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Review

Interventions for Dental Implant Placement in Atrophic Edentulous Mandibles: Vertical Bone Augmentation and Alternative Treatments. A Meta-Analysis of Randomized Clinical Trials

Octavi Camps-Font,* Genís Burgueño-Barris,* Rui Figueiredo,*† Ronald E. Jung,‡§ Cosme Gay-Escoda,†‖¶# and Eduard Valmaseda-Castellón*†**

Background: The purpose of the current study is to assess which vertical bone augmentation techniques are most effective for restoring atrophic posterior areas of the mandible with dental implants and compare these procedures with alternative treatments.

Methods: Electronic literature searches in PubMed (MEDLINE), Ovid, and the Cochrane Library were conducted to identify all relevant articles published up to July 1, 2015. Eligibility was based on inclusion criteria, and quality assessments were conducted. The primary outcome variables were implant and prosthetic failure. After data extraction, meta-analyses were performed.

Results: Out of 527 potentially eligible papers, 14 randomized clinical trials were included. Out of these 14 studies, four trials assessed short implants (5 to 8 mm) as an alternative to vertical bone augmentation in sites with a residual ridge height of 5 to 8 mm. No statistically significant differences were found in implant (odds ratio [OR]: 1.02; 95% confidence interval [CI]: 0.31 to 3.31; $P = 0.98$; I^2: 0%) or prosthetic failure (OR: 0.64; 95% CI: 0.21 to 1.96; $P = 0.43$; I^2: 0%) after 12 months of loading. However, complications at treated sites increased with the augmentation procedures (OR: 8.33; 95% CI: 3.85 to 20.0; $P < 0.001$; I^2: 0%). There was no evidence of any vertical augmentation procedure being of greater benefit than any other for the primary outcomes (implant and prosthetic failure).

Conclusions: Short implants in the posterior area of the mandible seem to be preferable to vertical augmentation procedures, which present similar implant and prosthetic failure rates but greater morbidity. All the vertical augmentation technique comparisons showed similar intergroup results. *J Periodontol 2016;87:1444-1457.*

KEY WORDS

Alveolar ridge augmentation; bone transplantation; dental implants; mandible; mandibular nerve; meta-analysis.

* Department of Oral Surgery and Implantology, Faculty of Dentistry, University of Barcelona, Barcelona, Spain.
† Bellvitge Biomedical Research Institute, Barcelona, Spain.
‡ Division of Implantology, Center of Dental Medicine, University of Zürich, Zürich, Switzerland.
§ Clinic for Fixed and Removable Prosthodontics and Dental Material Science, Zürich, Switzerland.
‖ Department of Oral and Maxillofacial Surgery, School of Dentistry, University of Barcelona.
¶ Department of Oral Surgery and Implantology, European Foundation for Health Research and Education, Belize City, Belize.
# Department of Oral Surgery and Implantology, Private Catalan Foundation for Oral Health, Barcelona, Spain.
** Department of Oral Surgery, Implantology, and Maxillofacial Surgery, Teknon Medical Center, Barcelona, Spain.

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Since Brånemark et al.[1] defined osseointegration in the mid-1960s, oral rehabilitation with dental implants has become a common practice, with reliable and safe long-term results.[2] However, presence of an adequate bone volume is mandatory to achieve optimum treatment outcomes.[3] Lack of sufficient bone height to place dental implants in the posterior mandible due to the presence of the inferior alveolar nerve is a common scenario in partially edentulous patients. Hence, an atrophic posterior mandible presents a great challenge for successful rehabilitation.[4]

Although removable partial dentures are the most common and simplest option, many patients seek fixed prosthesis treatment. However, atrophy precludes use of standard size implants in many cases. As a result, several surgical procedures have been proposed to rehabilitate these patients with fixed implant-supported prostheses.[4-6]

Vertical bone augmentation techniques using guided bone regeneration (GBR),[7-14] alveolar distraction osteogenesis,[3,15-21] interpositional block grafts,[19,22-30] or onlay bone grafting[20,29,31-35] have shown favorable outcomes, both clinically and histologically.[4] However, these procedures cannot be considered the standard of care due to the high rate of postoperative complications. Also, information on long-term results (≥10 years of follow-up) is scarce.[5]

Use of short implants may be considered an alternative to reduce treatment time, costs, and morbidity, and to increase feasibility of treatment by general practitioners.[5,24-27,31] Although there is still no consensus regarding the cutoff length between short and standard implants,[36,37] Renouard and Nisand[38] defined short implants as devices with an intrabony length of 8 mm or less. Several studies have reported successful outcomes in terms of implant and prosthetic survival as well as implant success rates in short-term follow-ups.[5,39,40] Nevertheless, there are still concerns regarding consequences of peri-implant bone loss and its impact on long-term success rate. Also, placement of short implants requires a certain amount of bone above the mandibular canal, which is not always available.

Inferior alveolar nerve lateralization or transposition has been suggested as an alternative to augmentation procedures, allowing simultaneous insertion of standard implants without minimum bone height requirements.[41-45] However, both temporary and permanent neurosensory dysfunction as well as mandibular fractures may occur postoperatively and overshadow the high survival rates reported.[44,45]

Although two meta-analyses have been published on this topic, in 2009[5] and 2014,[40] they did not include some well-designed recently published trials. Furthermore, one of these reviews[40] also analyzed the outcomes of implants placed in the maxilla. Thus, a new meta-analysis of randomized controlled trials centered exclusively on the posterior mandible may add new information.

Aims of the present study are to analyze all relevant data from randomized clinical trials (RCTs), to assess which vertical bone augmentation techniques are most effective for restoring atrophic posterior areas of the mandible with dental implants, and to compare vertical bone augmentation procedures with alternative treatments.

MATERIALS AND METHODS

This meta-analysis complies with the Quality of Reporting of Meta-Analyses Statement.[46]

Study Selection Criteria

Inclusion criteria were: 1) RCTs (including split-mouth designs) that considered the effect of two different vertical bone augmentation procedures, or two different biomaterials for the same vertical bone augmentation technique, on the outcome of atrophic posterior mandible implant rehabilitation; and 2) RCTs (including split-mouth designs) comparing vertical bone augmentation with alternative surgical treatments, such as short implants (length ≤8 mm[38]) or inferior alveolar nerve transposition/lateralization.

