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Clinical outcomes of vertical bone augmentation to enable dental implant placement: a systematic review

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Abstract

Background: This review addressed the focused question of what is the predictability of vertical ridge augmentation techniques for patients, who were diagnosed with insufficient alveolar bone volume for the placement of dental implants.

Material and Methods: A systematic online review of three main databases was performed between 1966 and 1 November 2007. Four groups of vertical bone augmentation techniques have been identified and evaluated: (1) guided bone regeneration, (2) distraction osteogenesis, (3) onlay bone grafting, and (4) an array of different techniques. Data extraction was based on the following outcomes: (a) success and failure rate of the procedure (vertical bone gain/loss), (b) complication rate of the procedure, and (c) implant survival, success and failure rate.

Results: The initial search identified 189 papers from the electronic database. The review produced seven papers for GBR, 13 reporting distraction osteogenesis, five for onlay bone grafting and three describing different techniques.

Conclusions: For the concept of vertical ridge augmentation to enable dental implant placement, there are clinical and histological data supporting its potential use. Given the confined number of investigators using these techniques and the low number of patient treatments reported in the literature, the generalizability of this approach is limited at this time.

Key words: distraction osteogenesis; GBR; onlay bone graft; vertical bone regeneration; vertical ridge augmentation

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The advent of osseointegration and advances in biomaterials and techniques has contributed to an increased application of dental implants in the restoration of partially and totally edentulous patients. An important prerequisite to predict long-term success for osseointegrated implants is a sufficient volume of healthy bone at recipient sites. However, a sufficient amount of bone volume is frequently lacking as a result of trauma, tooth loss or infectious diseases such as advanced periodontitis.

Vertical alveolar bone loss in partially edentulous patients constitutes a major challenge due to anatomical limitations and technical difficulties. The presence of the nasal cavity, the maxillary sinus and the mandibular inferior alveolar nerve limits the bone height available for proper implant placement. Moreover, a large interarch space alters coronal length and form and produces an unfavourable crown-to-root ratio in the final prosthetic reconstruction (Mecall & Rosenfield 1991). The latter may result in an esthetical unacceptable final prosthetic restoration and/or it could result in difficulties in performing adequate oral hygiene regimes, hence potentially jeopardizing the long-term prognosis.

A number of different techniques have been developed to vertically reconstruct deficient alveolar ridges to allow dental implant placement in either a simultaneous or staged approach.

The principles of GBR were applied in the early 1990s to atrophic jaws

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(Simion et al. 1994). Severe vertical defects were treated by means of a titanium reinforced non-resorbable barrier membrane in conjunction with titanium dental implants. The first mandibular distractor reported in humans dates to 1992, using an extraoral distractor in patients with hemifacial microsomias (McCarthy et al. 1992). Bone block grafts were introduced in the early 1990s to increase the vertical height of the maxillae and mandibulae by apposition (Isaksson et al. 1992). All the aforementioned techniques reported modest or more extensive modifications from the protocol over the years. Many authors have reported data on predictability, failure, complications, etc. of the procedures (Cano et al. 2006).

In 1999 for the Proceedings of the 3rd European Workshop in Periodontology, a narrative review on horizontal and vertical bone augmentation was presented (Simion et al. 1999). The author concluded, that the GBR technique had been proven to be successful in terms of vertical bone gain, however technically demanding. In addition, the papers presented reported follow-up that were too short to possibly draw any valuable conclusions. A narrative review was also recently reported on the general topic of bone augmentation techniques (McAllister & Haghighat 2007).

Two systematic reviews (Fiorellini & Nevins 2003, Esposito et al. 2006) report interesting data. Fiorellini and Nevins evaluated dental implant survival rates in patients treated with ridge augmentation or bone preservation techniques. The authors state similar survival rates for implants in regenerated bone by means of GBR or distraction osteogenesis.

Esposito et al. tested the null hypothesis of no difference in success, function, morbidity and patient satisfaction between different augmentation techniques. The sole conclusion that could be drawn from the vertical bone growth section was that both GBR and distraction osteogenesis could augment bone vertically, but it was unclear which was the most effective technique because direct comparisons have not been made.

