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SYSTEMATIC REVIEW

Esposito et al short versus longer implants in augmented mandibles

Short implants versus longer implants in vertically augmented atrophic mandibles: A systematic review of randomised controlled trials with a 5-year post-loading follow-up

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ABSTRACT

Purpose: To compare the clinical outcome of fixed prostheses supported by 4 to 8 mm-long implants with prostheses supported by longer implants placed in vertically augmented atrophic mandibles after a follow-up of 5 years in function.

Materials and methods: The Cochrane Central Register of Controlled Trials (CENTRAL) and MEDLINE were searched up to 1st September 2018 for randomised controlled trials (RCTs) with a follow up of at least 5 years in function comparing fixed prostheses supported by 4 to 8 mm-long implants with prostheses supported by longer implants placed in vertically augmented atrophic mandibles. Outcome measures were prosthesis failure, implant failures, augmentation procedure failures, complications, and peri-implant marginal bone level changes. Screening of eligible studies, assessment of the risk of bias and data extraction were conducted in duplicate and independently by two review authors. The statistical unit of the analysis was the prosthesis. Results were expressed as random-effects models using mean differences for continuous outcomes and risk ratios (RR) for dichotomous outcomes with 95% confidence intervals (CIs).

Results: Four eligible RCTs which included originally 135 patients were included. Two RCTs had a parallel group design and two a split-mouth design. Short implants were 5 to 6.6 mm long and were compared with longer implants placed in posterior mandibles

augmented with interpositional blocks of bone substitutes. All trials were judged at unclear risk of bias. Twelve (14%) bone augmentation procedures failed to achieve the planned bone height to allow placement of implants with the planned length. Five years after loading 28 patients (21%) dropped from the four RCTs. There were no differences for patients having prosthesis (RR = 1.46; 95% CI 0.52 to 4.09; P = 0.47; Chi² = 1.35, df = 3 (P = 0.72); I² = 0%) or implant (RR = 1; 95% CI 0.31 to 3.21; P = 1.00; Chi² = 0, df = 3 (P = 1.00); I² = 0%) failures between the two interventions, but there were more patients experiencing complications (RR = 4.72; 95% CI 2.43 to 9.17; P < 0.00001; Chi² = 3.02, df = 3 (P = 0.39); I² = 0%) and peri-implant marginal bone loss (mean difference = 0.60 mm; 95% CI 0.36 to 0.83; P < 0.00001; Chi² = 5.47, df = 3 (P = 0.14); I² = 45%) at longer implants in augmented bone.

Conclusions: Five years after loading, prosthetic and implants failures were similar between the two interventions, but complications and peri-implant marginal bone loss were higher and more severe at longer implants placed in vertically augmented mandibles. Larger trials and longer follow-ups up to 10 years after loading are needed to confirm or reject the present preliminary findings. However in the meantime short implants could be the preferable option.

Conflict-of-interest statement: Several authors of this review were also authors of the included original trials, however risk of bias assessment was done in duplicate by two authors not involved in the conduction of the original trials. This review was self-funded.

INTRODUCTION

Often in atrophic jaws it is not possible to place dental implants of “adequate length” because there is less than 8 mm of residual vertical bone height. Clinicians are faced with the dilemma whether to augment the bone or to place short implants having an intra-bony length of 8 mm or less(1). In old studies 7 mm-long or shorter implants have been associated with decreased success rates when compared to longer implants(2). However, this comparison is inappropriate because when adequate amounts of bone are available dentists tend to place longer implants. In absence of adequate bone height the outcome of short implants should be compared with those of longer implants placed in augmented bone. Various techniques are currently used to augment the bone, though just a few of these techniques have been evaluated in randomised controlled trials (RCTs)(3-6). Augmentation procedures are more technically demanding, therefore require skilful operators, can be associated with significant postoperative morbidity and complications, can be more expensive and may require longer times (up to 1 year) before patients are able to chew on their implant-supported prostheses(3-6). Short implants could be a simpler, cheaper and faster alternative if they could provide similar clinical outcomes to longer implants placed in augmented bone. There are some comparative studies comparing short implants with longer implants in augmented bone in a reliable way, suggesting that 4.0 to 8.5 mm long implants can be a good alternative to augmentation procedures(7-15), however longer follow-ups are definitively needed to validate the long-term outcomes of these procedures, since very little is actually known about the long-term prognosis of prostheses supported by short implants.

A few systematic reviews(3, 4, 16-19) evaluating the efficacy of short implants in comparison to longer implants placed in augmented bone, have been published over the

years but so far the follow-ups of the included trials was too short to draw reliable conclusions. It was therefore decided to compile this rigorous systematic review of RCTs focussing on the outcomes of mandibular prostheses supported by short implants (4 to 8 mm long) in comparison of similar prostheses supported by longer implants in vertically augmented mandibles with a follow-ups of 5 years in functions. Longer follow-ups are desirable but at the moment not yet available. It was decided to focus on the rehabilitation of atrophic mandibles only since their rehabilitations is clinically more challenging than those of the maxilla, especially in terms of vertical bone augmentations to allow the placement of longer implants. May be that especially in atrophic mandibles short implants could be an interesting treatment option.

The aim of this systematic review was to evaluate RCTs comparing the outcomes of prosthesis supported by mandibular short implants (4 to 8 mm-long) with similar prostheses supported by longer implants in purposely vertically augmented mandibles. This review was compiled following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (<http://www.prisma-statement.org/>) for improving the reporting of systematic reviews and meta-analyses.

MATERIALS AND METHODS

Criteria for considering studies for this review

All RCTs with a follow up of 5 years after loading of osseointegrated dental implants comparing fixed mandibular prostheses supported by short implants (4 to 8 mm-long) with longer implants placed in vertically augmented bone according to any bone type augmentation procedure (onlay, inlay or guided bone regeneration) in patients with

atrophic mandibles. Only the 5-year after loading time point was considered in the present review. Longer follow-up were not considered since not existing yet.