Table 1.

Issues of Interest by Study Population (P), Intervention (I), Control Group (C), and Outcome (O) (PICO factors)

Parameter	Issues of Interest
Population	Healthy partially edentulous patients with vertical atrophy of the posterior mandibular region who may require alveolar bone augmentation prior to or during dental implant placement procedures
Intervention	GBR Interpositional bone graft (inlay) Onlay block graft Alveolar distraction osteogenesis
Control	Other vertical augmentation procedures (e.g., short implants [≤8 mm length] and inferior alveolar nerve transposition/lateralization) Other biomaterials
Outcome	Implant and prosthesis survival rate Major postoperative complications rate Augmentation procedure failure Biologic and prosthetic complications rate Radiographic bone gain Radiographic MBL Patient preference

Table 2.

Description of Selected Studies

Author (Year) Country	Design	Surgical Site	Intervention (test versus control)	Mean Follow-Up After Loading, Months (range)
Bianchi et al.[19] (2008) Italy	RCT (parallel groups)	Partially edentulous patients having 5 to 9 mm of residual bone above the mandibular canal without severe knife-edge defects measured on CT scan	Distraction osteogenesis Extraoral inlay autograft	30 (18 to 38) 22.5 (18 to 48)
Chiapasco et al.[3] (2004) Italy	RCT (parallel groups)	Partially edentulous patients requiring vertical augmentation procedures without severe knife-edge defects measured on panoramic radiographs	Distraction osteogenesis GBR autograft and ePTFE membrane	31 (18 to 54) 35 (18 to 48)
Chiapasco et al.[20] (2007) Italy	RCT (parallel groups)	Partially edentulous patients requiring vertical augmentation procedures without severe knife-edge defects measured on panoramic radiographs	Intraoral onlay autograft Distraction osteogenesis	38 (24 to 48) 41.3 (38 to 48)
Chiapasco et al.[34] (2013) Italy	RCT (parallel groups)	Partially edentulous patients having severe atrophy of the alveolar ridges measured on CT scan	Intra- or extraoral onlay autograft and pericranium membrane Intra- or extraoral onlay autograft and no membrane	23.9 (12 to 48)
Dottore et al.[30] (2014) Brazil	RCT (split-mouth)	Partially edentulous patients having 4 to 5 mm of residual bone above the mandibular canal and at least 4 mm thickness measured on CT scan	Intraoral inlay autograft Synthetic inlay graft	12 (12 to 12) 12 (12 to 12)
Esposito et al.[24] (2014) Italy	RCT (split-mouth)	Partially edentulous patients having 7 to 8 mm of residual bone above the mandibular canal and at least 8 mm thickness measured on CT scan	Short implants Inlay xenograft and resorbable membrane	36 (36 to 36) 36 (36 to 36)
Felice et al.[28] (2009) Italy	RCT (split-mouth)	Partially edentulous patients having 5 to 7 mm of residual bone above the mandibular canal and at least 5 mm thickness measured on CT scan	Xenograft inlay and resorbable membrane Extraoral inlay autograft	12 (12 to 12) 12 (12 to 12)
Felice et al.[29] (2009) Italy	RCT (parallel groups)	Partially edentulous patients having 4.5 to 11 mm of residual bone above the mandibular canal and at least 5 mm thickness measured on CT scan	Extraoral inlay autograft Extraoral onlay autograft	18.5 (17 to 22) 17.5 (13 to 22)

Table 2. (continued)

Description of Selected Studies

Author (Year) Country	Design	Surgical Site	Intervention (test versus control)	Mean Follow-Up After Loading, Months (range)
Felice et al.[25] (2014) Italy	RCT (parallel groups)	Partially edentulous patients having 7 to 8 mm of residual bone above the mandibular canal and at least 5.5 mm thickness measured on CT scan	Short implants Inlay xenograft and resorbable membrane	70 (70 to 70) 70 (70 to 70)
Fontana et al.[12] (2008) Italy	RCT (split-mouth)	Partially edentulous patients having a vertical defect of at least 3 mm in relation to the bone adjacent to the last tooth measured on panoramic radiographs or CT scan	GBR allograft and ePTFE membrane GBR autograft and ePTFE membrane	Not reported (12 to 36)
Merli et al.[11] (2014) Italy	RCT (parallel groups)	Partially edentulous patients requiring vertical augmentation procedures measured on panoramic radiographs	GBR autograft and resorbable membrane GBR autograft and ePTFE membrane	72 (72 to 72) 72 (72 to 72)
Pistilli et al.[26] (2013) Italy	RCT (parallel groups)	Partially edentulous patients having 7 to 8 mm of residual bone above the mandibular canal and at least 6 mm thickness measured on CT scan	Short implants Inlay xenograft and resorbable membrane	12 (12 to 12) 12 (12 to 12)
Pistilli et al.[27] (2013) Italy	RCT (split-mouth)	Partially edentulous patients having 5 to 7 mm of residual bone above the mandibular canal and at least 5 mm thickness measured on CT scan	Short implants Inlay xenograft and resorbable membrane	12 (12 to 12) 12 (12 to 12)
Ronda et al.[13] (2014) Italy	RCT (parallel groups)	Partially edentulous patients having <7 mm of residual bone above the mandibular canal measured on CT scan	GBR autograft + allograft and dPTFE membrane GBR autograft + allograft and ePTFE membrane	Not reported (15 to 37)

CT = computed tomography; dPTFE = dense polytetrafluoroethylene.

The posterior area of the mandible was classified as atrophic when bone height from the alveolar crest to the inferior alveolar nerve canal did not allow placement of standard length dental implants (length >8 mm).

The present review excluded trials with <1 year of follow-up after loading the implant-supported prosthesis. Implant placement, abutment connection, and yearly follow-up visits after prosthetic loading were used as time points. The predefined study population, intervention, control group, and outcome parameters for eligibility of studies are summarized in Table 1.

