The Efficacy of Various Bone Augmentation Procedures for Dental Implants: A Cochrane Systematic Review of Randomized Controlled Clinical Trials

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Purpose: *To test* (a) *whether and when bone augmentation procedures are necessary and* (b) *which is the most effective augmentation technique for specific clinical indications. Trials were divided into 3 categories:* (1) *major vertical or horizontal bone augmentation (or both);* (2) *implants placed in extraction sockets;* (3) *fenestrated implants.* ***Materials and Methods:*** *An exhaustive search was conducted for all randomized controlled clinical trials (RCTs) comparing different techniques and materials for augmenting bone for implant treatment reporting the outcome of implant therapy at least to abutment connection. No language restriction was applied. The last electronic search was conducted on October 1, 2005.* ***Results:*** *Thirteen RCTs of 30 potentially eligible trials reporting the outcome of 332 patients were suitable for inclusion. Six trials evaluated techniques for vertical and/or horizontal bone augmentation. Four trials evaluated techniques of bone grafting for implants placed in extraction sockets, and 3 trials evaluated techniques to treat fenestrated implants.* ***Conclusions:*** *Major bone grafting procedures of extremely resorbed mandibles may not be justified. Bone substitutes may replace autogenous bone for sinus lift procedures of extremely atrophic sinuses. Both guided bone regeneration procedures and distraction osteogenesis can be used to augment bone vertically, but it is unclear which is the most efficient. It is unclear whether augmentation procedures are needed at immediate single implants placed in fresh extraction sockets; however, sites treated with barrier + Bio-Oss showed a higher position of the gingival margin than sites treated with barriers alone. More bone was regenerated around fenestrated implants with nonresorbable barriers than without barriers; however, it remains unclear whether such bone is of benefit to the patient. Bone morphogenetic proteins may enhance bone formation around implants grafted with Bio-Oss, but there was no reliable evidence supporting the efficacy of other active agents, such as platelet-rich plasma, in conjunction with implant treatment.* INT J ORAL MAXILLOFAC IMPLANTS 2006;21:696–710

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This review is based on a Cochrane systematic review titled "Interventions for replacing missing teeth: bone augmentation techniques for dental implant treatment" published in The Cochrane Library (see www.CochraneLibrary.net for information). Cochrane systematic reviews are regularly updated to include new research, and in response to comments and criticisms from readers. If you wish to comment on this review, please send your comments to the Cochrane website or to Marco Esposito. The Cochrane Library should be consulted for the most recent version of the review. The results of a Cochrane Review can be interpreted differently, depending on people's perspectives and circumstances. Please consider the conclusions presented carefully. They are the opinions of the review authors and are not necessarily shared by the Cochrane Collaboration.

Conflict-of-interest statement: Marco Esposito and Paul Coulthard are among the authors of 2 of the included trials; however, they were not involved in the quality assessment of these trials.

Different indications, numerous alternative techniques, and various "biologically active" agents and biomaterials are currently used to augment bone. Each type of augmentation material may be used in combination with a variety of different surgical techniques, so many permutations of treatment are possible, and the situation is rather complicated. In addition, new techniques and "active agents" are continuously introduced in clinical practice. Particular treatment options have strong proponents, with surgeons claiming that a particular material or technique offers improved implant success. Several reviews have been published on the topic. Among the older ones 3 are worth mentioning[1–3]; however, their findings were not based on the most reliable clinical trials. Therefore, the information presented has to be interpreted with a great deal of caution. A few other systematic reviews have been published more recently[4–7]; however, these were not conducted in a systematic way according to the Cochrane Collaboration criteria.

The general aim of the present review was to test the null hypothesis that there would be no difference in the success, function, side effect, and patient satisfaction between different bone augmentation techniques or no bone augmentation for dental implant treatment. More specific objectives were to determine whether and when augmentation procedures are necessary and which is the most effective augmentation technique for specific clinical indications. Augmentation procedures were divided into 3 broad categories of clinical indication: *(1)* techniques for vertical or horizontal bone augmentation or both (major augmentation procedures); *(2)* techniques to treat implants placed in extraction sockets (minor augmentation procedures); and *(3)* techniques to treat bone dehiscence or fenestrations around implants (minor augmentation procedures).

MATERIALS AND METHODS

Inclusion Criteria and Outcome Measures

The entire protocol for this review was conceived a priori, internally and externally refereed, and published electronically on the Cochrane database a priori, open to public criticism. To minimize bias[8,9] only randomized clinical trials (RCTs) and preference RCTs of adequate quality comparing any bone augmentation technique or active agent, eg, bone morphogenetic proteins (BMPs), platelet-rich plasma (PRP), or other biomaterials used with osseointegrated, root-formed dental implants were considered. The RCTs had to include implant placement, and the outcome of the therapy had to be reported at least through abutment connection. The treatment of peri-implant defects induced by peri-implantitis is analyzed in another Cochrane review.[10]

The following outcome measures were evaluated:

1. Prosthesis failure. This included planned prostheses which could not be placed due to implant failure(s) and loss of the prostheses secondary to implant failure(s).
2. Implant failure. Implant mobility was considered failure, as was the removal of stable implants dictated by progressive marginal bone loss or infection (biologic failures). Biologic failures were grouped as early (failure to establish osseointegration) and late failures (failure to maintain the established osseointegration). Failures that occurred before prosthesis placement were considered early failures. Implant mobility could be assessed manually, by Periotest (Siemens, Bensheim, Germany) or using resonance frequency analysis (Osstell; Integration Diagnostics, Göteborg, Sweden).
3. Augmentation procedure failure. Failure of the augmentation procedure (ie, of the bone graft or the guided bone regeneration [GBR] procedure) not affecting the success of the implant.
4. Major complications at augmented sites. These included infection, nerve injury, and hemorrhage.
5. Major complications at bone donor sites, such as nerve injury, gait disturbance, or infection.
6. Patient satisfaction, including esthetics.
7. Patient preference, including esthetics (only in split-mouth trials).
8. Vertical and/or horizontal bone gain.
9. Esthetics as evaluated by the clinician.
10. Duration of the treatment time from the first intervention to the functional loading of the implants.
11. Treatment costs.

Trials evaluating only histologic outcomes were not considered in this review.

Search Strategy

Search strategy for identification of studies, methods of the review, quality assessment, and data extraction and synthesis were described in a previous article.[11] The most recent electronic search was undertaken on October 1, 2005.