Outcomes measures were:

- Graft failure: when the vertical bone augmentation procedure failed to obtain sufficient bone to place long implants of the planned length. This outcome measure can be applied only at longer implant in augmented bone.
- Prosthesis failure: planned prosthesis which could not be placed because of implant failure(s), loss of the prosthesis secondary to implant failure(s) and replacement of a definitive prosthesis for any reason.
- Implant failure: implant mobility and removal of stable implants dictated by progressive marginal bone loss or infection (biological failures). Biological failures were grouped as early (failure to establish osseointegration) and late failures (failure to maintain the established osseointegration). Implant mobility could be assessed manually or with instruments such as Periotest (Siemens AG, Bensheim, Germany) or resonance frequency (Osstell, Integration Diagnostics, Göteborg, Sweden). Mechanical complications (e.g. implant fracture or deformation of the implant abutment connection) rendering the implant unusable also accounted as implant failures.
- Any complications at the implant or donor site (e.g. infection, nerve injury, haemorrhage, prosthesis loosening or fractures, etc.).
- Peri-implant marginal bone level changes over time evaluated on periapical radiographs taken with the paralleling technique, having as baseline implant placement.

Search strategy for identification of studies

For the identification of studies included or considered for this review the Cochrane Central Register of Controlled Trials (CENTRAL) and MEDLINE (1950 to 1st September 2018) were searched using the search strategy as presented in Table 1.

There were no language restrictions. All the authors of the identified RCTs were contacted, the bibliographies of all identified RCTs and relevant review articles were checked, and personal contacts were used in an attempt to identify unpublished or ongoing RCTs.

Study selection and data extraction

The titles and abstracts (when available) of all reports identified through the electronic searches were scanned independently by two review authors (Dr Carlo Barausse and Dr Roberta Gasparro). For studies appearing to meet the inclusion criteria, or for which there were insufficient data in the title and abstract to make a clear decision, the full report was obtained. The full reports obtained from all the electronic and other methods of searching were assessed independently by two review authors (Dr Carlo Barausse and Dr Roberta Gasparro) to establish whether the studies met the inclusion criteria or not. Disagreements were resolved by discussion. Where resolution was not possible, a third review author (Dr Marco Esposito) was consulted. All studies meeting the inclusion criteria then underwent risk of bias assessment and data extraction. Studies rejected at this or subsequent stages were to be recorded in the table of excluded studies, and reasons for exclusion recorded.

Data were extracted by two review authors (Dr Marco Esposito and Dr Jacopo Buti) independently using specially designed data extraction forms. The data extraction

forms were piloted on several papers and modified as required before use. Disagreements were resolved by discussion. All authors were to be contacted for clarification or missing information. Data were excluded until further clarification was available if agreement could not be reached. For each trial the following data were recorded: year of publication, country of origin and source of study funding; details of the participants including demographic characteristics; details on the type of intervention; details of the outcomes reported, including method of assessment and time intervals.

Risk of bias assessment

This was conducted using the recommended approach for assessing risk of bias in studies included in Cochrane reviews(20), It is a two-part tool, addressing the six specific domains (namely sequence generation, allocation concealment, blinding, incomplete outcome data, selective outcome reporting and ‘other issues’). Each domain includes one specific entry in a ‘risk of bias’ table. Within each entry, the first part of the tool involves describing what was reported to have happened in the study. The second part of the tool involves assigning a judgment relating to the risk of bias for that entry. This is achieved by answering a pre-specified question about the adequacy of the study in relation to the entry, such that a judgment of ‘Yes’ indicates low risk of bias, ‘No’ indicates high risk of bias, and ‘Unclear’ indicates unclear or unknown risk of bias.

The risk of bias assessment of the included trials was undertaken independently and in duplicate by two review authors (Dr Jacopo Buti and Dr Roberta Gasparro) as part of the data extraction process. In the case that the paper to be assessed had one or more review authors in the authors list, it was independently evaluated only by those review authors not involved in the trials. After taking into account possible additional information

provided by the authors of the trials, studies were grouped into the following categories. It was assumed that the risk of bias was the same for all outcomes and each study was assessed as follows:

(A) Low risk of bias (plausible bias unlikely to seriously alter the results) if all criteria were met.

(B) Unclear risk of bias (plausible bias that raises some doubt about the results) if one or more key domains were at unclear risk of bias.

(C) High risk of bias (plausible bias that seriously weakens confidence in the results) if one or more criteria were not met.(20)

Data synthesis

For binary outcomes the estimate of effect of an intervention was expressed as relative risks together with 95% confidence intervals (Cis), whereas for continuous outcomes mean differences (MD) and standard deviations were used to summarize the data for each group and were expressed as MD and 95% CIs. The statistical unit was the patient or the patient's side in split-mouth studies only and not the implant(s). Meta-analyses were done only if there were studies with similar comparisons reporting the same outcome measures. Risk ratios were combined for dichotomous data, using random-effect models provided there were more than three studies in the meta-analysis. If there were two studies fixed-effect models were to be used. Data from split-mouth studies were combined with data from parallel group trials with the method outlined by Elbourne,(21) using the generic inverse variance method in RevMan.

The Cochrane Handbook(20) recommendations were to be followed for studies with zero-cell counts. The fixed value of 0.5 was added to all cells with zero-cell counts

and risk ratios calculated with the RevMan software. If there were no events in both arms, no calculations were undertaken because in this situation the study does not provide any indication of the direction or magnitude of the relative treatment effect.

The significance of any discrepancies in the estimates of the treatment effects from the different trials was assessed by means of Cochran's test for heterogeneity and the I^2 statistics, which describes the percentage total variation across studies that is due to heterogeneity rather than chance.

DESCRIPTION OF STUDIES

Characteristics of the trial setting and investigators

Of the five potentially eligible trials(22-26), four trials were included(22, 24-26) and one trial(23) was excluded because the short implants used were eight to 11 mm long (the majority were actually 11 mm long) and they cannot be considered short implants. All the included RCTs were published in multiple publications at 4-month(27-30), 1-year(8, 13, 15, 31-33, 34, 3-year{Esposito, 2011 #5177})and 5-year(22, 24-26) after loading.

Two trials had a parallel group study design(22, 26) and two a split-mouth design(24, 25). Three trials(24, 25)included also an equal number of patients treated in the maxilla (maxillae were not considered in this review) while one trial included only patients treated in mandibles(22). All trials were conducted by the same group in Italy in several private practices and university dental clinics. All trials were partially supported by three different implant manufacturers and one biomaterial producer.

Characteristics of outcome measures

Outcome measures were identical for all trials and were measured at the same time-points: 4-month (implant stability), 1-, 3-, and 5-years after loading (implant stability and peri-implant marginal bone levels).

- Augmentation failures: presented by all trials
- Prosthesis failures: presented by all trials.
- Implant failures: presented by all trials.
- Complications: presented by all trials.
- Peri-implant marginal bone level changes: presented by all trials.