Primary outcome measures were as follows: 1) Implant survival: biologic failures were defined as implant mobility or removal of stable implants caused by progressive marginal bone loss (MBL) or infection. Mechanical failures were considered to comprise any mechanical complication, such as implant fractures or platform deformations, which rendered the implant unusable. Biologic failures were classified as early (failure to establish osseointegration before prosthetic loading) or late (failure to maintain the established osseointegration).[8] 2) Prosthesis survival: prosthetic failures were defined as failure to position the planned prosthesis due to implant failure(s) or loss of the prosthesis secondary to implant failure(s).[8]

Secondary outcome measures were as follows: 1) postoperative complications at augmented and/or donor sites (e.g., infection, nerve injury, hemorrhage) before prosthetic loading; 2) augmentation procedure failure: inability to position implants planned, not affecting survival of implant actually inserted; 3) biologic complications: implant function disturbances characterized by involvement of supporting tissues (e.g., peri-implantitis); 4) technical complications: mechanical damage to implants, implant components, and/or suprastructures (e.g., fractures of implants, screws, or abutments, fractures or deformations of the framework or veneers, or screw or abutment loosening); 5) radiographic bone gain (expressed in mm or as a percentage); 6) radiographic peri-implant MBL: marginal bone level changes over time, from baseline to last follow-up appointment (expressed in mm or as a percentage); and 7) patient preference (only in split-mouth trials).

Search Strategy

An electronic search of PubMed (MEDLINE), Ovid, and the Cochrane Library databases up to July 1, 2015 was conducted to identify all relevant human RCTs without year or language restrictions.

The following search terms were applied: [(vertical bone augmentation OR vertical ridge augmentation OR vertical ridge regeneration OR vertical bone regeneration OR guided bone regeneration OR bone graft OR block graft OR interpositional bone graft OR distraction osteogenesis) AND ("Dental Implants"[Mesh] OR short dental implants OR inferior alveolar nerve lateralization OR inferior alveolar nerve transposition) AND posterior mandible].

The search was completed by manual screening of references cited in the selected articles and reviews.

Selection of Studies

Two examiners (OC-F and GB-B) independently selected studies in accordance with inclusion criteria. Any disagreements were resolved by consensus.

Initially, duplicates or irrelevant publications (based on title) were excluded, and abstracts were examined. Finally, full texts of all remaining papers were assessed. Studies removed at this stage and reasons for their exclusion were recorded.

When multiple reports on the same patients were identified, the publication with the longest follow-up was included.

Data Extraction and Method of Analysis

Two reviewers (OC-F and GB-B) independently extracted data using data-extraction tables. Whenever possible, the following data were retrieved from the selected papers: 1) author(s); 2) year of publication; 3) country of origin; 4) study design; and 5) details of participants, intervention(s), and outcomes.

Implant and prosthesis survival rates were considered primary outcome variables. Secondary outcomes comprised: 1) major postoperative complication rate; 2) augmentation procedure failure rate; 3) mean radiographic bone gain; 4) MBL; and 5) patient preference.

Risk of Bias Assessment

Two reviewers (OC-F and GB-B) independently assessed risk of bias of the RCTs included as part of the data extraction process, using the Cochrane Collaboration tool for assessing risk of bias, suggested in the Cochrane Handbook for Systematic Reviews of Interventions (version 5.1.0).[47] The following items were evaluated: 1) sequence generation; 2) allocation concealment; 3) examiner and patient masking; 4) outcome masking; 5) incomplete outcome data addressed; 6) selective reporting; and 7) other sources of bias, such as conflict of interest. Publications were grouped into the following categories:[5] A) low risk of bias (possible bias not seriously affecting results) if all criteria were met; B) high risk of bias (possible bias seriously weakening reliability of results) if one or more criteria were not met; C) unclear risk of bias when too few details were available for classification as high or low risk. Authors were contacted for clarification of missing or unclear information when necessary.

Statistical Analyses

Statistical analysis was carried out with statistical software.†† For dichotomous outcomes, odds ratios

†† Review Manager v.5.3, The Cochrane Collaboration, Copenhagen, Denmark.

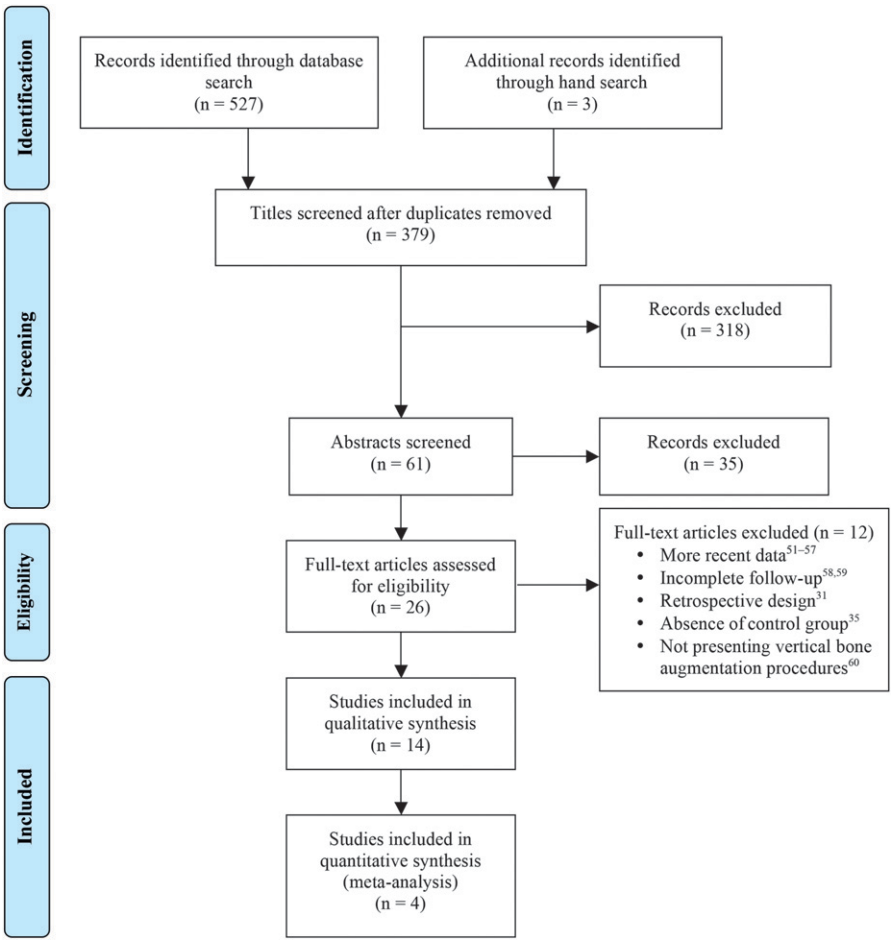

Figure 1.
Flowchart illustrating the study selection process.