For dichotomous outcomes, the estimates of effect of an intervention were expressed as odds ratios (ORs) together with 95% confidence intervals (CIs). For continuous outcomes, weighted mean differences and standard deviations (SDs)were used to summarize the data for each group using mean differences and 95%

Table 1 List of Excluded but Potentially Eligible RCTs with Reasons For Their Exclusion

Authors of study	Year published	Reason(s) for exclusion
Gher et al[14]	1994	Problems with design and analysis. The unit of randomization was both the patient and the implant, and it was not possible to use the data without further information from authors. No reply to letter.
Zitzmann et al[15]	1997	Unclear study design.
Froum et al[16]	1998	Described as RCT, unclear number of patients and tested interventions which seem to be much more than 8, unequal number of patients in the treatment groups. No reply to letter.
Schlegel et al[17]	1998	Inappropriate study design, neither parallel group nor split mouth.
Majzoub et al[18]	1999	Unable to use data as presented on the basis of site rather than patient. Conflicting reporting of infection and dehiscence data.
Antoun et al[21]	2001	Study initially included but later excluded because it does not contain any outcome measures related to implant treatment.
Tawil et al[22]	2001	Inappropriate study design, neither parallel group nor split mouth.
Friedmann et al[23]	2002	Study initially included but later excluded because it does not contain any outcome measures related to implant treatment.
Norton et al[25]	2002	The author kindly informed the authors of this article that the trial was not an RCT but a controlled clinical trial with unequal numbers of patients treated in the intervention groups and with a mixed parallel group/split-mouth design.
Prosper et al[27]	2003	Unclear how many patients were included in each group. No reply to the letter requesting additional clarification.
Barone et al[41]	2005	No clinical outcome measures related to implant treatment.
Bettega et al[31]	2005	Protocol of a study with no clinical outcomes related to implant treatment.
Boyne et al[32]	2005	Unclear number of patients, unequal number of patients in the treatment groups. No reply to letter.
Fiorellini et al[34]	2005	No clinical outcome measures related to implant treatment.
Kassolis et al[35]	2005	No clinical outcome measures related to implant treatment.
Schortinghuis et al[36]	2005	Interesting placebo-controlled pilot trial evaluating the efficacy of ultrasound in stimulating bone formation in a distraction gap. Excluded because only histological outcomes were reported; however, worth reading.
Suba et al[40]	2006	No clinical outcome measures related to implant treatment.

CIs. The statistical unit was the patient, not the augmentation procedure or the implants.

Only if there were studies with similar comparisons reporting the same outcome measures was meta-analysis to be attempted. ORs were to be combined for dichotomous data, and mean differences for continuous data, using random-effects models. Data from split-mouth studies were to be combined with data from parallel group trials with the method outlined by Elbourne and colleagues,[12] using the generic inverse variance method in RevMan (the statistical package of the Cochrane Collaboration). No studies comparing similar interventions were found, so a meta-analysis was not conducted.

Description of Studies

Of the 30 potentially eligible trials,[13–41] 17 were excluded (Table 1) because of problems with study design,[14–17,22,25] because they reported only histologic outcomes and did not report any implant-related outcomes,[21,23,31,34–36,40,41] or because it was not possible to use any of the data presented.[18,27,32]

Of the 13 included trials (Table 2), 9 trials had a parallel-group study design and 4 had a split-mouth design.[13,24,26,37] One of the split-mouth trials[24] had a third intervention group composed of those patients who refused to undergo autogenous bone harvesting and were treated with a xenograft (preference trial).

For 7 trials, commercial support was received from a party directly involved in the product being tested.[13,19,24,28,33,37] One trial received support from the implant manufacturer; however, the trial was designed to test not the implants, but the augmentation techniques.[39] The authors of 4 trials declared that no support was received from commercial parties whose products were being tested in the trials.[26,29,30,38] One trial[26] tested a product which had been produced internally.

Eight trials were conducted at university or specialist dental clinics. Five trials were conducted in private practices.[30,33,38,39] One of the centers (Brugge, Belgium) of the multicenter trial was also a private practice.[37] All studies included only adults.

Table 2 List of the Included RCTs

Author of study	Year of publication	Country
Dahlin et al[13]	1991	Sweden
Chen et al[33] (1)*	2005	Australia
Chen et al[33] (2)	2005	Australia
Carpio et al[19]	2000	United States
Wannfors et al[20]	2000	Sweden
Hallman et al[24]	2002	Sweden
Jung et al[26]	2003	Switzerland
Stellingsma et al[28]	2003	The Netherlands
Stellingsma et al[42]	2004	The Netherlands
Stellingsma et al[43]	2005	The Netherlands
Chiapasco et al[29]	2004	Italy
Cornelini et al[30]	2004	Italy
Szabó et al[37]	2006	European multicenter
Merli et al[39]	2006	Italy
Chen and Darby[38]	in press	Australia

Two follow-up studies have been published since the publication of this article.[42,43] In the text only the "primary" reference, ie, the first published report of the RCT, was cited.
*In Chen et al (1)[33] 2 distinct RCTs were presented together in a single article as if they were a single RCT. However, the authors clarified this, and in the present review the data has been correctly presented separately for the 2 RCTs.

Characteristics of the Interventions

The main inclusion and exclusion criteria used by the authors of the included RCTs are described in Figs 1 and 2; the evaluated outcome measures are listed in Fig 3. In several studies, the implants were followed through abutment connection/implant loading.[13,19,26,30,37] One sample was followed for 1 year postloading,[24] 2 for 2 years postloading,[28,33] and 3 for 3 years postloading.[20,29,38] According to the authors, who were contacted regarding the matter, 5-year follow-up reports are expected for many of the trials.[20,24,26,28,29,39]

Methodological Quality of Included Studies

After additional information kindly provided by the authors of the trials was incorporated, the articles were scored for quality; the scores are summarized in Table 3.

Each trial was assessed for risk of bias. Eight studies were judged to be at high risk of bias, and 5 were considered at low risk of bias.[13,19,26,30,39]

Sample Size

A priori calculation for the sample size was undertaken in only 1 trial.[39] The calculation was based on the complications that occurred in another similar RCT.[23] Twenty-one patients were needed in each group to detect a difference between a proportion of complications from 0.27 to 0.80. However, the report was an interim report presenting data of the first 20 patients; therefore, the sample size requirement had not yet been fulfilled.

- Extremely resorbed mandibles, ie, symphyseal height of 6 to 12 mm as measured on standardized lateral radiographs of patients who had been edentulous for at least 2 years and experienced severe functional problems with their lower dentures.[28]
- Two to 7 mm of residual alveolar bone in the floor of the edentulous sinus.[20]
- Less than 5 mm of residual alveolar bone in the floor of the edentulous sinus.[24,37]
- Dehiscences or fenestrations at implant placement.[19,26] In 1 trial testing the effect of rhBMP-2 on GBR, the distance between test and control sites had to be at least 7 mm.[26]
- Edentulous maxillae with buccal fenestrations at implant placement around at least 2 contralateral implants having a similar size.[13] In all cases a marginal bone buttress was present. The vertical bone could not be less than 13 mm in height, and horizontal resorption of the alveolar crest was required, with buccal concavities at the mid-portion of the ridge, as determined using computed tomography.
- Edentulous ridges requiring vertical regeneration.[29,39]
- Single postextractive fresh sockets.[30]
- Single postextractive fresh sockets at maxillary anterior and premolar sites.[33,38]

Fig 1 List of the main inclusion criteria used in the included RCTs.

