Marco Esposito, Jacopo Buti, Carlo Barausse, Roberta Gasparro, Gilberto Sammartino, Pietro Felice

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

KEY WORDS

dental implants, randomised controlled trial, short implants, systematic review, vertical augmentation review

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 that included originally 135 patients were included. Two RCTs had a parallel-group design and two a split-mouth design. Short implants were 5.0 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%) had dropped out from the four RCTs. There were no differences for patients having prosthesis (RR = 1.46; 95% CI: 0.52 to 4.09; $P = 0.47$; $I^2 = 0\%$) or implant (RR = 1.00; 95% CI: 0.31 to 3.21; $P = 1.00$; $I^2 = 0\%$) failures between the two interventions, but there were more patients experiencing complications (RR = 4.72; 95% CI: 2.43 to 9.17; $P < 0.00001$; $I^2 = 0\%$) and peri-implant marginal bone loss (mean difference = 0.60 mm; 95% CI: 0.36 to 0.83; $P < 0.00001$; $I^2 = 45\%$) at longer implants in augmented bone.

Conclusions: Five years after loading, prosthetic and implant 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 intrabony length of 8 mm or less[1]. In previously published 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 dental practitioners 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, although only 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 needed to validate the long-term outcomes of these procedures, since very little is 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 with similar prostheses supported by longer implants in vertically augmented mandibles with follow-ups of 5 years in function. Longer follow-ups are desirable but not yet available. It was decided to focus on the rehabilitation of atrophic mandibles only, since their rehabilitation is clinically more challenging than those of the maxilla, especially in terms of vertical bone augmentations to allow the placement of longer implants. It 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 prostheses 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-years-after-loading time point was considered in the present review. Longer follow-ups were not considered since they are not yet available.

Outcomes measures were as follows.

- 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 implants in augmented bone.
- Prosthesis failure: planned prosthesis which could not be placed because of graft or 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 (Medizintechnik Gulden, Modautal, Germany) or resonance frequency (Osstell, Integration Diagnostics, Gothenburg, Sweden). Mechanical complications (e.g. implant fracture or deformation of the implant–abutment connection) rendering the implant unusable also counted as implant failures.
- Any complications at the implant or donor site (e.g. infection, nerve injury, haemorrhage, prosthesis loosening or fractures, peri-implantitis).
- 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.

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

MEDLINE (OVID) search strategy	The Cochrane Central Register of Controlled Trials (CENTRAL) search strategy
1. exp Dental Implants/	1. DENTAL IMPLANTS explode all trees (MeSH)
2. exp Dental Implantation/ or dental implantation	2. DENTAL IMPLANTATION explode all trees (MeSH)
3. exp Dental Prosthesis, Implant-Supported/	3. DENTAL PROSTHESIS IMPLANT-SUPPORTED single term (MeSH)
4. ((osseointegrated adj implant$) and (dental or oral))	4. ((osseointegrat* near implant*) and (dental* or oral*))
5. dental implant$	5. (dental next implant*)
6. (implant$ adj5 dent$)	6. (implant* near dent*)
7. (((overdenture$ or crown$ or bridge$ or prosthesis or restoration$) adj5 (Dental or oral)) and implant$)	7. dental-implant*
8. "implant supported dental prosthesis"	8. ((overdenture* near dental*) and implant*)
9. ("blade implant$" and (dental or oral))	9. ((overdenture* near oral*) and implant*)
10. ((endosseous adj5 implant$) and (dental or oral))	10. ((crown* near dental*) and implant*)
11. ((dental or oral) adj5 implant$)	11. ((crown* near oral*) and implant*)
12. OR/1-11	12. ((bridge* near dental*) and implant*)
	13. ((bridge* near oral*) and implant*)
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(20).	14. ((prosthesis near dental*) and implant*)
1. randomized controlled trial.pt.	15. ((prosthesis near oral*) and implant*)
2. controlled clinical trial.pt.	16. ((prostheses near dental*) and implant*)
3. randomized.ab.	17. ((prostheses near oral*) and implant*)
4. placebo.ab.	18. ((restoration* near dental*) and implant*)
5. drug therapy.fs.	19. ((restoration* near oral*) and implant*)
6. randomly.ab.	20. (implant next supported next dental next prosthesis)
7. trial.ab.	21. (blade next implant*)
8. groups.ab.	22. ((endosseous near implant*) and dental)
9. or/1-8	23. ((endosseous near implant*) and oral*)
10. exp animals/ not humans.sh.	24. ((dental* near implant*) or (oral* near implant*))
11. 9 not 10	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)