(ORs) with 95% confidence intervals (CIs) were used to estimate effect of an intervention. Parametric and non-parametric tests (Pearson χ^2, Fisher, and Mann–Whitney tests) were used to compare groups. For continuous outcomes, mean differences and standard deviations (SDs) were used to summarize data for each group. The level of significance was set at a P value <0.05.

In parallel group studies, the statistical unit was the patient, not the augmentation procedure or implants. In split-mouth designs, augmentation procedures or prostheses used in each pair were the unit of analysis.[48]

A meta-analysis was only performed when there were studies comparing similar techniques and reporting the same outcome measures. ORs and mean differences were combined for dichotomous and continuous data, respectively, using random-effects models. Data from split-mouth studies were combined with data from parallel group trials using the generic inverse variance method.[49]

Statistical heterogeneity was estimated by means of χ^2 (Q value) and I^2 analyses. A χ^2 P value of <0.05 and an I^2 value of >50% were interpreted as significant heterogeneity.[50]

Had there been a sufficient number of meta-analyzed trials (more than 10), publication bias and clinical heterogeneity assessment, as well as sensitivity analyses, would have been performed according to Higgins and Green.[47]

RESULTS

Study Selection and Description

The initial electronic database search yielded 527 references, and three additional papers[26,27,34] were included after hand searching reference lists for pertinent articles and reviews. After duplicate removal and assessment of both title and abstract, a total of 26 articles were eligible for full-text analysis. Reviewer agreement was 95.2%, with a κ index of 0.90 (almost perfect agreement).

Twelve publications were excluded after applying study criteria: seven were removed as more recent data were available;[51-57] two trials were excluded as the follow-up after prosthetic loading was <1 year;[58,59] and another three papers were rejected because of retrospective design,[31] absence of a control group,[35] and not presenting vertical bone augmentation procedures,[60] respectively.

Finally, 14 RCTs fulfilled the inclusion criteria and were selected for qualitative synthesis (Table 2).[3,11-13,19,20,24-30,34] As four of these compared short implants to implants placed in vertically augmented bone by means of interpositional block xenografts, a meta-analysis of their results at 12 months after prosthetic loading was conducted.[24-27]

A flowchart of the screening process is shown in Figure 1.

Risk of Bias Assessment

All studies included were considered to have a high risk of participant and clinician/researcher masking bias due to difficulties in masking the selected treatment.[61] Hence, results of the present systematic review and meta-analysis should be interpreted with caution. Figure 2 summarizes the quality of RCTs included.

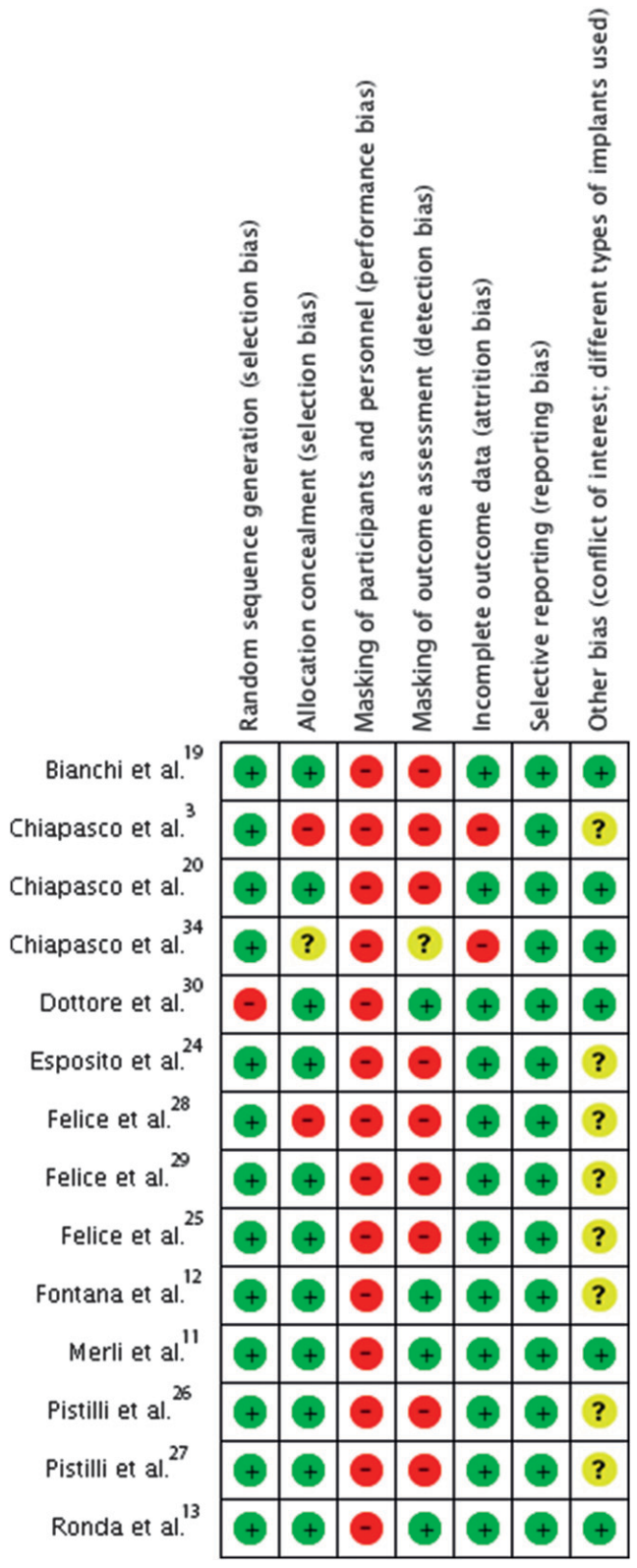

Figure 2.
Risk of bias assessment of selected studies. + = low risk of bias; - = high risk of bias; ? = unclear risk of bias.