These reviews were conceived having a broad focus, including an array of different surgical approaches. Given the variety of vertical ridge augmentation studies (GBR, distraction osteogenesis, onlay bone grafts, as well as other techniques) performed to date, the goal of our report was to summarize the findings of this approach in a systematic fashion.

Material and Methods

For the purpose of this review, the following vertical bone augmentation techniques were evaluated:

1. guided bone regeneration (GBR) principles,
2. distraction osteogenesis (DO),
3. onlay bone grafts (OBG), and
4. an array of different techniques.

The following outcome measures were evaluated for each technique:

(a) success and failure rate of the procedure (vertical bone gain/loss),
(b) complication rate of the procedure, and
(c) implant survival, success and failure rate.

An additional outcome was analysed for the GBR group only:

(d) the histological outcome in terms of new bone formation and bone to implant contact.

Study selection and inclusion criteria

Studies included in this structured review fulfilled the following inclusion criteria: (1) randomized and non-randomized clinical trials, cohort studies, case control studies, and case reports; (2) relevant data only on *vertical* bone augmentation; (3) a minimum number of five patients completed; (4) follow-up data available of a minimum of 12 months of prosthetic loading; and (5) English language restriction. If more than one publication referred to the same data, the most recent report was used. Studies reporting horizontal bone augmentation, extraction socket preservation or sinus lift procedures were excluded.

To increase the data available of the clinical outcomes (vertical bone gain/loss and complication rate of the procedure) of GBR, the inclusion criterion (#4) was modified from a minimum prosthetic loading of 12 months to the time of abutment connection (Fig. 1).

In addition, to better evaluate the histological outcomes of new bone formation and bone to implant contact, a separate review was performed for GBR only. These studies included both animal and human data. No restrictions were posed in terms of minimum number of patients enrolled or follow-up data. The key words used were the same as previously described with the adjunct combination of ''histology''.

Search strategy

A computerized literature search was performed. Three distinct databases were utilized; Medline, Embase and Ovid. The following keywords were used in different combinations: (i) vertical bone augmentation AND; (ii) vertical ridge augmentation AND; (iii) vertical ridge regeneration AND; (iv) vertical bone regeneration in the time range from 1966 to 1 November 2007. Moreover, the Cochrane Controlled Trials Register and The Cochrane Health Group Specialized Register were checked for publications on the relevant topic. In addition, a manual search was carried out from 1990 to 1 November 2007 in the *Clinical Oral Implant Research, International Journal of Oral and Maxillofacial Implants, Journal of Oral and Maxillofacial Surgery, International Journal of Periodontics and Restorative Dentistry, Journal of Cranio-Maxillofacial Surgery, Journal of Clinical Periodontology*, and *Journal of Periodontology, Periodontology 2000*. Furthermore, a manual search was conducted through the bibliographies of all relevant papers and review articles covering the period from 1 January 1990 to 1 November 2007.

Data extraction and validity and correlation of reviewers

A master list of 189 studies with potentially useful outcomes information was generated from the literature search strategy.

Titles and abstracts of the initially identified 189 articles were included or excluded by one reviewer. Then, the identified 26 papers with abstracts containing potentially relevant information were selected for further critical appraisal of the full text by two independent examiners. If necessary, the authors were contacted via mail for further questions/clarifications regarding their manuscripts. Full texts of all papers that were considered suitable for inclusion were obtained.

Two reviewers independently, and in duplicate, assessed the relevance of each potentially applicable article with regard