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 (CB, RG). 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 (CB, RG) 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 (ME) 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 (ME, JB) 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 judgement 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 judgement 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 (JB, RG) as part of the data extraction process. In the case that the paper to be assessed had one or more review authors in the author 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 (SDs) were used to summarise 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 (RRs) were combined for dichotomous data, using random-effect models provided there were more than three studies in the meta-analysis. If there were up to three 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 et al[21], using the generic inverse variance method in RevMan (The Cochrane Collaboration).

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 RRs 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 statistic, which describes the percentage total variation across studies that is due to heterogeneity rather than chance.

Results

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 8 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 months[27-30], 1 year[31-34], 3 years[8,13,15,35] and 5 years[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[24-26] 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 months (implant stability) and 1, 3 and 5 years after loading (implant stability and peri-implant marginal bone levels). The outcome measures were:

- 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

The main inclusion criteria were:

- patients partially edentulous in posterior mandibles
- 7 to 8 mm of residual crestal height and at least 5.5-mm thickness above the mandibular canal measured with computed tomography (CT) scans[22]
- 5 to 7 mm of residual crestal height and at least 8-mm thickness above the mandibular canal bilaterally measured with CT scans[24]
- 6 to 8 mm of residual crestal height and at least 5-mm thickness above the mandibular canal bilaterally measured with CT scans[25]
- 5 to 7 mm of residual crestal height and at least 5-mm thickness above the mandibular canal measured with CT scans[26].

The main exclusion criteria were identical for all trials:

- 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

There were 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[22].
- Two g of amoxicillin (or clindamycin 600 mg if allergic to penicillin) 1 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 plates were stabilised using osteosynthesis plates, and finally were covered with resorbable membranes.

In two trials[22,24], anorganic bovine blocks (Bio-Oss, Geistlich Pharma, 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, Tuttlingen, Germany) were used to stabilise the graft. The grafted areas were covered with resorbable collagen barrier (Bio-Gide, Geistlich Pharma).

In one trial[25], collagenated cancellous equine bone (Sp-Block, OsteoBiol, Tecnoss, Coazze, 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 to 1000 µm 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-long 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 (Ti_6Al_4V) 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, Gyeongbuk, South Korea) implants with a diameter of 6 mm and internal connection, made of commercially pure titanium with a surface airborne-particle abraded with hydroxyapatite particles and cleaned with acid versus 10-, 11.5- and 13-mm-long EZ Plus (MegaGen) implants, all with a diameter of 4 mm, internal connection and identical materials and surface characteristics.

In one trial[25], one to three 6-mm-long versus 10-, 11.5- and 13-mm-long implants, all having a

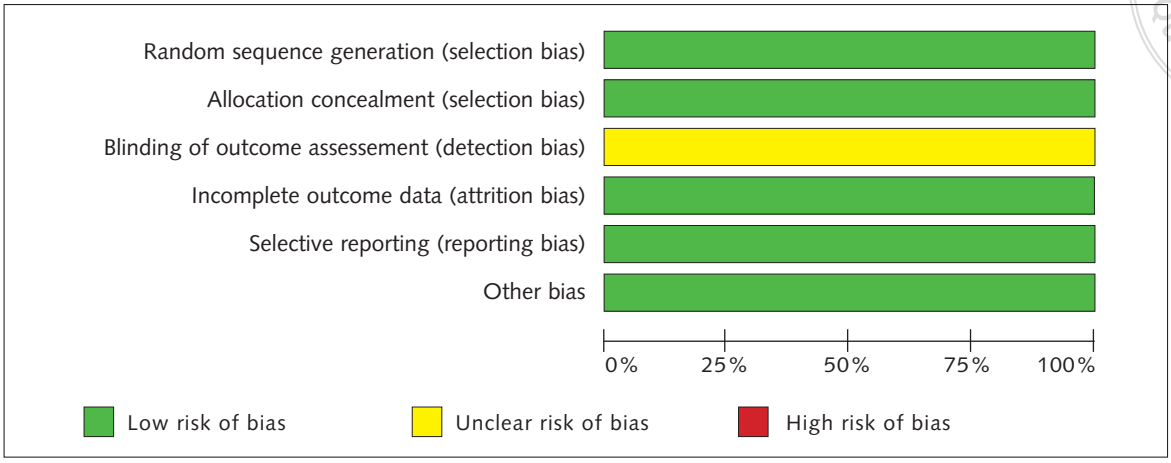

Fig 1 Risk of bias graph: review authors' judgements about each methodological quality item presented as percentages across all included studies.

diameter of 4 mm (Southern Implants, Irene, South Africa), made of commercially pure titanium with an external hexagon connection and a roughened airborne-particle-abraded surface, were used.