Extraction Data

Qualitative synthesis. The fourteen studies selected comprised 276 patients, of whom 18 could not be analyzed due to dropout within the follow-up period (weighted mean dropout rate: 2.9%) (Table 3).[3,11-13,19,20,24-30,34]

None of the studies revealed significant differences between groups in terms of implant and prosthesis failure rates (P >0.05).

One hundred eight postoperative complications were reported in 243 vertical augmentation procedures (weighted mean postoperative complication rate: 44.4%; range: 8.3% to 89.5%) (Table 3). The most common complications were transient paraesthesia of the mental nerve (62.0%), surgical wound dehiscence (15.7%), and postoperative infections (13.9%). None of the studies revealed significant differences among groups (P >0.05) (Table 3).[3,11-13,19,20,24-30,34]

Fourteen postoperative complications were reported in 76 patients who received short dental implants (weighted mean postoperative complication rate: 18.4%; range: 0% to 42.1%). The most common complication was transient paraesthesia of the mental nerve (92.9%).[24-27] Of the four studies comparing short implants with augmentation procedures, three trials showed significantly more complications in the grafted group.[25-27]

In one trial, distraction osteogenesis showed a significantly higher bone gain than an autogenous inlay graft (10.4 versus 4.3 mm; P <0.01).[19]

Peri-implant MBL was registered in both groups in all of the studies. Autogenous onlay grafts were significantly associated with higher MBL than inlay grafts (2.9 versus 0.7 mm; P <0.01).[29] Additionally, two papers reported statistically significantly less bone loss around short implants.[25,26]

Quantitative synthesis. The four trials meta-analyzed involved a total of 135 patients.[24-27] Two had a split-mouth design.[24,27] Consequently, 85 patients were treated with short dental implants (test group) and 85 patients were reconstructed with interpositional block xenografts covered with a resorbable membrane to receive long implants (control group).

No statistically significant differences were found in: 1) implant failure (OR: 1.02; 95% CI: 0.31 to 3.31; P = 0.98; I^2: 0%) (Fig. 3A); 2) prosthetic failure (OR: 0.64; 95% CI: 0.21 to 1.96; P = 0.43; I^2: 0%) (Fig. 3B); 3) biologic complications (OR: 3.12; 95% CI: 0.12 to 85.21; P = 0.49; I^2: not applicable) (see supplementary Figure 1 in online *Journal of Periodontology*); 4) technical complications (OR: 3.12; 95% CI: 0.12 to 85.21; P = 0.49; I^2: not applicable) (see supplementary Figure 2 in online *Journal of Periodontology*); 5) patient preference (OR: 32.43; 95% CI: 0.02 to 42211.19; P = 0.34; I^2: 90%) (see supplementary Figure 3 in online *Journal of*

Table 3.