Characteristics at baseline

Main inclusion criteria

All trial included partially edentulous patients in posterior mandibles.

- Seven to 8 mm of residual crestal height and at least 5.5 mm thickness above the mandibular canal measured with computed tomographic (CT) scans(22).
- Five to 7 mm of residual crestal height and at least 8 mm thickness above the mandibular canal bilaterally measured with CT scans(24).
- Six to 8 mm of residual crestal height and at least 5 mm thickness above the mandibular canal bilaterally measured with CT scans(25).
- Five to 7 mm of residual crestal height and at least 5 mm thickness above the mandibular canal measured with CT scans (26).

Main exclusion criteria

The main exclusion criteria were identical for all trials and were:

- Medically compromised patients (metabolic diseases, uncontrolled diabetes, immune deficient or under immune-suppressive therapy, irradiated, treated with intravenous bisphosphonates, etc.).
- Untreated periodontal disease, poor oral hygiene and motivation.
- Substance abusers, psychiatric problems or unrealistic expectations.
- Acute infection at the site to be treated.
- Lack of opposite occluding dentition in the area to be included in the trial.

Comparability of control and treatment groups at entry

No apparent major baseline differences for all trials, however, implants with a larger diameter (6 mm) were used in the short implant group in one trial(24) versus a diameter of 4 mm for the longer implants in the augmented group.

Characteristics of the interventions

Antibiotic prophylaxis

- One g of amoxicillin + clavulanic acid (or erythromycin 500 mg if allergic to penicillin) starting the night before augmentation, twice a day, for 7 days(22).
One hour prior to implant placement 2 g of amoxicillin (or erythromycin 500 mg) were administered.
- Two g of amoxicillin (or clindamycin 600 mg if allergic to penicillin) one hour prior to augmentation and implant placement and 1 g of amoxicillin (or 300 mg clindamycin) was prescribed to be taken twice a day for 7 days only after augmentation procedures(24-26).

Characteristics of the materials used for the vertical bone augmentation procedure

In all cases blocks of bone substitutes were used as interpositional grafts, residual voids were filled with a granular bone substitute, the vertically lifted bone plate were stabilised using osteosynthesis plates, and finally were covered with resorbable membranes.

- In two trials(22, 24), anorganic bovine blocks (Bio-Oss®, Geistlich Pharma AG, Wolhusen, Switzerland) plus granulated bone originated from the blocks were used and left to heal before implant placement for 5 months. Titanium miniplates and miniscrews (Gebrüder Martin GmbH & Co. KG, Tuttlingen, Germany) were used to stabilise the graft. The grafted areas were covered with resorbable collagen barrier (Bio-Gide®, Geistlich Pharma AG).
- In one trial(25), collagenated cancellous equine bone (Sp-Block, OsteoBiol®, TecnoSS®, Coazze, TO, Italy) plus a mix of cancellous and cortical porcine-derived collagenated bone having a granulometry of 250 to 1000 µm (Gen-Os®, OsteoBiol) were used and left to heal before implant placement for 5 months. Titanium miniplates and miniscrews (Gebrüder) were used to stabilise the graft, and grafted areas were covered with collagen resorbable membranes (Evolution, Fine 30 × 30 mm, OsteoBiol) derived from equine pericardium.
- In one trial(26), collagenated cancellous bovine bone (Sp-Block, OsteoBiol®) plus a sticky paste made of 600-1000 micron pre-hydrated collagenated cortico-cancellous bone granules of porcine origin (mp3®, OsteoBiol®) were used and left to heal before implant placement for 4 months. Titanium miniplates and miniscrews (Gebrüder) were used to stabilise the graft, and grafted areas were covered with collagen resorbable membranes (Evolution®, Fine 30 × 30 mm, OsteoBiol®) derived from equine pericardium.

Characteristics of the implants

- In one trial(22), one to three 6.6 mm versus 9.6, 11.1 and 12.6 mm-long parallel-walled implants, all having a diameter of 4 mm (Nanotite, External Hex, Biomet 3i, Palm Beach, FL, USA), made of titanium alloy (Ti6Al4V) with an external hexagon connection and a surface dual etched and partially covered (about 50% of the surface) with nanoscale calcium phosphate crystals, called DCD (discrete crystalline deposition) were used.
- In one trial (24), one to three 5 mm-long Rescue (MegaGen Implant Co., Gyeongbuk, South Korea) implants with a diameter of 6 mm and internal connection, made of commercially pure titanium with a surface blasted with hydroxyapatite particles and cleaned with acid versus 10, 11.5 and 13 mm-long EZ Plus (MegaGen) all with a diameter of 4 mm, internal connection and identical materials and surface characteristics.
- In one trial(25), one to three 6 mm versus 10, 11.5 and 13 mm-long implants, all having a diameter of 4 mm (Southern Implants, Irene, South Africa), made of commercially pure titanium with an external hexagon connection and a roughened grit-blasted surface, were used.
- In one trial(26), one to three 5 mm versus 10, 11.5 and 13 mm-long implants ExFeel (MegaGen), all having a diameter of 5 mm, with an external hexagon connection and a novel nanostructured calcium-incorporated titanium surface (Xpeed) sanded with hydroxyapatite particles and cleaned with acid.

Type and frequency of maintenance

- In all trials, patients were enrolled in a maintenance program at the respective treatment centres with recalls every 4 months(22, 24-26).

Duration of the studies (after implant loading)

All trials had a five year duration after implant placement, however, for one of the trials(22), the 8 years data were in press(35) but were not used in the present review.

Sample size

A sample size calculation was performed in three trials(22, 24, 25) and was not performed in one trial(26).

- For one trial(22), the sample size was calculated for implant failure: a two group continuity corrected chi-square test with a 0.050 two-sided significance level had 80% power to detect the difference between a proportion of 0.100 and a proportion of 0.300 for patients experiencing at least one implant failure (odds ratio of 3.857) when the sample size in each group was 72. However only 30 patients were recruited in each group, since that was the number of patients the sponsor was willing to sponsor in terms of free implants.
- For two trials(24, 25), the sample size was calculated for patient preference, to detect a preference of one group over another against the alternative hypothesis that the treatments are equally preferred. This reduced to a simple one sample proportion scenario. A one-group chi-square test with a 0.050 two-sided significance level had 80% power to detect the difference between the null hypothesis proportion of 0.500 and the alternative proportion of 0.900 when the sample size is 10. The sample was increased by one-third since it was hypothesized that patient preference would not be so definite in this trial. Fifteen

partially edentulous patients with similar bilateral posterior mandible atrophy were included.