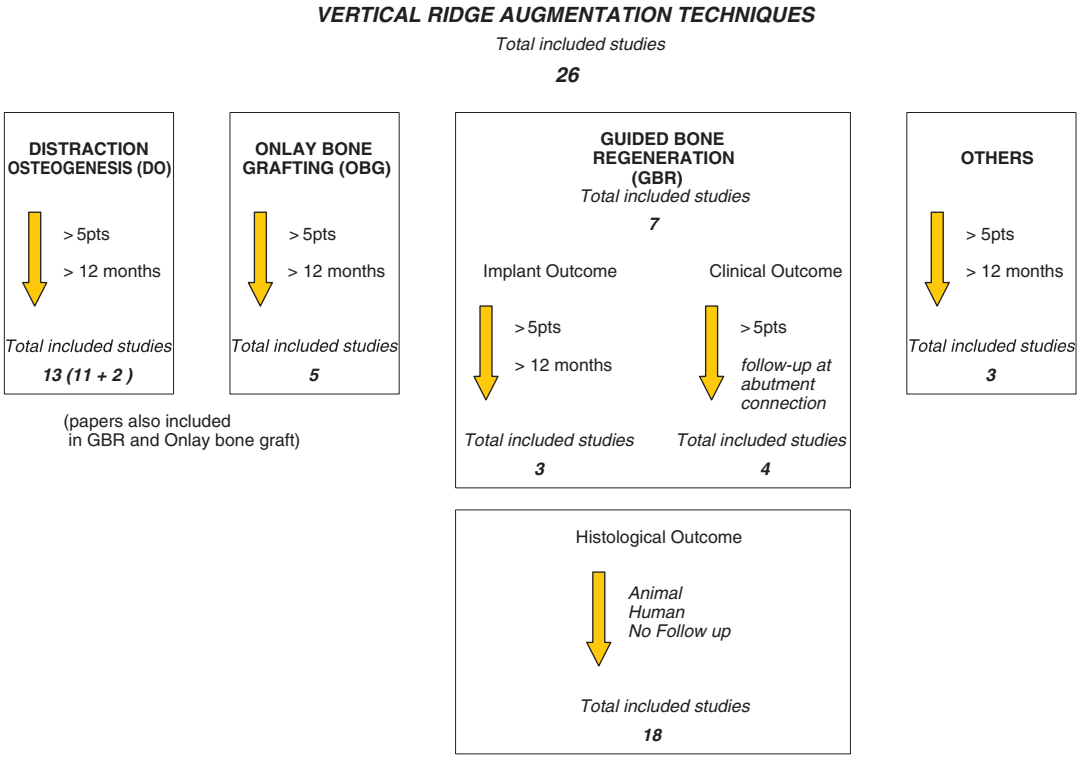

Fig. 1. Vertical ridge augmentation techniques.

to the inclusion or exclusion of the paper. The agreement of inclusion and exclusion was identical yielding a κ statistic of 1.

Results

The electronic literature search provided a total of 189 articles, of which 91 were potentially eligible and entered the initial screening. Twenty-three studies out of 91 were related to GBR technique, 37 to distraction osteogenesis, 16 to onlay bone grafts and 15 to different techniques used for vertical bone augmentation.

When the abstracts and full texts were thoroughly evaluated, a total of 26 human original papers fulfilled the inclusion and exclusion criteria and were included in this review. The 26 papers were divided as follows: seven reporting GBR technique, 13 dedicated to distraction osteogenesis, five with onlay bone grafts and three with data on different techniques.

For the GBR group, three papers reported a minimum mean follow-up at 12 months of prosthetic loading and four studies reported data to abutment connection time (Fig. 1).

The limited number of selected articles included a wide range of approaches to study design, data reporting, implant surface, one or two stage approach, surgical area, graft type used, etc. (see Tables 1–5). Consequently, no attempt was made to perform a meta-analysis given the oveall paucity of data and limited RCTs available.

GBR: outcome of the procedure

Quality of included studies and study design

The seven publications that entered this category are displayed in Table 1.

When quality of the reviewed articles was assessed, most of the articles were retrospective case studies (3). Two case series and two randomized controlled trials (RCTs) were present (Parma-Benfenati et al. 1999, Chiapasco et al. 2004b, Merli et al. 2007, Simion et al. 2007b).

Most papers reported the use of autogenous bone graft combined with non-resorbable membranes, while some authors describe the use of a blood clot, deproteinized bovine bone matrix or allograft. All but one author used titanium reinforced e-PTFE membranes. Two studies reported the use of osteosynthesis plates covered by resorbable collagen barriers (Merli et al. 2006, 2007). One or two stage procedures were examined. Only four papers report values of vertical bone gain and three articles provide data on bone stability over time (Simion et al. 2001, 2004, Chiapasco et al. 2004b).