Comparison of Selected Studies

Variable	Bianchi et al.[19] (2008)	Chiapasco et al.[3] (2004)	Chiapasco et al.[20] (2007)	Chiapasco et al.[34] (2013)	Dottore et al.[30] (2014)	Esposito et al.[24] (2014)	Felice et al.[28] (2009)	Felice et al.[29] (2009)	Felice et al.[25] (2014)	Fontana et al.[12] (2008)	Merli et al.[11] (2014)	Pistilli et al.[26] (2013)	Pistilli et al.[27] (2013)	Ronda et al.[13] (2014)
Number of patients (dropouts)														
Test	5 (0)	5 (0)	8 (0)	8 (0)	11 (0)	15 (2)	10 (0)	10 (0)	30 (5)	5 (0)	11 (0)	20 (1)	20 (1)	12 (0)
Control	6 (0)	5 (0)	7 (0)	6 (0)	11 (0)	15 (1)	10 (0)	10 (0)	30 (5)	5 (0)	11 (1)	20 (1)	20 (1)	11 (0)
Implant failure														
Test, n (%)	0 (0)	0 (0)	0 (0)	0 (0)	1 (9.1)	1 (7.7)	1 (10)	0 (0)	3 (12)	0 (0)	0 (0)	1 (5.3)	0 (0)	0 (0)
Control, n (%)	0 (0)	0 (0)	0 (0)	0 (0)	1 (9.1)	1 (7.1)	1 (10)	0 (0)	3 (12)	0 (0)	0 (0)	1 (5.3)	1 (5.3)	0 (0)
OR (95% CI)	—	—	—	—	1.0 (0.1 to 18.3)	1.1 (0.1 to 19.3)	1.0 (0.1 to 18.6)	—	1.0 (0.2 to 6.3)	—	—	1.0 (0.1 to 17.3)	0.3 (0.0 to 8.3)	—
P value	>0.99	>0.99	>0.99	>0.99	>0.99	0.96	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.49	>0.99
Prosthesis failure														
Test, n (%)	0 (0)	0 (0)	0 (0)	0 (0)	1 (9.1)	1 (7.7)	1 (10)	0 (0)	4 (16)	0 (0)	0 (0)	0 (0)	0 (0)	0
Control, n (%)	0 (0)	0 (0)	0 (0)	0 (0)	1 (9.1)	0 (0)	1 (10)	0 (0)	5 (20)	0 (0)	0 (0)	2 (10.5)	2 (10.5)	0
OR (95% CI)	—	—	—	—	1.0 (0.1 to 18.3)	3.5 (0.1 to 93.3)	1.0 (0.1 to 18.6)	—	0.8 (0.2 to 3.2)	—	—	0.2 (0.0 to 4.0)	0.2 (0.0 to 4.0)	—
P value	>0.99	>0.99	>0.99	>0.99	>0.99	0.46	>0.99	>0.99	0.71	>0.99	>0.99	0.28	0.28	>0.99
Postoperative complications														
Test, n (%)	3 (60)	1 (20)	4 (50)	1 (12.5)	3 (27.3)	4 (30.8)	2 (20)	7 (70)	2 (8)	1 (20)	4 (36.4)	8 (42.1)	0 (0)	1 (8.3)
Control, n (%)	1 (16.7)	2 (40)	2 (28.6)	1 (16.7)	3 (27.3)	10 (71.4)	1 (10)	5 (50)	20 (80)	2 (40)	5 (50)	17 (89.5)	10 (52.6)	2 (18.2)
OR (95% CI)	7.5 (0.5 to 122.7)	0.4 (0.0 to 6.4)	2.5 (0.3 to 21.4)	0.7 (0.0 to 14.4)	1.0 (0.2 to 6.5)	0.2 (0.1 to 1.1)	2.3 (0.2 to 29.8)	2.3 (0.4 to 14.6)	0.0 (0.0 to 0.1)	0.4 (0.0 to 6.4)	0.6 (0.1 to 3.3)	0.1 (0.0 to 0.5)	0.0 (0.0 to 0.4)	0.4 (0.0 to 5.3)
P value	0.16	0.50	0.40	>0.99	>0.99	0.06	0.54	0.37	<0.01*	0.50	0.53	<0.01*	0.01*	0.49
Augmentation procedure failure														
Test, n (%)	0 (0)	0 (0)	1 (12.5)	0 (0)	0 (0)	NA	1 (10)	1 (10)	NA	0 (0)	2 (18.2)	NA	NA	0 (0)
Control, n (%)	0 (0)	1 (20)	1 (14.3)	1 (16.7)	0 (0)	0 (0)	0 (0)	1 (10)	2 (8)	0 (0)	1 (10)	1 (5.3)	3 (15.8)	0 (0)
OR (95% CI)	—	0.3 (0.0 to 8.5)	0.9 (0.0 to 16.9)	0.2 (0.0 to 6.3)	—	NA	3.3 (0.1 to 91.6)	1.0 (0.1 to 18.6)	NA	—	2.0 (0.2 to 26.2)	NA	NA	—
P value	>0.99	0.46	>0.99	0.37	>0.99	—	0.48	>0.99	—	>0.99	0.60	—	—	>0.99
Biologic complications														
Test, n (%)	1 (20)	0 (0)	0 (0)	0 (0)	1 (9.1)	1 (7.7)	1 (10)	0 (0)	2 (8)	1 (20)	0 (0)	0 (0)	0 (0)	0 (0)
Control, n (%)	1 (16.7)	1 (20)	0 (0)	0 (0)	1 (9.1)	0 (0)	1 (10)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
OR (95% CI)	1.3 (0.1 to 26.9)	0.3 (0.0 to 8.5)	—	—	1.0 (0.1 to 18.3)	3.5 (0.1 to 93.3)	1.0 (0.1 to 18.6)	—	5.4 (0.2 to 119.0)	3.7 (0.1 to 113.7)	—	—	—	—
P value	0.89	0.46	>0.99	>0.99	>0.99	0.46	>0.99	>0.99	0.28	0.46	>0.99	>0.99	>0.99	>0.99
Technical complications	NR	NR	NR	NR						NR				
Test, n (%)					0 (0)	1 (7.7)	0 (0)	0 (0)	4 (16)		0 (0)	0 (0)	0 (0)	0 (0)
Control, n (%)					1 (0)	0 (0)	0 (0)	0 (0)	1 (4)		0 (0)	0 (0)	0 (0)	0 (0)
OR (95% CI)					0.3 (0.0 to 8.3)	3.5 (0.1 to 93.3)	—	—	4.6 (0.5 to 44.2)		—	—	—	—
P value					0.48	0.46	>0.99	>0.99	0.19		>0.99	>0.99	>0.99	>0.99

Table 3. (continued)
Comparison of Selected Studies

Variable	Bianchi et al.[19] (2008)	Chiapasco et al.[3] (2004)	Chiapasco et al.[20] (2007)	Chiapasco et al.[34] (2013)	Dottore et al.[30] (2014)	Esposito et al.[24] (2014)	Felice et al.[28] (2009)	Felice et al.[29] (2009)	Felice et al.[25] (2014)	Fontana et al.[12] (2008)	Merli et al.[11] (2014)	Pistilli et al.[26] (2013)	Pistilli et al.[27] (2013)	Ronda et al.[13] (2014)
Bone gain (mm)														
Test, mean (SD)	10.4 (3.0)	4.8 (1.6)	4.6 (1.1)	NR	7.0 (2.6)	NR	NR	5.2 (1.1)	NR	4.7 (0.5)	2.2 (1.5)	NR	NR	5.5 (1.6)
Control, mean (SD)	6.1 (0.7)	5.8 (1.5)	5.3 (1.6)		6.5 (1.6)			6.2 (1.1)		4.1 (0.9)	2.5 (1.1)			4.1 (1.9)
Mean difference (95% CI)	4.3 (1.6 to 7.0)	-1.0 (-2.9 to 0.9)	-0.7 (-1.5 to 0.1)		0.5 (-1.3 to 2.3)			-1.0 (-2.0 to 0.0)		0.6 (-0.3 to 1.5)	-0.3 (-1.4 to 0.8)			1.4 (0.0 to 2.8)
P value	<0.01*	0.31	0.33		0.59			0.04*		0.19	0.60			0.06
MBL (mm)		NR		NR										NR
Test, mean (SD)	2.0 (1.3)		1.1 (0.5)		0.8 (0.8)	1.4 (0.4)	1.3 (0.6)	0.7 (0.8)	2.2 (0.5)	1.3 (1.2)	1.3 (0.8)	0.9 (0.1)	1.1 (0.1)	
Control, mean (SD)	1.0 (0.2)		1.3 (0.4)		1.0 (0.9)	1.6 (0.5)	1.6 (0.9)	2.9 (1.1)	3.0 (0.7)	0.8 (0.9)	1.0 (1.0)	1.0 (0.1)	1.1 (0.1)	
Mean difference (95% CI)	1.0 (-0.2 to 2.2)		-0.2 (-0.7 to 0.3)		-0.2 (-0.9 to 0.5)	-0.2 (-0.5 to 0.1)	-0.3 (-1.0 to 0.4)	-2.2 (-3.0 to -1.4)	-0.8 (-1.1 to -0.5)	0.5 (-0.8 to 1.8)	0.3 (-0.5 to 1.1)	-0.1 (-0.2 to 0.0)	0.0 (-0.1 to 0.1)	
P value	0.09		0.39		0.58	0.26	0.41	<0.01*	<0.01*	0.46	0.45	<0.01*	0.31	
Patient preference (%)	NA	NA	NA	NA	NR			NA	NA	NR	NA	NA		NA
Test						2 (14.3)	8 (80)						20 (100)	
Control						2 (14.3)	0 (0)						0 (0)	
Both						10 (71.4)	2 (20)						0 (0)	
OR (95% CI)						1.0 (0.1 to 8.3)	33.0 (1.1 to 10236)						441.0 (7.8 to 243727)	
P value						>0.99	0.05*						<0.01*	