Risk of bias assessment

The final risk of bias assessment is summarized in **Figure 1** and **2** and in **Table 2**. It was not necessary to ask for unclear or missing information to the trial authors since all the information was reported in the publications. For each trial we assessed whether it was at low, unclear or high risk of bias. All trials were judged to be at an unclear risk of bias. The reason for this is that it was not possible to blind the outcome assessor for complications and peri-implant marginal bone loss.

RESULTS

In total 135 patients who were supposed to receive 170 prostheses (85 prostheses per group) were enrolled in four trials.

- One study(22) of parallel group design recruited 30 patients per group. Five years after loading three patients dropped out from the short implant group and five from the augmented group. In two augmented mandibles the planned 10 mm long implants could not be placed. Five prostheses failed in four patients of the 6.6 mm short implant group versus five prostheses in five patients in the augmented group. Five short implants failed in three patients versus three long implants in three patients. There were 25 complications in 21 augmented patients versus six complications in six patients of the short implant group.
- One study(24) of split-mouth design recruited 15 patients. Five years after loading five patients dropped out. In five augmented mandibles the planned 10 mm long implants could not be placed. One prosthesis failed in the 5 mm short implant

group versus none in the long implant group. One long implant failed versus two short implants in one patient. Six patients had 11 complications at short implants and 10 patients had 12 complications at long implants.

- One trial(25) of split-mouth design recruited 20 patients. Five years after loading five patients dropped out. In three augmented mandibles the planned 10 mm long implants could not be placed. One prosthesis failed on short implants versus three prostheses that could not be placed on long implants. One patients lost two short implants versus one patient who lost three long implants in the augmented mandible. Twelve complications occurred in nine patients at augmented sites versus three complications in three patients with 6 mm-long implants.
- One trial(26) of parallel group design recruited 20 patients per group. Five years after loading four patients dropped out from the short implant group and six from the augmented group. In two augmented mandibles the planned 10 mm long implants could not be placed due to graft failures. Two prostheses could not be delivered in the augmented group because of multiple complications versus one patient of the 5 mm short implant group who lost his crown. One short implant failed versus two long implants in one patient. There were 18 complications in 17 augmented patients versus 10 complications in nine patients of the short implant group.

In total 12 (14%) bone augmentation procedures failed to achieve the planned bone height to allow placement of implants with the planned length, so new grafting procedures were implemented or short implants were inserted in those patients still willing to rehabilitate of the area with an implant-supported fixed prostheses.

The meta-analysis of the four trials for prosthesis (**Figure 3**) and implant failures (**Figure 4**) did not show any statistical significant difference between prostheses rehabilitated by short implants or longer implants in vertically augmented mandibles for prosthesis failure (RR = 1.46; 95% CI 0.52 to 4.09; P = 0.47; Chi² = 1.35, df = 3 (P = 0.72); I² = 0%) and implant failure (RR = 1; 95% CI 0.31 to 3.21; P = 1.00; Chi² = 0, df = 3 (P = 1.00); I² = 0%).

The meta-analysis of the four trials for complications (**Figure 5**) and marginal peri-implant bone loss (**Figure 6**) showed statistically significant less complications (RR = 4.72; 95% CI 2.43 to 9.17; P < 0.00001; Chi² = 3.02, df = 3 (P = 0.39); I² = 0%) and bone loss (mean difference = 0.60 mm; 95% CI 0.36 to 0.83; P < 0.00001; Chi² = 5.47, df = 3 (P = 0.14); I² = 45%) at short implants.

A list of the complications reported by study group from all trials is presented in **Table 3**.

DISCUSSION

Only four RCTs(22, 24-26) comparing fixed prostheses supported by short implants 5 to 6.6 mm-long with prostheses supported by longer implants placed in vertically augmented atrophic mandibles with a follow-up of 5 years in function could be included in this review. It was easy to meta-analyse these trials since they were all conducted by the same group using similar inclusion criteria, clinical procedures and outcomes measures, though different implant brands and biomaterials were used. Nevertheless the meta-analyses on prosthesis and implants failures could be still underpowered, therefore only limited indications can be gained from them.

The meta-analyses of the four RCTs found no statistically significant differences for both prosthesis and implant failures, however we should also consider that 12 (14%) vertical bone augmentation procedures failed to achieve the planned bone height to allow placement of implants with the planned length, so in these cases when prosthesis rehabilitations could be made, they were usually supported by short implants.

The number and severity of complications were clearly in favour of short implants. It is quite intuitive that more invasive procedure are associated with more complications and post-operative morbidity, however now we have the data suggesting that the risk of complications is at least duplicated with interpositional graft of bone substitutes.

Peri-implant marginal bone loss was 0.6 mm higher at longer implants in vertically augmented bone. This statistically significant difference was originally present in all trials. While we can debate whether this difference could have a clinical impact, it is definitely better that affected longer implants and not the short ones, since the long-term concern of short implants is that a progressive marginal bone loss could shorten their life-span favouring the longer ones.

All included trials were designed and conducted by the same group of operators, using similar procedures and outcome measures but different implant systems. While it would be preferable to have similar trials conducted by different research groups, it is easier to conduct a systematic review when trials are homogeneous. In the present review were also involved external authors to evaluate the risk of bias of the included trials in order to minimize bias.

With respect to generalization of the results of the present review to general practice, the operators performing vertical bone augmentations in the included trials were highly experienced so it might be hypothesized that less experienced practitioners may not achieve similar success rates. Caution is therefore recommended when deciding to perform vertical bone augmentation procedures in mandibles to allow placement of longer implants. At the present time, it might be sensible to suggest placement of short implants as the preferred option for the treatment of atrophic mandibles. Bone augmentation procedures could be used as a second option in the case of failures of short implants. Longer follow-ups, however, remain essential for knowing the 10-year outcomes of both procedures in order to help clinicians to suggest the best therapeutic option to their patients.

Conclusions

Five years after loading, prosthetic and implants failures were similar between the two interventions, but complications and peri-implant marginal bone loss were higher and more severe at longer implants placed in vertically augmented mandibles. Larger trials and longer follow-ups up to 10 years after loading are needed to confirm or reject the present preliminary findings. However in the meantime short implants could be the preferable option. More specifically trials evaluating different vertical bone augmentation procedures of mandibles rather than interpositional grafts of bone substitutes should be evaluated against short implants.