In one trial[26], one to three 5-mm-long 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) airborne-particle abraded with hydroxyapatite particles and cleaned with acid.

Type and frequency of maintenance

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

Duration of the studies (after implant loading)

All trials had a 5-year duration after implant placement; however, for one of the trials[22], the 8-year data were in press[36] 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 hypothesised 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 summarised in Figs 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. Each trial was assessed as 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

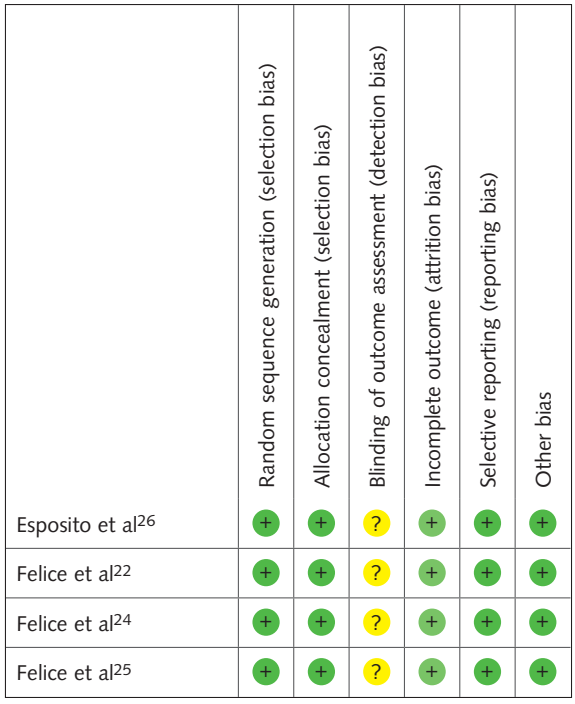

Fig 2 Risk of bias summary: review authors' judgements about each methodological quality item for each included study.

was not possible to blind the outcome assessor for complications and peri-implant marginal bone loss.

Description of the studies

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

Table 2 Summary of risk of bias assessment

Study	Characteristic	Authors' judgement	Support for judgement
Felice et al[22]	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 password 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 blind. 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.

Study	Characteristic	Authors' judgement	Support for judgement
Felice et al[24]	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 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 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 clinicians … not involved in the treatment of the patients performed all clinical and radiographic assessments without knowledge of 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 radiopaque 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]	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	"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 dental practitioner … 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"
	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]	Random sequence generation	Low risk	"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 password-protected portable computer."
	Allocation concealment	Low risk	"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."
	Blinding of outcome assessment	Unclear risk	"Three clinicians … 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 clinician … 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."
	Incomplete outcome data	Low risk	"Sixteen patients dropped-out before the 5-year evaluation (four short mandibles … six augmented mandibles …)."
	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.

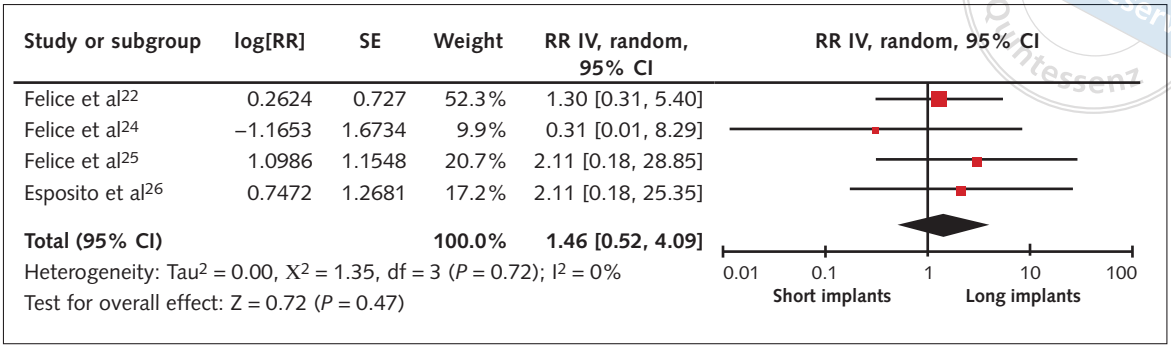

Fig 3 Meta-analysis comparing prosthesis failures for short implants versus longer implants in vertically augmented mandibles after 5 years in function.