- Heavy smokers (more than 2 packs of cigarettes per day)[19]
- More than 20 cigarettes per day[39]
- More than 15 cigarettes per day[29]
- Smokers[33]
- Metabolic bone diseases[19,20]
- Medication interfering with bone metabolism (eg, corticosteroids, bisphosphonates)[19,20]
- Sinusitis[19,20]
- Severe knife-edge ridges[29]
- Acute infection and suppuration at the fresh extraction socket[30,33,38] and > than 5 mm of attachment loss at buccal aspects[38]
- Mucosal disease, such as lichen planus, in the areas to be treated[29]
- None specified[13,24,26,37]

Fig 2 List of the main exclusion criteria used in the included RCTs.

- Prosthesis failure[20,24,28-30,33,37–39]
- Implant failure: All trials
- Augmentation procedure failure[13,19,20,24,26,29,37–39]
- Major complications at the augmented site[13,19,24,26,28–30,33,37–39]
- Major complications at the bone donor site[24,28,29,37,39]
- Perforation of the sinus membrane[20]
- Patient satisfaction, including esthetics[28,38]
- Patient preference, including esthetics (only in split-mouth trials): No trial
- Horizontal or vertical bone gain, expressed either in millimeters[19,26,29,33,38,39] or percentage[13]
- Esthetics, assessed by dentist[30,38]
- The position of the mucosal margin in relation to the implant shoulder[30]
- Occurrence of marginal mucosa recession[38]
- Duration of the treatment period starting from the first intervention to functional loading of the implants: All trials
- Treatment costs: No trial. However, this outcome measure was indirectly extrapolated by the authors of this review for all trials

Fig 3 Outcome measures evaluated in the included RCTs.

Table 3 Results of Quality Assessment After Correspondence with the Authors

Authors of study	Year of publication	Allocation	Blinding of assessor	Clear explanation of withdrawals	Risk of bias
Dahlin et al[13]	1991	Adequate	Yes	Yes	Low
Carpio et al[19]	2000	Adequate	Yes	Yes	Low
Wannfors et al[20]	2000	Unclear	No	Yes	High
Hallman et al[24]	2002	Adequate*	No	Yes	High
Jung et al[26]	2003	Adequate	Yes	Yes	Low
Stellingsma et al[28]	2003	Unclear	No	Yes	High
Chiapasco et al[29]	2004	Inadequate	No	Yes	High
Cornelini et al[30]	2004	Adequate	Yes	Yes	Low
Chen et al[33] (1)	2005	Adequate	No	Yes	High
Chen et al[33] (2)	2005	Adequate	No	Yes	High
Szabó et al[37]	2005	Unclear	No	Yes	High
Merli et al[39]	2006	Adequate	Not possible	Yes	Low
Chen and Darby[38]	in press	Adequate	No	Yes	High

*Only for the randomized interventions.

Baseline Comparability Between Treatment Groups

For the majority of the studies, no major baseline differences were apparent.[19,20,28–30,33,38,39] For 3 studies, it was unclear whether major baseline differences existed.[13,24,37] For Jung et al, defect depth was shallower for control sites.[26]

A percentage agreement of 100%, as well as a kappa score of 1.0, were found between the 2 raters for allocation concealment, outcome assessor blinding, and completeness of follow-up.

RESULTS

In total 332 patients were enrolled in the 13 trials. Since different techniques were evaluated, no meta-analysis could be performed.

Techniques for Vertical and/or Horizontal Bone Augmentation (Major Augmentation Procedures)

Is The Augmentation Procedure Necessary? (1 trial). One trial[28] (Table 4) evaluated the use of 4 short implants (8 to 11 mm; Twin Plus IMZ implants; Friatec, Mannheim, Germany) versus the use of interposed iliac bone grafts and 4 longer implants (13 to 18 mm; specially designed IMZ apical screw implants) in atrophic mandibles (residual bone height between 6 to 12 mm) to support overdentures. Twenty patients were enrolled in each group. Two patients dropped out.

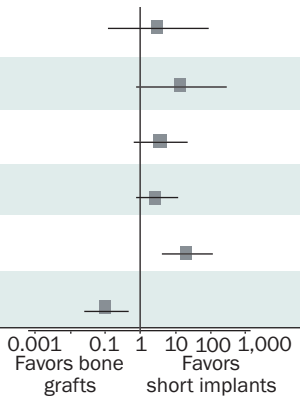
Complications. In the short implant group, 1 patient experienced bleeding during surgery and another suffered permanent unilateral hypoesthesia. No patients experienced implant failure. In the augmented group, 1 patient had a postoperative sublingual edema which left the patient in intensive care for 3 days; 2 patients experienced wound dehiscence; 2 reported unilateral dysesthesia, 1 of whom completely recovered; and 1 patient developed necrosis of the osteotomized cranial fragment of the mandible. Four patients lost 1 implant each and a fifth patient lost all implants (possibly because of necrosis of the osteotomized cranial fragment) before or at abutment connection. Although the *P* value for the OR was not statistically significant ($P = .08$) in RevMan, a 2-sided Fisher exact test found a significant difference ($P = .048$), with higher implant failures for the augmented mandibles, which confirmed the findings of the original article.

Prosthetic Aftercare. There were 4 unplanned interventions in the short implant group versus 10 in the graft group.

Patient Satisfaction. Numerous aspects, including esthetics, were investigated using validated questionnaires at 1 year, and no statistically significant differences among groups were found. The following statistically significant differences were found 3 weeks after the first surgical intervention: *(a)* 85% of the patients in the augmentation group reported serious pain for more than 1 week versus 20% of the patients in the short implant group (OR 22.7; 95% CI 4.4 to 117.5); *(b)* 30% of the patients in the augmentation group reported no improvement in their facial appearance versus 80% of the patients in the short implant group (in this group, 70% reported no change, and 10% reported a deterioration of their facial appearance) (OR 0.11; 95% CI 0.03 to 0.46); and *(c)* significantly more patients (50%) in the augmentation group experienced the operation more nega-

Table 4 Interventions for Replacing Missing Teeth: Bone Augmentation Techniques for Dental Implant Treatment

Study or subcategory	Bone grafts (n/N)	Short implants (n/N)	OR (fixed) 95% CI	Weight (%)	OR (fixed)	95% CI
Prosthetic failure (2 years)						
Stellingsma et al[28]	1/19	0/19		100.00	3.16	0.12 to 82.64
Implant failure (2 years)						
Stellingsma et al[28]	5/19	0/19		100.00	14.79	0.76 to 289.43
Major complication at augmented site						
Stellingsma et al[28]	6/20	2/20		100.00	3.86	0.67 to 22.11
Experienced the operation negatively						
Stellingsma et al[28]	10/20	5/20		100.00	3.00	0.79 to 11.44
Severe pain for > 1 week						
Stellingsma et al[28]	17/20	4/20		100.00	22.67	4.37 to 117.47
No improvement of facial appearance (3 weeks)						
Stellingsma et al[28]	6/20	16/20		100.00	0.11	0.03 to 0.46



Comparison: augmentation versus no augmentation: vertical/horizontal
Outcome: Sandwich bone grafts versus short implants in atrophic mandibles

tively than expected versus 25% in the short implant group. However, the last difference was not found to be significant using RevMan.