References

1. Renouard F, Nisand D. Impact of implant length and diameter on survival rates. *Clinical Oral Implants Research* 2006;17 Suppl 2:35-51.
2. das Neves FD, Fones D, Bernardes SR, do Prado CJ, Neto AJ. Short implants - an analysis of longitudinal studies. *The International Journal of Oral and Maxillofacial Implants* 2006;21:86-93.
3. Esposito M, Grusovin MG, Felice P, Karatzopoulos G, Worthington HV, Coulthard P. Interventions for replacing missing teeth: horizontal and vertical bone augmentation techniques for dental implant treatment. *Cochrane Database of Systematic Reviews* 2009: Chichester, UK: John Wiley & Sons, Ltd.
4. Esposito M, Felice P, Worthington HV. Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. *Cochrane Database of Systematic Reviews* 2014: Chichester, UK: John Wiley & Sons, Ltd.
5. Esposito M, Davó R, Marti-Pages C, Ferrer-Fuertes A, Barausse C, Pistilli R, Ippolito DR, Felice P. Immediately loaded zygomatic implants vs conventional dental implants in augmented atrophic maxillae: 4 months post-loading results from a multicentre randomised controlled trial. *European Journal of Oral Implantology* 2018;11:11-28.
6. Pistilli R, Felice P, Piatelli M, Nisii A, Barausse C, Esposito M. Blocks of autogenous bone versus xenografts for the rehabilitation of atrophic jaws with dental implants: preliminary data from a pilot randomised controlled trial. *European Journal of Oral Implantology* 2014;7:153-171.
7. Cannizzaro G, Felice P, Minciarelli AF, Leone M, Viola P, Esposito M. Early implant loading in the atrophic posterior maxilla: 1-stage lateral versus crestal sinus lift and 8 mm hydroxyapatite-coated implants. A 5-year randomised controlled trial. *European Journal of Oral Implantology* 2013;6:13-25.
8. Esposito M, Pistilli R, Barausse C, Felice P. Three-year results from a randomised controlled trial comparing prostheses supported by 5 mm-long implants or by longer implants in augmented bone in posterior atrophic edentulous jaws. *European Journal of Oral Implantology* 2014;7:383-395.
9. Gulje FL, Raghoobar GM, Vissink A, Meijer HJ. Single crowns in the resorbed posterior maxilla supported by either 6-mm implants or by 11-mm implants combined with sinus floor elevation surgery: A 1-year randomised controlled trial. *European Journal of Oral Implantology* 2014;7:247-255.
10. Esposito M, Barausse C, Pistilli R, Sammartino G, Grandi G, Felice P. Short implants versus bone augmentation for placing longer implants in atrophic maxillae: One-year post-loading results of a pilot randomised controlled trial. *European Journal of Oral Implantology* 2015;8:257-268.
11. Thoma DS, Brandenberg F, Fehmer V, Buchi DL, Hammerle CH, Sailer I. Randomized Controlled Clinical Trial of All-Ceramic Single Tooth Implant Reconstructions Using Modified Zirconia Abutments: Radiographic and Prosthetic Results at 1 Year of Loading. *Clinical Implant Dentistry and Related Research* 2016;18:462-472.
12. Bolle C, Felice P, Barausse C, Pistilli R, Trullenque-Eriksson A, Esposito M. Four mm-long versus longer implants in augmented bone in posterior atrophic jaws: One year post-loading results from a multicentre randomised controlled trial. *European Journal of Oral Implantology* 2018;10:31-47.

13. Gastaldi G, Felice P, Pistilli R, Barausse C, Ippolito DR, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 5x5 mm implants with a nanostructured calcium-incorporated titanium surface or by longer implants in augmented bone. Three-year results from a randomised controlled trial. *European Journal of Oral Implantology* 2018;10:49-61.
14. Gastaldi G, Felice P, Pistilli R, Barausse C, Trullenque-Eriksson A, Esposito M. Short implants as an alternative to crestal sinus lift: a 3-year multicentre randomised controlled trial. *European Journal of Oral Implantology* 2018;11:391-400.
15. Felice P, Barausse C, Pistilli V, Piattelli M, Ippolito DR, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 6 mm long 4 mm wide implants or by longer implants in augmented bone. Three-year post-loading results from a randomised controlled trial. *European Journal of Oral Implantology* 2018;11:in press.
16. Lee SA, Lee CT, Fu MM, Elmisalati W, Chuang SK. Systematic review and meta-analysis of randomized controlled trials for the management of limited vertical height in the posterior region: short implants (5 to 8 mm) vs longer implants (> 8 mm) in vertically augmented sites. *International Journal of Oral and Maxillofacial Implants* 2014;29:1085-1097.
17. Camps-Font O, Burgueno-Barris G, Figueiredo R, Jung RE, Gay-Escoda C, Valmaseda-Castellon E. Interventions for Dental Implant Placement in Atrophic Edentulous Mandibles: Vertical Bone Augmentation and Alternative Treatments. A Meta-Analysis of Randomized Clinical Trials. *Journal of Periodontology* 2016;87:1444-1457.
18. Tong Q, Zhang X, Yu L. Meta-analysis of randomized controlled trials comparing clinical outcomes between short implants and long implants with bone augmentation procedure. *International Journal of Oral and Maxillofacial Implants* 2017;32:e25-e34.
19. Toti P, Marchionni S, Menchini-Fabris GB, Marconcini S, Covani U, Barone A. Surgical techniques used in the rehabilitation of partially edentulous patients with atrophic posterior mandibles: A systematic review and meta-analysis of randomized controlled clinical trials. *Journal of cranio-maxillo-facial surgery : official publication of the European Association for Cranio-Maxillo-Facial Surgery* 2017;45:1236-1245.
20. Higgins JPT, Green S (eds). *Cochrane Handbook for Systematic Reviews of Interventions* 5.0.2 [updated September 2009]: www.cochrane-handbook.org, 2009.
21. Elbourne DR, Altman DG, Higgins JPT, Curtin F, Worthington HV, Vail A. Meta-analyses involving cross-over trials: methodological issues. *International Journal of Epidemiology* 2002;31:140-149.
22. Felice P, Cannizzaro G, Barausse C, Pistilli R, Esposito M. Short implants versus longer implants in vertically augmented posterior mandibles: A randomised controlled trial with 5-year after loading follow-up. *European Journal of Oral Implantology* 2014;7:359-369.
23. Visser A, Stellingsma C, Raghoobar GM, Meijer HJ, Vissink A. A 15-year comparative prospective study of surgical and prosthetic care and aftercare of overdenture treatment in the atrophied mandible: augmentation versus nonaugmentation. *Clinical Implant Dentistry and Related Research* 2016;18:1218-1226.
24. Felice P, Barausse C, Pistilli R, Ippolito DR, Esposito M. Five-year results from a randomised controlled trial comparing prostheses supported by 5 mm long implants or by

longer implants in augmented bone in posterior atrophic edentulous jaws. *International Journal of Oral Implantology* 2019;12: in press.