— = Not calculable from a mathematical point of view. For example, OR for 0 events in both experimental and control groups or when the variable was not applicable in one of the groups, leading to an undetermined outcome; NA = not applicable; NR = not reported.
* Significantly associated (P <0.05).

Periodontology); or 6) peri-implant MBL (mean difference: –0.03 mm; 95% CI: –0.11 to 0.05; P = 0.44; I^2: 53%) (see supplementary Figure 4 in online *Journal of Periodontology*) after 12 months of prosthetic loading. However, augmentation groups were associated with an increased rate of postoperative complications (56 out of 85 patients) compared with short implant groups (18 out of 85 patients) (OR: 8.33; 95% CI: 3.85 to 20.0; P <0.001; I^2: 0%) (Fig. 3C).

DISCUSSION

The present study, which used recommended methods for systematic reviews and meta-analyses, aimed to compare effectiveness of different vertical ridge augmentation procedures and then compare these procedures with treatment alternatives. However, due to the lack of data on many therapeutic approaches, the only comparison that could be made was between alveolar ridge augmentation and short implants or inferior alveolar nerve transposition.

Four trials involving atrophic posterior mandibles with a residual bone height of 5 to 8 mm evaluated whether short implants could be an alternative to inlay augmentation with xenograft blocks in combination with the placement of standard-length implants (≥10 mm).[24-27] Meta-analysis of these papers showed short implant groups were associated with significantly fewer postoperative complications, without compromising implant and prosthetic survival (Fig. 3).[24-27] However, these results should be treated with caution since all four trials had a potential risk of bias. In addition, they were all conducted by the same research group, using a similar augmentation protocol, and with limited follow-up and sample sizes. What is more, their internal validity might be compromised since they were all conducted mainly in multiple private practices, and in two of the studies, operations were not performed by the same surgeon, leading to potential operator-dependent

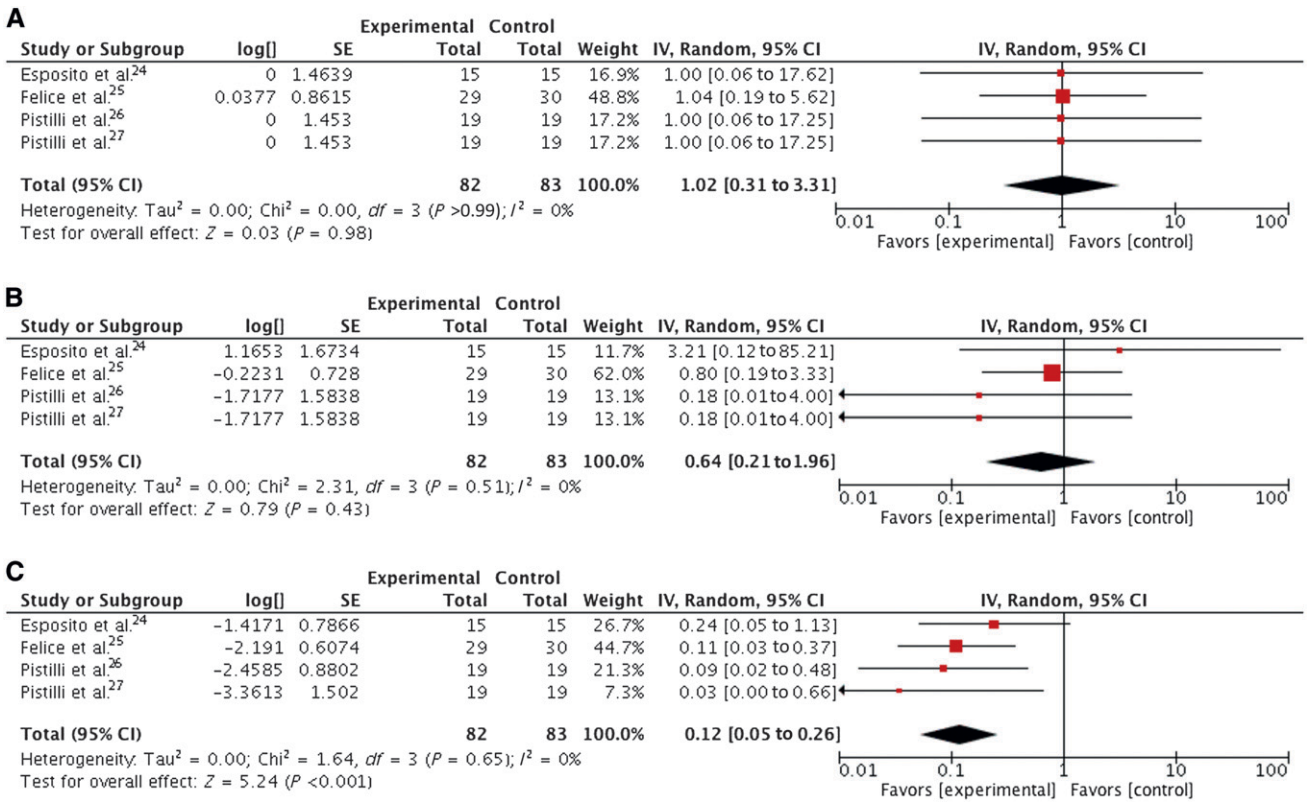

Figure 3.
*Forest plots (OR) for implant failure **(A)**, prosthetic failure **(B)**, and postoperative complications **(C)** comparing short implants (test group) with interpositional block xenografts covered with a resorbable membrane to receive long implants (control group) at 12 months' follow-up. IV = independent variable.*

bias.[26,27] This issue could affect reliability and quality of the studies. In addition, the small number of participants in all these studies might have led to a Type 2 error (failure to reject a false null hypothesis). Indeed, if implant failure is defined as the primary outcome and a 0.2 difference between groups is considered clinically significant (as proposed by Felice et al.[25]), only one study had a statistical power greater than 70%.[27] Furthermore, due to the small number of papers available for review, no evaluation of publication bias (i.e., funnel plot) could be made.[47] Finally, all but one of the selected articles reported on studies performed in Italy, so their external validity would seem to be threatened as well.[30] Another possible limitation of the present paper is that gray literature and hand searching of related journals were not included in the search strategy, so some studies might have been neglected.