Cost and Treatment Time. Short implants were placed under local anesthesia, whereas grafts were performed under general anesthesia. Patients who received grafts were hospitalized for a mean of 5.9 days, required double the healing time (about 3 additional months), and could not wear the mandibular denture for 6 months.

Which Is the Most Effective Augmentation Technique? (5 trials). One trial[20] compared 1-stage sinus augmentations with monocortical iliac bone blocks (20 patients) versus a 2-stage sinus lift with particulated bone from the iliac crest (20 patients) in atrophic maxillary sinuses (2 to 7 mm of residual alveolar bone) using turned Brånemark implants (Nobel Biocare, Göteborg, Sweden). Patients were rehabilitated with screw-retained cross-arch implant-supported prostheses. Three patients refused to have their prostheses removed to verify implant stability and also refused the radiographic examination at the 3-year follow-up.

Complications. In the 1-stage group, there were 11 perforations of the sinus membrane in 9 patients, and 11 early implant losses in 8 patients. In the 2-stage group, there were 11 perforations in 10 patients and 7 early implant losses in 6 patients. An additional 5 implants had been lost by 1 year in the 1-stage group versus 1 in the 2-stage group. At 3 years, 1 additional implant had been lost in the 1-stage group versus 2 in the 2-stage group.

Prosthetic Aftercare. In the 1-stage group, at 1 year 1 prosthesis was lost because of failures of the 4 supporting implants, and 1 prosthesis had to be redesigned because of lack of space for the tongue (this was not considered a failure in the calculations, since it was independent of the bone grafting technique). In the 2-stage group, at 1 year 1 prosthesis was lost because of the failure of 1 implant in a critical position. There was no statistically significant difference for any of the outcomes considered in this review.

Cost and Treatment Time. All the procedures were performed under general anesthesia. Patients in the 2-stage group required 1 additional surgical intervention, whereas implants were placed simultaneously with the augmentation procedure in the 1-stage group. Consequently, the healing period was 6 months longer in the 2-stage group.

One trial[24] compared three 1-stage techniques for augmenting atrophic maxillary sinuses having less than 5 mm of alveolar bone height in the sinus floor. The trial was designed as a sort of split-mouth/parallel preference trial. Eleven patients willing to provide autogenous bone from the mandibular ramus were treated with a split-mouth approach (autogenous bone versus 80% Bio-Oss [Geistlich Pharmaceutical, Wolhusen, Switzerland] and 20% autogenous bone). Ten patients who refused to have their bone harvested were treated with 100% Bio-Oss, but the healing period was prolonged to an average of 8.5 months. Four patients in the 100% Bio-Oss group were treated bilaterally; 1 of the 2 sides was selected at random for the statistical evaluation. Turned Brånemark implants were used. Patients were rehabilitated with screw-retained metal-ceramic fixed prostheses. All patients were followed up to 1 year after loading.

Complications. In the post-operative phase, no complications occurred. However, a severe resorption of the autogenous bone graft occurred in 2 patients.

At abutment connection 6 implants failed in 5 patients in the autogenous bone group, and 2 implants failed in 2 patients in the group treated with 80% Bio-Oss. No early implant failures occurred in the randomly selected sinuses treated with 100% Bio-Oss; however, 2 implant failures occurred in 2 of the 4 randomly excluded sinuses. No implant or prosthesis was lost at the 1-year evaluation. The author stated that additional implants were lost at the 2-year follow-up in 2 patients in the split-mouth group, causing the failure of the fixed prostheses. The complete information should be published in a future 5-year follow-up report. There was no statistically significant difference for any of the outcomes considered in this review.

Cost and Treatment Time. All the procedures were performed under local anesthesia, and the only difference in cost was the use of bone substitutes and a collagen barrier in the 100% Bio-Oss group.

Another trial[37] compared two 2-stage techniques for augmenting atrophic maxillary sinuses having less than 5 mm of alveolar bone height in the sinus floor with a split-mouth design: particulated bone from the iliac crest versus 100% Cerasorb (Curasan, Kleinostheim, Germany; a β-tricalcium phosphate bone substitute) in 20 patients. In 10 patients an additional autogenous onlay bone block was placed to widen the alveolar crest. Grafts were left to heal for 6 months. In 16 patients Ankylos (Degussa, Friadent, Germany) implants were used, whereas in 4 patients Protetim (Hódmezo'vásárhely, Hungary) implants were used. The authors did not provide an explanation for their use of 2 different implant systems. Two implants were placed in each augmented sinus. All patients were followed up to implant loading.

Complications. No serious postoperative complications occurred at the implant sites. Three complications occurred at the bone graft donor sites: 1 patient experienced permanent sensory loss of the lateral femoral cutaneous nerve, and 2 experienced prolonged wound drainage (2 to 3 weeks). By abutment connection 2 implants had failed, 1 in each group. Both implants had to be replaced to place the prosthesis, and this caused a delay of 3 to 6 months. There was no statistically significant difference for any of the outcomes considered in this review.

Cost and Treatment Time. Due to the nature of split-mouth study design, all the procedures were performed under general anesthesia and patients were hospitalized for an unspecified number of days. The healing time was about 1 year. The use of the bone substitutes caused a difference in treatment cost between the 2 groups.

One trial[29] compared distraction osteogenesis in 11 patients versus GBR with nonresorbable barriers and particulated autogenous bone grafts taken from the mandibular ramus (as well as from the chin if necessary) in 10 patients for the vertical augmentation of edentulous ridges. Patients were rehabilitated with screw-retained metal-ceramic fixed prostheses and were followed for 3 years after loading. Implants were placed protruding 2 to 7 mm from the bone level. Two different vertical GBR procedures were used: in 6 patients a 1-stage approach was used, and the abutment connection was performed 6 to 7 months after implant placement. A 2-stage approach was used in 5 patients; in these cases, based on subjective evidence, the patients were felt to be at risk for insufficient primary implant stability. Implants were placed after 6 to 7 months of graft healing and left submerged for additional 3 to 5 months. Brånemark Mk III implants were used in 19 patients and sandblasted, large-grit, acid-etched (SLA) implants (Straumann, Waldenburg, Switzerland) were used in 2 patients, depending on the implant system used by the referring dentists. No patients dropped out.