25. Felice P, Pistilli R, Barausse C, Piattelli M, Buti J, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 6 mm long 4 mm wide implants or by longer implants in augmented bone. Five-year post-loading results from a randomised controlled trial. *International Journal of Oral Implantology* 2019;12: in press.

26. Esposito M, Barausse C, Pistilli R, Piattelli M, Di Simone S, Ippolito DR, Felice P. Posterior atrophic jaws rehabilitated with prostheses supported by 5x5 mm implants with a nanostructured calcium-incorporated titanium surface or by longer implants in augmented bone. Five-year results from a randomised controlled trial. *International Journal of Oral Implantology* 2019;12: in press.

27. Felice P, Cannizzaro G, Checchi V, Marchetti C, Pellegrino G, Censi P, Esposito M. Vertical bone augmentation versus 7-mm-long implants in posterior atrophic mandibles. Results of a randomized controlled clinical trial of up to 4 months after loading. *European Journal of Oral Implantology* 2009;2:7-20.

28. Felice P, Checchi V, Pistilli R, Scarano A, Pellegrino G, Esposito M. Bone augmentation versus 5-mm dental implants in posterior atrophic jaws. Four-month post-loading results from a randomised controlled clinical trial. *European Journal of Oral Implantology* 2009;2:267-281.

29. Esposito M, Cannizzaro G, Soardi E, Pistilli R, Piattelli M, Corvino V, Felice P. Posterior atrophic jaws rehabilitated with prostheses supported by 6 mm-long and 4 mm-wide implants or by longer implants in augmented bone. Preliminary results from a pilot randomised controlled trial. *European Journal of Oral Implantology* 2012;5:19-33.

30. Felice P, Pistilli R, Piattelli M, Soardi E, Corvino V, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 5x5 mm implants with a novel nanostructured calcium-incorporated titanium surface or by longer implants in augmented bone. Preliminary results from a randomised controlled trial. *European Journal of Oral Implantology* 2012;5:149-161.

31. Felice P, Pellegrino G, Checchi L, Pistilli R, Esposito M. Vertical augmentation with interpositional blocks of anorganic bovine bone vs. 7-mm-long implants in posterior mandibles: 1-year results of a randomized clinical trial *Clinical Oral Implants Research* 2010;21:1394-1403.

32. Esposito M, Pellegrino G, Pistilli R, Felice P. Rehabilitation of posterior atrophic edentulous jaws: prostheses supported by 5 mm short implants or by longer implants in augmented bone? One-year results from a pilot randomised clinical trial. *European Journal of Oral Implantology* 2011;4:21-30.

33. Pistilli R, Felice P, Cannizzaro G, Piattelli M, Corvino V, Barausse C, Buti J, Soardi E, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 6 mm long 4 mm wide implants or by longer implants in augmented bone. One-year post-loading results from a pilot randomised controlled trial. *European Journal of Oral Implantology* 2013;6:359-372.

34. Pistilli R, Felice P, Piattelli M, Gessaroli M, Soardi E, Barausse C, Buti J, Corvino V, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 5 x 5 mm implants with a novel nanostructured calcium-incorporated titanium surface or by longer implants in augmented bone. One-year results from a randomised controlled trial. *European Journal of Oral Implantology* 2013;6:343-357.

35. Felice P, Barausse C, Pistilli R, Ippolito DM, Esposito M. Short implants versus longer implants in vertically augmented posterior mandibles: Results at 8-years after loading from a randomised controlled trial. *European Journal of Oral Implantology* 2018;11: in press.
36. Higgins JPT, Green S (eds). *Cochrane Handbook for Systematic Reviews of Interventions* 5.1.0 [updated March 2011]: www.cochrane-handbook.org, 2011.

Table 1: Search strategies used to identify eligible trials for this systematic review.

MEDLINE (OVID) search strategy

1. exp Dental Implants/
2. exp Dental Implantation/ or dental implantation
3. exp Dental Prosthesis, Implant-Supported/
4. ((osseointegrated adj implant\$) and (dental or oral))
5. dental implant\$
6. (implant\$ adj5 dent\$)
7. (((overdenture\$ or crown\$ or bridge\$ or prosthesis or restoration\$) adj5 (Dental or oral)) and implant\$)
8. "implant supported dental prosthesis"
9. ("blade implant\$" and (dental or oral))
10. ((endosseous adj5 implant\$) and (dental or oral))
11. ((dental or oral) adj5 implant\$)
12. OR/1-11

The above subject search was linked to the Cochrane Highly Sensitive Search Strategy (CHSSS) for identifying randomised trials in MEDLINE: sensitivity maximising version (2008 revision) as referenced in Chapter 6.4.11.1 and detailed in box 6.4.c of the Cochrane Handbook for Systematic Reviews of Interventions, Version 5.1.0(36).

1. randomized controlled trial.pt.
2. controlled clinical trial.pt.
3. randomized.ab.
4. placebo.ab.
5. drug therapy.fs.
6. randomly.ab.
7. trial.ab.
8. groups.ab.
9. or/1-8
10. exp animals/ not humans.sh.
11. 9 not 10