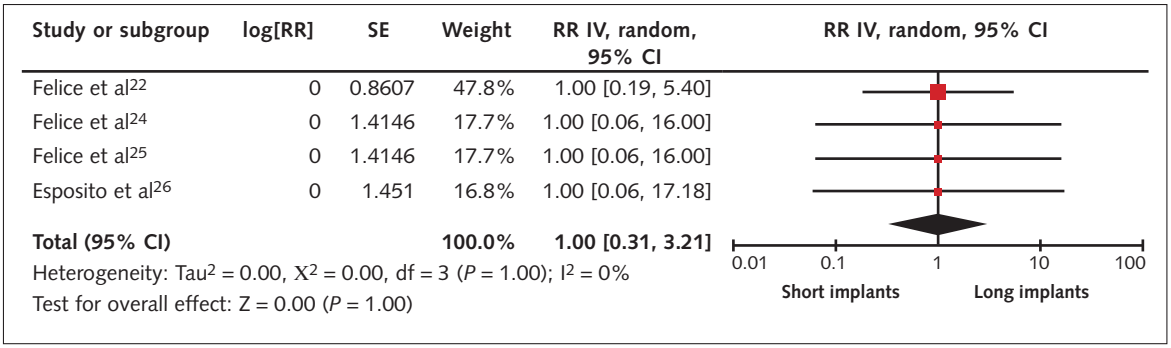

Fig 4 Meta-analysis comparing implant failures for short implants versus longer implants in vertically augmented mandibles after 5 years in function.

versus three prostheses that could not be placed on long implants. One patient 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 the area with an implant-supported fixed prosthesis.

The meta-analysis of the four trials for prosthesis (Fig 3) and implant failures (Fig 4) did not show any statistically significant differences between prostheses rehabilitated by short implants or longer implants in vertically augmented mandibles for prosthesis failure (relative risk [RR] = 1.46; 95% CI: 0.52 to 4.09; $P = 0.47$; $X^2 = 1.35$, degrees of freedom [df] = 3 [$P = 0.72$]; $I^2 = 0\%$) and implant failure (RR = 1; 95% CI: 0.31 to 3.21; $P = 1.00$; $X^2 = 0$, df = 3 [$P = 1.00$]; $I^2 = 0\%$).

The meta-analysis of the four trials for complications (Fig 5) and marginal peri-implant bone loss (Fig 6) showed statistically significantly less complications (RR = 4.72; 95% CI: 2.43 to 9.17; $P < 0.00001$; $X^2 = 3.02$, df = 3 [$P = 0.39$]; $I^2 = 0\%$) and bone loss (mean difference = 0.60 mm; 95% CI: 0.36 to 0.83; $P < 0.00001$; $X^2 = 5.47$, df = 3 [$P = 0.14$]; $I^2 = 45\%$) at short implants.

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

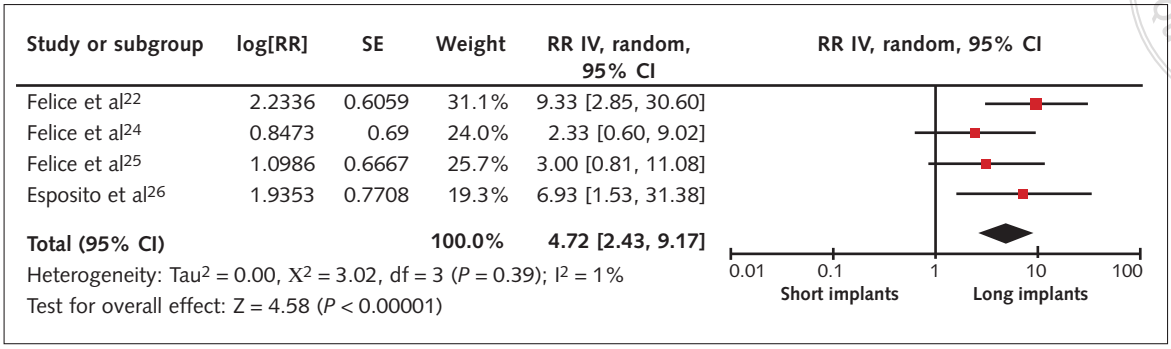

Fig 5 Meta-analysis comparing complications at short implants versus longer implants in vertically augmented mandibles after 5 years in function.