Complications. Two patients in the distraction osteogenesis group experienced a lingual inclination of the bone fragment during the distraction phase, probably because of traction on the osteotomized segment by muscles in the floor of the mouth. The complications were successfully treated by applying orthodontic traction until the bone segments consolidated in the desired position. In the GBR group, 5 complications occurred in 4 patients: 3 barrier exposures, 1 of which was associated with an infection, and 2 cases of transient paresthesia of the chin area lasting 1 and 4 weeks, respectively. Both cases of paresthesia occurred in the only 2 chin graft donor sites. All procedures for harvesting bone from the ramus were complication-free. No implant or prosthesis failed over the 3-year follow-up period. The mean bone gain after the augmentation procedure was reported for both groups; however, neither the reference points used in measurement nor the method used for recording this information were reported. There was no statistically significant difference for any of the outcomes considered in this review.

Cost and Treatment Time. The cost of the barriers and fixing pins was unique to the GRB group; the distraction osteogenesis group was responsible for the cost of the intraoral distractor and related orthodontic therapy when needed. In the distraction osteogenesis group, abutments were connected between 6.5 months (mandible) and 9.5 months (maxilla). Patients were not allowed to use their prostheses for about 3.5 months during the distraction procedure and the consolidation of the bone blocks. In the GBR group, abutments were connected after 6 to 7 months, when implants were placed simultaneously with the GBR procedure. In cases where a 2-stage augmenta-

tion procedure was used, abutments were connected after 9 to 12 months. Patients were left without their removable prostheses for 6 to 7 months.

The last trial,[39] an interim report of a larger RCT, compared 1-stage particulated autogenous bone grafts from intraoral locations in 11 patients treated with nonresorbable titanium reinforced barriers (Gore-Tex; WL Gore and Associates, Flagstone, AZ) stabilized with miniscrews with 11 patients treated with resorbable barriers (Bio-Gide; Geistlich Pharma), supported by appropriately adapted osteosynthesis plates (Gebrüder Martin, Tuttlingen, Germany) fixed with miniscrews.

XiVE CELLplus (Friadent) implants were used, and patients were rehabilitated with provisional fixed resin prostheses. One implant per patient was used for the statistical calculations. No patients dropped out.

Complications. In the resorbable group, 2 abscesses resulted in the designation of 2 grafting procedures as failures. One barrier was exposed without signs of infection, and a swelling suggesting an early infection was successfully treated with antibiotics. In the nonresorbable group, infection led to failure of the graft in 1 case. Three other patients presented with fistulas, and 1 patient a had swollen lymph node suggestive of an infection. No study implant failed and all planned prostheses were delivered. Both treatments resulted in statistically significant vertical bone gain; however, no statistically significant differences were found among the 2 procedures.

Cost and Treatment Time. In the resorbable group, the cost of the treatment included the cost of 1 or 2 barriers, the osteosynthesis plates, and related fixation pins; in the nonresorbable group, the cost of treatment included a titanium-reinforced barrier and related pins. Thus, treatment with a nonresorbable barrier may have been slightly less expensive. The mean healing time for both groups was about 4.5 months, slightly less than the originally planned 5 months, due to the premature removal of some infected barriers.

Techniques to Treat Implants Placed in Extraction Sockets (Minor Augmentation Procedures)

Is the Augmentation Procedure Necessary? (1 trial). One trial[33] compared immediate single implants placed in fresh extraction sockets at maxillary anterior and premolar sites in 14 patients treated with particulated autogenous bone from the osteotomy site with 12 patients not subjected to any augmentation procedure. In the original publication,[33] data of 2 distinct RCTs were presented together in a single article as if it was a single RCT. However, the authors clarified this, and in the present review the data has been correctly presented separately for the 2 RCTs. The trial presented here has been designated Chen et al[33] (1).

Patients were treated with turned Brånemark implants. The autogenous bone was collected by a filter attached to a dedicated suction line. Wound closure was achieved with a palatal connective tissue graft. The following bone measurements at implant placement and at implant exposure 6 months later were included in the present review: the vertical height of the defect (VDH), which was measured from the most apical point of the defect to the coronal aspect of the implant collar, and the horizontal depth of the defect (HDD), which was measured buccolingually from the most buccal aspect of the implant collar to the labial bone crest. No patients dropped out.

Complications. There were 2 complications in the autogenous bone group: 1 abscess (which determined the failure of the implant) and a wound dehiscence. Two implants were lost. No complications or failures were experienced in the nonaugmented group. Both treatments resulted in statistically significant bone gain; however, no statistically significant differences were found between the 2 procedures.

Cost and Treatment Time. The differences may not be clinically significant.

Which Is the Most Effective Augmentation Technique? (3 trials). One trial[30] compared 10 patients treated with a resorbable barrier (Bio-Gide) with 10 patients treated with a resorbable barrier + Bio-Oss using single SLA transmucosal implants (Straumann) placed in fresh extraction sockets. Barriers were fixed to the implants by healing screws and were left to heal for 6 months. No patients dropped out, and no prosthesis or implant failed. The position of the soft tissue margins in relation to the implant shoulder was observed to be significantly higher for patients treated with the barrier + Bio-Oss (at buccal sites, 2.1 mm versus 0.9 mm; mean difference = –1.2 mm [95% CI, –2.29 to –0.11]) (Table 5).

Complications. There were no complications.

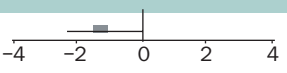
Cost and Treatment Time. The only difference between the 2 procedures was the additional cost of the Bio-Oss.

One trial, Chen et al (2),[33] compared immediate single implants placed in fresh extraction sockets at maxillary anterior or premolar sites in 12 patients treated with nonresorbable barriers (Gore-Tex) with 11 patients treated with resorbable barriers (Resolut) and with 13 patients treated with resorbable barriers (Resolut) and particulated autogenous bone from the implant osteotomy site using a filter attached to a dedicated suction line. Wound closure was achieved by palatal connective tissue graft. Turned Brånemark implants were used. No patients dropped out.

Complications. Two dehiscences were noted in the resorbable group. In the resorbable barriers + bone group, there was 1 abscess (successfully treated with

Table 5 Interventions for Replacing Missing Teeth: Bone Augmentation Techniques for Dental Implant Treatment

Study or subcategory	n	Resorbable mean (SD)	n	Resorbable + Bio-Oss mean (SD)	WMD (random) 95% CI	Weight (%)	WMD (random)	95% CI
Esthetics by dentist (mucosal margin from implant head in mm)								
Cornelini et al[30]	10	0.90 (1.20)	10	2.10 (1.29)		100.00	−1.20	−2.29 to −0.11



Comparison: augmentation versus augmentation: immediate implants in extraction sockets
Outcome: resorbable versus resorbable + Bio-Oss (continuous)

Favors resorbable + Bio-Oss

Favors resorbable

systemic antibiotics) and 1 dehiscence. No implants were lost. All treatments resulted in statistically significant bone gain, with no statistically significant differences among the 3 procedures.

Cost and Treatment Time. Differences among groups may not be clinically significant.