The Cochrane Central Register of Controlled Trials (CENTRAL) search strategy

- #1 DENTAL IMPLANTS explode all trees (MeSH)
- #2 DENTAL IMPLANTATION explode all trees (MeSH)
- #3 DENTAL PROSTHESIS IMPLANT-SUPPORTED single term (MeSH)
- #4 ((osseointegrat* near implant*) and (dental* or oral*))
- #5 (dental next implant*)
- #6 (implant* near dent*)
- #7 dental-implant*
- #8 ((overdenture* near dental*) and implant*)
- #9 ((overdenture* near oral*) and implant*)
- #10 ((crown* near dental*) and implant*)
- #11 ((crown* near oral*) and implant*)
- #12 ((bridge* near dental*) and implant*)
- #13 ((bridge* near oral*) and implant*)
- #14 ((prosthesis near dental*) and implant*)
- #15 ((prosthesis near oral*) and implant*)
- #16 ((prostheses near dental*) and implant*)
- #17 ((prostheses near oral*) and implant*)
- #18 ((restoration* near dental*) and implant*)
- #19 ((restoration* near oral*) and implant*)
- #20 (implant next supported next dental next prosthesis)
- #21 (blade next implant*)
- #22 ((endosseous near implant*) and dental)
- #23 ((endosseous near implant*) and oral*)
- #24 ((dental* near implant*) or (oral* near implant*))
- #25 (#1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9 or #10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19 or #20 or #21 or #22 or #23 or #24)

Table 2: Summary of risk of bias assessment

Felice et al(22)	Author's judgement	Support for judgement
Random sequence generation	Low risk	"A computer generated restricted randomisation list was created. Only one of the investigators (Marco Esposito), not involved in the selection and treatment of the patients, was aware of the random sequence and could have access to the random list stored in his pass-word protected portable computer."
Allocation concealment	Low risk	"The random codes were enclosed in sequentially numbered, identical, opaque, sealed envelopes. Envelopes were opened sequentially after eligible patients signed the informed consent form to be enrolled in the trial. Therefore, treatment allocation was concealed to the investigators in charge of enrolling and treating the patients."
Blinding of outcome assessment	Unclear risk	"...outcome assessors were blinded, however the Bio-Oss augmented sites could be identified on radiographs because they appeared more radio-opaque and implants were longer."
Incomplete outcome data	Low risk	"At the 5-year post-loading endpoint 8 patients dropped out, 5 from augmented and 3 from the short implant group". Missing outcome data balanced in numbers across intervention groups, with similar reasons for missing data across groups.
Selective reporting	Low risk	All of the study's pre-specified (primary and secondary) outcomes that are of interest in the review have been reported in the pre-specified way.
Other bias	Low risk	The study appears to be free of other sources of bias.
Felice et al(24)	Author's judgement	Support for judgement
Random sequence generation	Low risk	"A computer generated restricted randomisation list was created. Only one of the investigators (Dr Marco Esposito), not involved in the selection and treatment of the patients, was aware of the randomisation sequence and could have access to the randomisation list stored in his pass-word protected portable computer."
Allocation concealment	Low risk	"The information on how to treat site number 1 was enclosed in sequentially numbered, identical, opaque, sealed envelopes. Envelopes were opened sequentially the same day of the augmentation procedure and the surgeon treated in that occasion only the site allocated to the augmentation procedure. Therefore, treatment allocation was concealed to the investigators in charge of enrolling and treating the patients."
Blinding of outcome assessment	Unclear risk	"Two dentists.... not involved in the treatment of the patients performed all clinical and radiographic assessments without knowing group allocation, however augmented sites could be easily identified both clinically when testing implant stability because of the different implant diameters and on radiographs because they appeared more radio-opaque and the implants were different."
Incomplete outcome data	Low risk	Reasons for missing outcome data unlikely to be related to true outcome.
Selective reporting	Low risk	All of the study's pre-specified (primary and secondary) outcomes that are of interest in the review have been reported in the pre-specified way.
Other bias	Low risk	The study appears to be free of other sources of bias.
Felice et al(25)	Author's judgement	Support for judgement
Random sequence generation	Low risk	"A computer generated restricted random list was created. Only one of the investigators (Dr Marco Esposito), not involved in the selection and treatment of the patients, was aware of the random sequence and could have access to the random list stored in his password protected portable computer."
Allocation concealment	Low risk	"The information on how to treat site number 1 was enclosed in sequentially numbered, identical, opaque, sealed envelopes. Envelopes were opened sequentially before giving anaesthesia and surgeons were to treat both sites in the same surgical session, starting from the intervention allocated to site number 1. Therefore, treatment allocation was concealed to the investigators in charge of enrolling and treating the patients."

Blinding of outcome assessment	Unclear risk	<i>"Six dentists...not involved in the treatment of the patients performed all clinical measurements without knowing group allocation, however mandibular augmented sites could be easily identified because of the different anatomy of the two sides after the augmentation procedure. One dentist ... not involved in the treatment of the patients performed all radiographic assessments without knowing group allocation, however augmented sites could be easily identified on radiographs due to the different implant lengths"</i>
Incomplete outcome data	Low risk	Reasons for missing outcome data unlikely to be related to true outcome.
Selective reporting	Low risk	All of the study's pre-specified (primary and secondary) outcomes that are of interest in the review have been reported in the pre-specified way.
Other bias	Low risk	The study appears to be free of other sources of bias.
Esposito et al(26)	Author's judgement	Support for judgement
Random sequence generation	Low risk	<i>"A computer generated restricted random list was created. Only one of the investigators (Marco Esposito), not involved in the selection and treatment of the patients, was aware of the random sequence and could have access to the random list stored in his pass-word protected portable computer."</i>
Allocation concealment	Low risk	<i>"The information on how to treat each patient was enclosed in sequentially numbered, identical, opaque, sealed envelopes. Envelopes were opened sequentially after the patients signed the informed consent accepting to participate into the trial. Therefore, treatment allocation was concealed to the investigators in charge of enrolling and treating the patients."</i>
Blinding of outcome assessment	Unclear risk	<i>"Three dentists... not involved in the treatment of the patients performed all clinical measurements without knowing group allocation, however mandibular augmented sites could be easily identified because the different anatomy of the two sides after the augmentation procedure. One dentist.... not involved in the treatment of the patients, performed all radiographic assessments without knowing group allocation, however augmented sites could be easily identified on radiographs due to the different implant lengths."</i>
Incomplete outcome data	Low risk	<i>"Sixteen patients dropped-out before the 5-year evaluation (four short mandibles...six augmented mandibles...)"</i>
Selective reporting	Low risk	All of the study's pre-specified (primary and secondary) outcomes that are of interest in the review have been reported in the pre-specified way.
Other bias	Low risk	The study appears to be free of other sources of bias.

Table 3: List of complications by study group. Some patients had multiple complications or complications at both sides.