Peñarrocha-Oltra et al.[31] described similar survival and success rates for implant treatment in sites with vertical bone defects involving autogenous onlay block grafts or short dental implants, but the rate of complications was significantly higher in the augmented group (this article was excluded because of its retrospective design).

On the other hand, a recent meta-analysis of RCTs showed no differences among the groups regarding implant survival/success and complications.[40] A possible explanation for this difference could be related to the fact that none of the four articles selected for that paper were considered in the present review: two trials[51,52] were replaced by others with more recent data,[24,25] one study included augmentation techniques in the posterior maxilla,[62] and one paper was rejected because standard implants were placed in native bone.[63]

Treatment duration and cost may also play an important role in the decision and willingness of the patient to undergo vertical ridge augmentation.[64] Undeniably, bone regeneration techniques entail additional biologic and financial costs associated with one additional surgical procedure, a bone substitute, and a barrier membrane, and at least an additional 4 months to complete treatment. In the studies reviewed, almost twice the number of patients preferred short implants to augmentation procedures, although the difference was not significant, probably due to the small number of meta-analyzed studies reporting patient-based outcomes.[24,27]

Several reports show implant length has no impact on peri-implant MBL in the short term.[65-67] However, it seems reasonable to assume that peri-implant bone loss around short implants can be more critical than in standard implants, as loss of osseointegration can occur in a short time span.[65] Therefore, it is crucial to control main risk factors for peri-implant diseases and apply strict maintenance programs for long-term performance of these implants.

Information on inferior alveolar nerve transposition is scarce, highlighting the need to perform RCTs to assess whether this approach offers advantages over other surgical techniques in the posterior area of the mandible. Thus, in the opinion of the authors, until data from well-designed RCTs become available for analysis, other options such as use of short implants or augmentation techniques seem preferable.

Although 10 of the trials included aimed to determine the most effective vertical bone augmentation techniques, a meta-analysis could not be performed since there were insufficient trials comparing the same interventions.[3,11-13,19,20,28-30,34]

Vertical augmentation techniques evaluated showed some failures[3,11,20,24,26-30,34] and were associated with high complication rates, ranging from 8%[13] to 90%.[26] Furthermore, it has to be taken into account that since most grafting procedures were performed by experienced clinicians, caution is recommended when extrapolating results to other clinical scenarios such as general practice.

Distraction osteogenesis allows more bone gain[19] and a reduction in treatment time.[3,19,20] However, other procedures such as GBR or onlay block grafting techniques may permit simultaneous bone widening if needed.[5]

Autogenous bone is often considered the "gold standard" material for bone augmentation procedures.[5] Nevertheless, three trials compared autogenous grafts with bone substitutes and observed no differences for any clinical outcomes registered.[12,28,30] Indeed, Felice et al.[28] reported eight out of 10 patients preferred augmentation procedures with a bone substitute, probably due to lower postoperative morbidity. On the other hand, from a histomorphometric point of view, two of the studies revealed more residual grafted material at implant placement in the group treated with bone substitutes.[28,30] Moreover, implants placed in bone augmented with substitutes showed a tendency to increased MBL.[12,28] Further research is needed to clarify which graft material is most cost-effective.

Similarly, non-resorbable titanium-reinforced expanded polytetrafluoroethylene (ePTFE) membranes are traditionally considered the benchmark for vertical GBR.[8,9,68,69] However, an increased rate of soft tissue complications after premature membrane exposure has been reported as a major disadvantage of these barriers.[70] Once exposed to the oral cavity, their porous surface (100- to 300-μm porosity)[13] is rapidly colonized by bacteria, leading to infections of adjacent tissues that require early membrane removal, resulting in impaired bone regeneration.[71,72] Another disadvantage of non-resorbable membranes is the need for re-entry surgery and membrane removal, which is associated with patient morbidity. To overcome such drawbacks and simplify surgical protocols, resorbable membranes have been proposed.[73] Merli et al.[11] revealed similar outcomes with fewer postoperative complications when using resorbable barriers in comparison with non-resorbable ones after a 6-year follow-up period. Nevertheless, when ePTFE was used, a higher bone gain was recorded, and less peri-implant MBL was registered over time.

CONCLUSIONS

Placement of short implants (5 to 8 mm) seems to be the best option for treating atrophic posterior areas of the mandible, since this approach is less invasive and has a significantly lower complication rate when compared with more demanding grafting procedures. Furthermore, survival rates and marginal bone level changes after 1 year of loading seem similar. To confirm these results, large-sample studies involving several centers and countries, different surgical protocols, and patient-centered outcomes should be conducted.

Different surgical protocols for vertical bone augmentation seem to provide similar intergroup results. Bone substitutes usually entail less postoperative morbidity and may be a valid alternative to autogenous bone. Well-designed RCTs are needed to determine which bone augmentation techniques are more effective, simpler, and safer and have better long-term results.

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Correspondence: Dr. Rui Figueiredo, Faculty of Dentistry, University of Barcelona, Campus de Bellvitge, Facultat d'Odontologia, Cirugía e Implantología Bucal, C/ Feixa Llarga, s/n; Pavelló Govern, 2ª planta., 08907 L'Hospitalet de Llobregat, Barcelona, Spain. E-mail: rui@ruibf.com.

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