One trial[38] compared 10 patients receiving Bio-Oss with 10 patients receiving Bio-Oss + a resorbable barrier (Bio-Gide) at immediate single implants placed in fresh extraction sockets at maxillary anterior or premolar sites. Barriers were fixed to SLA implants (Straumann) by the healing screws. Implants were not submerged and were left to heal for 6 months. A third control group of 10 patients who received no barrier and no graft could not be evaluated, since some patients were systematically excluded from that group and included in the remaining 2 groups. After 3 years, 3 patients had dropped out of the Bio-Oss group and 5 patients had dropped out of the Bio-Oss + barrier group. There were no prosthesis or implant failures.

Complications. Two complications occurred in the Bio-Oss + barrier group: 1 abscess developed during the healing period, and 1 implant displayed chronic inflammation of the peri-implant tissues for the entire study period. All treatments resulted in statistically significant bone gain, with no statistically significant differences in bone gain between the 2 procedures. After delivery of the prostheses 1 patient in each group, when asked by the operator, was dissatisfied with esthetics because of recession of the mucosa on the buccal aspect but refused a corrective intervention with a soft tissue graft. Esthetics (position of the soft tissue margin in relation to the adjacent teeth) were also evaluated by the operator after the 6-month healing period, at placement of the final restorations, and after 3 years of loading. After healing, 3 of 10 sites treated with Bio-Oss and 4 of 10 sites treated with Bio-Oss + barrier were considered esthetically unsatisfactory by the operator (including the 2 sites judged as unsatisfactory by the patients). The operator then treated 2 sites with recession in the Bio-Oss group and 1 patient with recession and 1 without recession (marginal mucosa judged to be too thin) in the Bio-Oss + barrier group with connective tissue grafts. After placement of the final restorations (about 2 months after), the operator judged esthetics to be poor in 2/10 patients from the Bio-Oss group and in 4/10 patients from the Bio-Oss + barrier group. After 3 years of loading, the operator judged esthetics to be poor in 2/7 patients of the Bio-Oss group and in 2/5 patients of the Bio-Oss + barrier group.

Cost and Treatment Time. The only difference between the 2 procedures was the additional cost of the barrier.

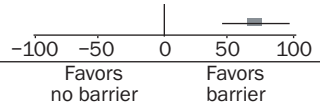
Techniques to Treat Bone Dehiscences or Fenestrations Around Implants (Minor Augmentation Procedures)

Is the Augmentation Procedure Necessary? (1 trial). A split-mouth trial[13] with 7 patients with fenestrated implants at implant placement examined whether a nonresorbable barrier (Gore-Tex) kept for 6 to 7 months was able to regenerate more bone than no barrier. A slight space was maintained over the exposed surface of the turned Brånemark implants by manual convex shaping of the barrier, which was locked in position by tucking 1 edge under the periosteum. No bone chips or synthetic material were used as a space maintainer, as confirmed by the investigators. No dropouts, significant complications, or implant failures occurred at implant exposure. There was a significant increase in percent bone gain for the GBR implants when compared to the untreated implants (mean difference = 71; 95% CI, 45 to 98; P = .002) (Table 6). However, in 4 of 7 test implants, the regenerated bone covered only about 55% of the fenestrated implant surface. The only difference in cost between the 2 procedures was the barrier.

Which Is the Most Effective Augmentation Technique? (2 trials). One trial[19] compared resorbable Bio-Gide (23 subjects) with nonresorbable Gore-Tex barriers (25 patients) around turned implants

Table 6 Interventions for Replacing Missing Teeth: Bone Augmentation Techniques for Dental Implant Treatment

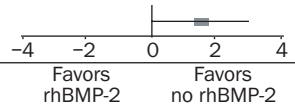
Study or subcategory	Barrier (N)	No barrier (N)	Mean difference (SE)	Mean difference (fixed) 95% CI	Weight (%)	Mean difference (fixed)	95% CI
Bone gain (%)							
Dahlin et al[13]	7	7	71.4290 (13.4460)		100.00	71.43	45.08 to 97.78



Comparison: augmentation versus augmentation: fenestration.
Outcome: nonresorbable barrier versus no barrier (continuous).

Table 7 Interventions for Replacing Missing Teeth: Bone Augmentation Techniques for Dental Implant Treatment

Study or subcategory	rhBMP-2 (N)	No rhBMP-2 (N)	Mean difference (SE)	Mean difference (random) 95% CI	Weight (%)	Mean difference (random)	95% CI
Bone gain (length)							
Jung et al[26]	11	11	−1.5450 (0.7600)		100.00	−1.55	−3.03 to −0.06



Comparison: augmentation versus augmentation: fenestration.
Outcome: rhBMP-2 versus no rhBMP-2 (continuous).

(3i/Implant Innovations, West Palm Beach, FL) showing minor dehiscence and fenestrations at placement. Both groups had a 1:1 mixture of bovine anorganic bone (Bio-Oss) and autogenous bone derived from the implant osteotomy sites. Barriers were stabilized with either 2 polylactic acid bioabsorbable pins, the implant cover screw, or the mucogingival flap only, and were kept for 6 months. There were no dropouts.

Complications. There were no significant differences between the groups with respect to implant failures (5 failures in the resorbable barrier group and 4 in the nonresorbable group); various complications (11 in the resorbable group and 11 in the non-resorbable group); or reduction in length or width of defect.

Cost and Treatment Time. Cost and treatment time were similar for the 2 groups.

One trial[26] evaluated the effect of a BMP (rhBMP-2; 1 mL of 0.5 mg/mL) versus placebo (1 mL of 0.01% trifluoroacetic acid, the solution in which rhBMP-2 was dissolved) on Bio-Oss and a resorbable barrier (Bio-Gide) on turned Brånemark implants showing bone dehiscences or fenestrations in a split-mouth study including 11 patients for 6 months. There were no dropouts, and no implant failures occurred.

Complications. One wound dehiscence was noted in the rhBMP-2 group. No differences in early implant failure or complications were observed; however, a borderline statistically significant difference in defect height reduction of 1.5 mm was observed favoring implants treated with rhBMP-2 (mean difference = 1.5 mm; 95% CI, 0.06 to 3.03, $P = .04$; Table 7).

Cost and Treatment Time. The only difference in cost was caused by the expense of production of the rhBMP-2. Treatment times were similar for the 2 groups.