Study id	Short implants	Long implants in augmented bone
Felice et al(22)	2 transient post-implantation lip/chin paraesthesiae 2 loosening of the abutment screws 1 fracture of the ceramic lining of the prosthesis 1 fracture of the prosthesis	3 blocks fragmented into many pieces at placement 16 transient paraesthesiae of the mental nerve 4 soft tissue dehiscence 10 to 30 days after augmentation 1 abutment screw loosening 1 fracture of the ceramic lining of the prosthesis
Felice et al(24)	3 transient post-implantation lip/chin paraesthesiae 1 mucositis 3 abscesses/peri-implantitis 3 abutment loosening 1 discementation of the prosthesis	12 transient paraesthesiae of the mental nerve
Felice et al(25)	1 loosening of the abutment screw 1 discementation of the prosthesis 1 peri-implantitis	3 graft infections 7 transient paraesthesiae of the mental nerve 1 mucositis 2 peri-implantitis
Esposito et al(26)	8 transient mandibular nerve paraesthesia 1 chipping of the ceramic lining of the prosthesis 1 peri-implant mucositis	3 graft infections 14 transient mental nerve paraesthesia
Totals	30	67

Repeated and clearly correlated complications were accounted only once

Figure 1: Risk of bias graph: review authors' judgements about each methodological quality item presented as percentages across all included studies

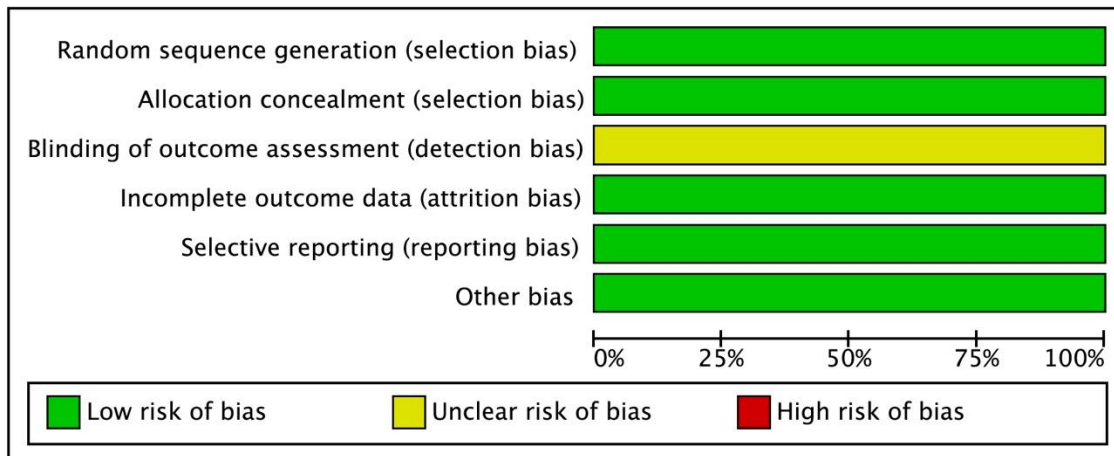


Figure 2: Risk of bias summary: review authors' judgements about each methodological quality item for each included study.

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Esposito et al. (26)	+	+	?	+	+	+
Felice et al. (22)	+	+	?	+	+	+
Felice et al. (24)	+	+	?	+	+	+
Felice et al. (25)	+	+	?	+	+	+

Figure 3: Meta-analysis comparing prosthesis failures for short implants versus longer implants in vertically augmented mandibles after 5 years in function.

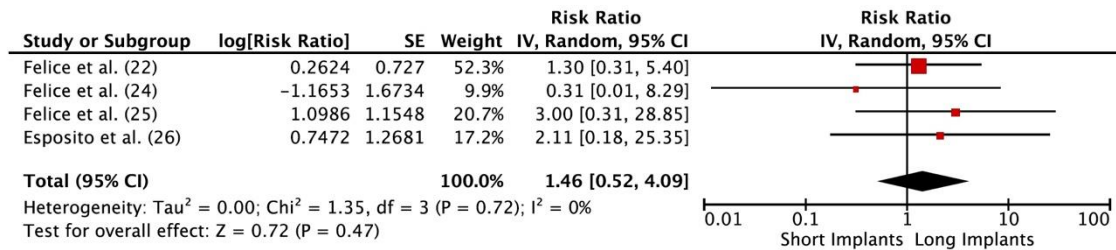


Figure 4: Meta-analysis comparing implant failures for short implants versus longer implants in vertically augmented mandibles after 5 years in function.

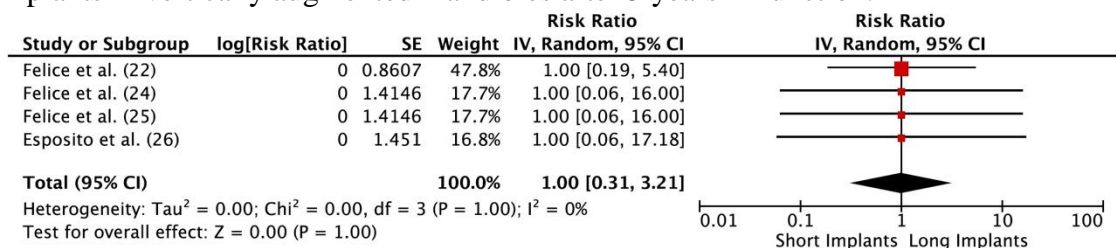


Figure 5: Meta-analysis comparing complications at short implants versus longer implants in vertically augmented mandibles after 5 years in function.

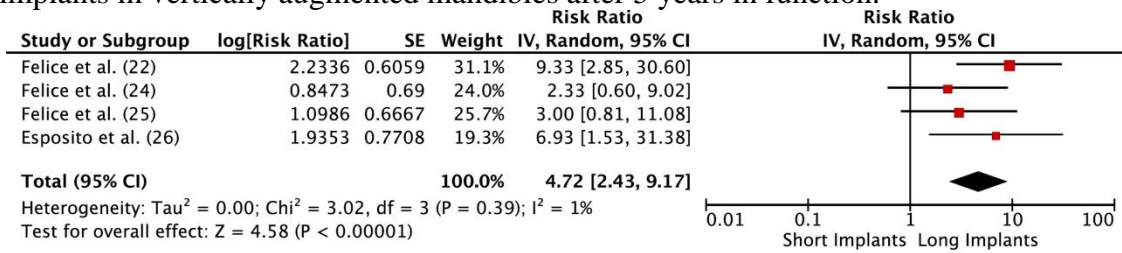


Figure 6: Meta-analysis comparing marginal per-implant bone loss in mm at short implants versus longer implants in vertically augmented mandibles after 5 years in function.