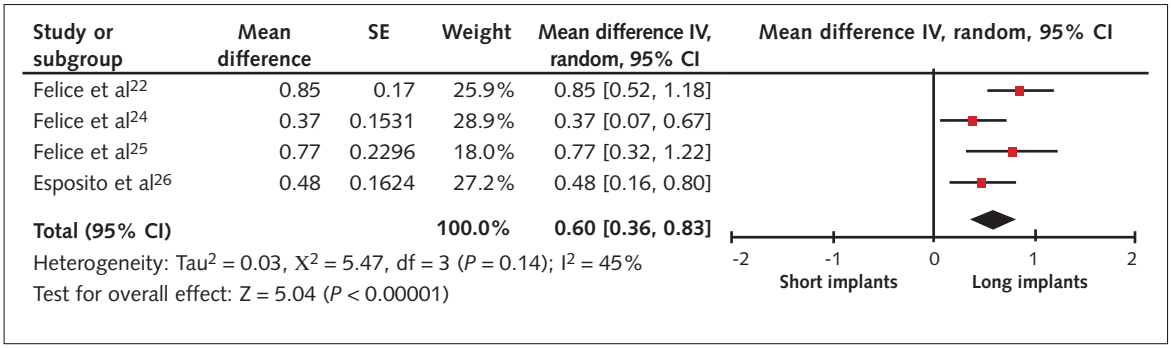

Fig 6 Meta-analysis comparing marginal per-implant bone loss in mm at short implants versus longer implants in vertically augmented mandibles after 5 years in function.

Table 3 List of complications by study group (some patients had multiple complications or complications at both sides)

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

Repeated and clearly correlated complications were counted only once.

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 implant 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, it should also be considered 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 procedures are associated with more complications and postoperative morbidity; however, there are now the data to suggest 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. Although it can be debated whether this difference could have a clinical impact, it is a useful conclusion that longer implants were more affected by peri-implant marginal bone loss than short implants, since the long-term concern of short implants is that a progressive marginal bone loss could shorten their life-span.

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 external authors were also involved to evaluate the risk of bias of the included trials in order to minimise bias.

With respect to generalisation 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 hypothesised 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 understanding the 10-year outcomes of both procedures in order to help clinicians to suggest the best therapeutic option to their patients.

Conclusions

In the presence of 5 to 8 mm of vertical residual bone above the mandibular canal, 5 years after loading, prosthetic and implant failures were similar between the short implants and vertical bone augmentations with interpositional blocks of bone substitutes to place implants at least 10 mm long, 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.

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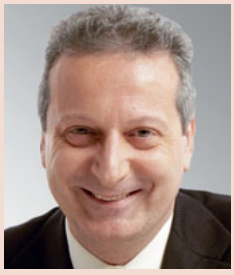

Marco Esposito

Marco Esposito, DDS, PhD
Freelance Researcher; and Associate Professor, Department of Biomaterials, The Sahlgrenska Academy at Göteborg University, Gothenburg, Sweden

Jacopo Buti, DDS, PhD, MPerio RCSEd
Senior Lecturer, Department of Periodontology, UCL Eastman Dental Institute, London, UK

Carlo Barausse, DDS
Resident, Department of Biomedical and Neuromotor Sciences, Unit of Periodontology and Implantology, University of Bologna, Bologna, Italy

Roberta Gasparro, DDS, PhD
Resident, Department of Neuroscience and Reproductive and Odontostomatological Sciences, University of Naples Federico II, Naples, Italy

Gilberto Sammartino, MD, DDS
Professor, Clinic of Oral Surgery, University of Naples Federico II, Naples, Italy

Pietro Felice, MD, DDS, PhD
Researcher; Department of Biomedical and Neuromotor Sciences, Unit of Periodontology and Implantology, University of Bologna, Bologna, Italy

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Correspondence to:
Dr Marco Esposito, Casella Postale 34, 20862 Arcore (MB), Italy. E-mail: espositomarco@hotmail.com