DISCUSSION

This review was conceived as having a broad focus, and it was decided to include any RCT dealing with any aspect of bone augmentation in relation to implant placement. Thirty potentially eligible trials were identified, but only data from 13 investigations could be used. Seventeen studies were excluded for various reasons (Table 1). These methodological problems are not uncommon in the dental implant literature,[44] and it is recommended that clinicians seek advice from clinical research methodologists and statisticians when designing and analyzing studies. Only in 1 trial was a sample size calculation undertaken[39]; however, as this study was an interim report, the planned sample had not yet been achieved. Sample sizes of all studies were relatively small. It is therefore likely that many of these studies were underpowered to demonstrate any significant difference in outcome measures between groups. Nevertheless the included trials did provide limited but useful clinical information and indications which should be carefully evaluated by clinicians when deciding whether to perform an augmentation procedure and which augmentation procedure to select. A great deal of time was spent contacting RCTs'

authors, who have kindly provided useful unpublished information on their trials. These contacts have made the present review more complete and useful for the readers. It is also worth observing that all authors of the included trials replied to requests for clarifications. It is unusual to have such a high response rate. This might be partly explained by the serious research interests of the investigators conducting RCTs in the area, and may be indicative of a growing consciousness that high-quality systematic reviews can be of great benefit to the entire society. A considerable increase in the number of RCTs published in 2005 and 2006 was also noticed. This should be viewed positively, since it may indicate that in the near future some of today's unanswered clinical questions might finally have an evidence-based answer that might supersede the traditional "opinion-biased" approach to clinical decision-making. The priority now is to concentrate research efforts on a few important clinical questions, increase sample sizes, and decrease the number of treatment variables in the trials. This might be obtained through collaborative efforts among various research groups.

At the protocol stage, trials were divided into 3 broad groups: *(1)* trials evaluating different techniques for vertical or horizontal bone augmentation or both (major augmentation procedures); *(2)* trials evaluating different techniques to treat implants placed in extraction sockets (minor augmentation procedures); and *(3)* trials evaluating different techniques to treat bone dehiscences or fenestrations around implants (minor augmentation procedures). Obviously there are limitations in this classification, as in many classifications, since the exact borders among the different categories may not always be easily identified. However, in the future, when more information will be available, this classification might be improved, making it more detailed and precise. Further, trials were divided into those evaluating *(a)* whether and when a certain augmentation procedure is necessary and *(b)* which is the most effective augmentation technique for a precise clinical indication. This distinction is of great relevance, since it is possible that many complicated, painful, and even potentially dangerous procedures are widely performed, despite the fact that they improve neither the prognosis of the treatment nor life quality of the patients.

Three trials included in the present review could be used to evaluate whether and when augmentation procedures are indicated.[13,28,33]

One split-mouth trial,[13] which nowadays can be considered a historical trial, was designed to test as a proof or principle whether it was possible to regenerate new bone around fenestrated implants according to the principles of GBR. While this trial showed that bone can be regenerated at exposed implant surfaces, no proof was given that bone augmentation was actually necessary or provided any kind of benefit to the patients. This is not to say that it is not useful to regenerate bone around exposed implant surfaces; however, it should be acknowledged that there is not any available evidence proving that it could be useful. It could also be that the real indications for regenerating bone around exposed implant surfaces are more restricted than is generally believed.

One parallel design trial[33] evaluated whether autogenous bone grafting was needed at single immediate implants placed in fresh extraction sockets at maxillary anterior and premolar sites. No statistically significant differences could be observed among the groups, which included relatively few patients. However, all complications and failures (1 abscess which determined an early implant failure, 1 dehiscence and another implant failure) occurred at the augmented sites, whereas no complication or failure occurred at the nonaugmented control sites.

Even more interesting are the findings of the third trial,[28] a well-designed and well-conducted study conducted to investigate which was the best technique for treating edentulous patients who had resorbed mandibles (6 to 12 mm of bone height) and were dissatisfied with their dentures. Three treatment alternatives were tested: *(1)* iliac crest interposed bone grafting; *(2)* short implants; and *(3)* transmandibular implants. The latter option performed worse than the short implant alternative and was not of interest. For almost any of the outcome measures considered, the bone graft technique performed statistically and clinically significantly worse than short implants. Therefore, when considering resorbed mandibles, the interposed iliac crest bone grafting technique, although generally considered the best grafting option currently available for this indication, may not be the optimal choice.

Of the 3 properly designed trials that were found, in 1 case, the clinical usefulness of GBR was not assessed;[13] in another trial,[33] no statistically significant difference was observed (the sample size was small), and all complications and failures occurred at the augmented sites and none at the nonaugmented control sites; and in the third trial, which focused on atrophic mandibles,[28] the augmentation procedure resulted in more serious complications (including a life threatening sublingual edema), major discomfort and pain, significantly higher costs for society, longer treatment time, and clinically poorer outcomes than the use of short implants. These examples clearly illustrate that a more critical approach should be taken when evaluating the need for bone augmentation procedures for dental implants.

When evaluating which are the most effective augmentation techniques for specific clinical situations, 10 trials were found to provide some indications for 4 different clinical conditions: *(1)* the atrophic posterior maxilla,[20,24,37] *(2)* vertical ridge augmentation,[29,39] *(3)* immediate implants in fresh extraction sockets,[30,33,38] and *(4)* bone dehiscence or fenestrations around implants.[19,26]

1. When comparing a 1-stage monocortical bone block with a 2-stage technique with particulated bone harvested from the iliac crest for sinus lifting, no statistically or clinically significant differences were observed.[20] However, the use of autogenous bone blocks from the iliac crest in a 1-stage procedure is a technique that is seldom used anymore. The available evidence suggests that with a 1-stage approach it is possible to achieve similar results as with a 2-stage approach, with the advantages of shortening the healing period and avoiding a surgical intervention.

   Of particular clinical interest are the results of those trials testing the efficacy of bone substitutes in maxillary sinuses having less than 5 mm of residual alveolar bone.[24,37] With a relatively simple, rapid, and inexpensive procedure it was possible to achieve results similar to those achieved with autogenous bone, which is considered to be the gold standard. Another advantage when using bone substitutes is that patient morbidity can be decreased, since there is no need to harvest autogenous bone. Therefore, autogenous bone grafting might be replaced by bone substitutes for this indication. Such trials deserve some sort of priority in the research agenda in order to see whether similar results can be obtained by other centers with larger patient samples before the use of bone substitutes can be recommended as a routine treatment for the augmentation of extremely resorbed sinuses.

2. Both osteodistraction and various GBR techniques can be successful for augmenting bone vertically.[29,39] However, there is insufficient evidence to suggest whether one technique is preferable. The osteodistraction technique may not be used in all circumstances (for instance, in the presence of thin knife-edge bone). It is more expensive than GBR but may reduce treatment time and allow for more vertical ridge augmentation than GBR if needed. On the other hand, GBR techniques also allow for simultaneous bone widening, if needed. Two cases of transient paresthesia of the chin area were reported when the chin grafts were harvested. The use of the chin as an intraoral donor site should be carefully evaluated. GBR techniques were also associated with high complication rates (50%[29] and 40%[39]); however, only 15% of the interventions resulted in the failure of the GBR procedure.[39] It is therefore recommended that both clinicians and patients carefully evaluate the pros and cons in relation to the desired outcome before deciding whether to use vertical ridge augmentation techniques.

