatment effectiveness, and patient satisfaction for the treatment alternatives of ridge augmentation and placement of longer implants versus the use of short implants without the need for grafting.

7 | CONCLUSIONS

Within the limitations of the present analysis and review, the following conclusions may be drawn:

1. Short implants (≤6 mm) were found to have *higher variability* and *lower predictability* in survival rates compared to longer implants (>6 mm) after periods of 1 to 5 years in function. The mean survival rate was 96% (range: 86.7%–100%) for short implants, and 98% (range 95%–100%) for longer implants.
2. The risk ratio (RR) for short implant failure compared to longer implants was 1.29 (95% CI: 0.67, 2.50, $p = 0.45$), demonstrating that short implants (≤6 mm) demonstrated a 29% higher risk of failure to implants longer than 6 mm.
3. Prosthesis survival for short and longer implants following a period of 1 to 5 years was similarly high. The mean prosthesis survival rate was 98.6% (range: 90%–100%) for short implants, and 99.5% (range: 95%–100%) for the longer implants.
4. Based on the available evidence from RCTs, indications for short implants with ≤6 mm length should be carefully selected because they may present a greater risk for failure over time compared to implants longer than 6 mm.

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CONFLICT OF INTEREST

No conflicts declared.

ORCID

Panos Papaspyridakos http://orcid.org/0000-0002-8790-2896

Andre Souza http://orcid.org/0000-0002-3835-7262

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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