3. No differences were observed for various techniques aimed at augmenting single immediate implants in fresh extraction sockets,[30,33,38] with the exception of a slightly higher position (1.2 mm) of the gingival margin in relation to the implant head for sites augmented with Bio-Oss + barrier when compared to barrier alone.[30] Due to the small sample sizes, there was insufficient evidence to suggest whether 1 technique could be preferable. Esthetic parameters are also important for evaluating the efficacy of augmentation procedures at implants placed in fresh extraction sockets. In 1 trial esthetics were evaluated by the patients at the request of the operator.[38] In a couple of trials,[30,38] the position of the peri-implant soft tissue margins was evaluated by the clinicians. However, independent blind outcome assessors were not used in the Chen and Darby trial.[38] Esthetic parameters should be evaluated in an objective way; moreover, it is important that the final users, ie, the patients, evaluate the esthetic results. In 1 trial[38] it was reported that after delivery of the restorations 90% of the patients were satisfied by the esthetic results, whereas the provider was not satisfied in more than a third of the cases, and additional interventions (soft tissue grafts) were provided to improve the situation. After 3 years in function the operator was unsatisfied with the esthetic appearance in more than a third of the cases. The potential differences in perception of esthetics by patients and dentists should also be explored properly. It might also be worthwhile to evaluate the efficacy of "old-fashioned" alternatives to dental implants such as adhesive bridges and soft tissue corrections, when needed, in long-term RCTs.

4. No differences were observed for various techniques aimed at augmenting bone in implants with dehiscence/fenestration.[19] There are 2 possibilities: either too few patients were included in the trials to detect a statistically significant difference, or no major differences exist among the different tested techniques. Clinical trials with larger patient samples have to be conducted to determine which of these is true. However, a placebo-controlled split-mouth trial,[26] judged to be at low risk of bias,

tested the effect of a human bone promoting factor (rhBMP-2) and showed a borderline statistically significant difference in defect height reduction of 1.5 mm favoring implants treated with rhBMP-2. However, the authors tested the active factor (rhBMP-2) and the placebo at a distance of only 7 mm (or less) in the same patient. Since the systemic effects and at which distance "active" molecules might be effective are largely unknown, the risk of crossover effects cannot be ruled out.

Another generally accepted paradigm, which has not been confirmed in the present systematic review, is that of autogenous bone as the "gold standard" for bone augmentation procedures. The majority of the trials included in this review suggested that this may not always be the case. A more cautious approach to the use of autogenous bone collected with "bone traps" might be needed. Abscesses, fistulas, and dehiscences occurred in several trials in which autogenous bone fragments collected with bone traps were used,[19,29,33,39] despite the fact that antibiotic prophylaxis was generally administered and the use of dedicated suction devices to collect bone. It is in fact known that a considerable amount of bacteria can be found in the particulated bone collected with bone traps even when dedicated suction devices are used.[45] Even for sinus lift procedures, bone substitutes might be able to replace autogenous bone, though such preliminary findings need to be confirmed by larger and more "robust" trials.

With respect to generalization of the results of the present review to general practice, many of the augmentation procedures evaluated were rather complex undertakings performed by experienced and skillful clinicians. Although the patients underwent strict postoperative control regimens, complications were common, and in a few instances severe. It is therefore recommended that caution be used when considering the use of an augmentation procedure. The first clinical question that clinicians should ask themselves is, what are the benefits to the patient? The expected benefits then need to be carefully weighted against the risk for complications of the chosen procedure.

CONCLUSIONS

Three trials investigated whether and when augmentation procedures are necessary:

1. The augmentation of resorbed mandibles of 6 to 12 mm height with an interposed iliac crest graft resulted in more surgical and prosthetic complications, and statistically significantly more implant failures, severe pain, days of hospitalization, costs, and longer treatment time than using short implants. The current evidence may not justify major bone grafting procedures for resorbed mandibles.
2. There is evidence that nonresorbable barriers allow statistically significantly more bone regeneration than no barrier at fenestrated implants; however, it has not been proven that such newly generated bone is of any use or benefit for the patient. While bone regenerative procedures at exposed implants might be useful, there is not yet reliable evidence of which are the proper indications.
3. There is not enough reliable evidence supporting or refuting the need for augmentation procedures at immediate implants placed in fresh extraction sockets.

Ten trials investigated which are the most effective augmentation techniques for specific clinical indications:

1. Bone substitutes (Bio-Oss and Cerasorb) might be as effective as autogenous bone grafts for augmenting extremely atrophic maxillary sinuses. Therefore, they might be used as a replacement for autogenous bone grafts, although these preliminary findings need to be confirmed by large multicenter trials.
2. Osteodistraction and various GBR techniques are able to regenerate bone in a vertical direction; however, there is insufficient evidence to indicate whether one of these techniques is preferable. Osteodistraction is of little use in the presence of thin ridges but may allow more vertical regeneration. Complications with GBR techniques are common and in some cases determined the failure of the augmentation procedure. Clinicians and patients should carefully evaluate the benefits and risks in relation to the desired outcome when deciding whether to use vertical ridge augmentation techniques.
3. There is no reliable evidence to show that any of the alternative techniques for augmenting bone at fenestrated implants is superior to the others.
4. There is not enough reliable evidence proving superior success of any of the alternative techniques for augmenting bone at immediate implants placed in fresh extraction sockets. Sites treated with barrier + Bio-Oss showed a higher position of the gingival margin when compared to sites treated with barriers alone.
5. BMPs (rhBMP-2) used in conjunction with Bio-Oss and resorbable barriers may promote bone formation at exposed implants in need of lateral ridge augmentation.

6. There is no reliable evidence supporting the efficacy of other active agents such as PRP in conjunction with implant treatment.
7. The use of particulated autogenous bone from intraoral locations, using a filter attached to a dedicated suction line, might be associated with an increased risk of infective complications.

These findings are based on few trials, which included few patients, sometimes had short follow-up, and were often judged to be at high risk of bias.

In order to understand when bone augmentation procedures are needed and which are the most effective techniques for the specific clinical indications, larger, well-designed trials are needed. Such trials should be reported according to the Consolidated Standards of Reporting Trials (CONSORT) guidelines[46] (http://www.consort-statement.org). It is difficult to provide clear indications with respect to which augmentation procedures should be tested first; however, once the clinical situations in which augmentation procedures are actually needed have been established, priority could be given to those interventions which look the most simple, are the least invasive, involve the least risk of complications, and reach their goals within the shortest timeframe. The efficacy of bone substitutes for replacing autogenous bone in augmenting severely atrophic maxillary sinuses should be confirmed by large multicenter trials. It would also be worthwhile to further evaluate the potential ability of BMPs (rhBMP-2) to favor bone growth in conjunction with bone substitutes, autogenous bone, or a combination of the two. Studies to determine which donor sites provide sufficient bone with the least patient discomfort and risk of complications are also needed. Patient-centered outcomes ought to be considered when designing such trials. Trials on augmentation procedures at implants placed in fresh extraction sockets should evaluate first whether such procedures are necessary. "Objective" esthetic outcomes assessed by blind outcome assessors and the patient's own perception of esthetics also need to be properly evaluated.

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