What is the efficacy of the procedure in terms of vertical bone gain, bone stability and complications?

The methods used to report the outcome variables were described in detail in six out of seven papers. All papers were consistent in reporting a range of vertical bone gain of 2–8 mm.

Long-term bone stability was reported in three studies only. A bone loss from 1.27 to 2.0 mm for a follow-up of 1–7 years was observed.

A broad range of complications (0–45.5%) was reported by all studies. The most common complication was barrier membrane exposure and its sequelae, which in some patients prevented implant placement. In one paper, the authors experienced complications in 45.5% of the treated cases, while the other studies cited a range of 0–25% (Merli et al. 2007).

Table 1. Clinical outcome criteria assessed in guided bone regeneration studies

Author	# pts/ # impl.	Smoke	Anatomical area	One stage/ two stage (pts)	Graft	Barrier	Impl. surface	Time interval before abutment connection (months)	Reported follow-up period (months)	Height gain range (mm)	Impl. success (%)	Impl. survival (%)	Impl. failure (%)	Compli-cations (%)	Marginal bone loss (ΔDIB)	Level of evidence	Comments
Parma-Benfenati et al. (1999)	6/30	NE	Mand.	One	Autog. partic.	TR e-PTFE	NE Nobel Biocare	12	6	5–7	NE	NE	NE	NE	NE	Case series	Yes histo
Simion et al. (2001)	49/123	NE	Max. & mand.	46/49 one 3/49 two	Blood clot Allograft Autog.	TR e-PTFE	NE Nobel Biocare	6–12	1–5 years	2–8	97.5	NE	NE	18.4	1.35 ± 0.78 1.87 ± 0.85 1.71 ± 0.97	Retrospective multicentre	Δ DIB at 1 year of examination. Further: no loss Histo of cited papers
Chiapasco et al. (2004b)	21/59 group 1 11/25	No	Max. & mand.	1.a 6/11 one 1.b 5/11 two	1. Autog. partic.	1. TR e-PTFE	1. 25 Branemark	1.a 6–7 one 1.b 9–14 two	1–3 years	1.a 2.5–7 1.b 4–7	1.a 61.5 1.b 75	1.a 100 1.b 100	0	1. 27.3 (3/11)	1.a 2.06 1.b 2.96	Randomized control trial	
Simion et al. (2004)	14/38	4/38	Max.	7/14 one 7/14 two	Autog. partic.	TR e-PTFE	Machi Nobel Biocare	6–13 one 11–13 two	1–7 years	NE	76.3	92.1	7.9	12.5	1.65 ± 0.98 1.68 ± 1.18	Retrospective	ΔDIB mesial side ΔDIB No histo
Merli et al. (2006)	11/18 group	0/11	Max & mand. Cawood & Howell class III–VI	One	1. Autog. partic. 2. Autog. partic.	1. TR e-PTFE 2. Osteo-synthesis plate+ resorbable collagen	Machined (NB) Ti-Unite (NB) Osseotite (3i) Micro (Astra)	4–9	NE	NE	NE	NE	NE	9 25	NE	Retrospective Cohort study	
	18/11 group 2	3/8															
Merli et al. (2007)	11/42 group 1	2/11	NE	One	1. Autog. partic. 2. Autog. partic.	1. TR e-PTFE 2. Osteo-synthesis plate+ resorbable collagen	XiVE CELLplus	5	6	2.48 ± 1.13	NE	NE	NE	45.5 (5/11)	NE	Randomized Control trial	No stat sign height gain or complication
	11/55 group 2	2/11								2.16 ± 1.51				36.4 (4/11)			
Simion et al. (2007b)	7/10 sites/27	NE	Mand. Applegate–Kennedy class I/II	One 5/10 sites Two 5/10 sites	Autog. partic. +DBBM	TR e-PTFE	Ti-Unite Nobel Biocare	6–9.5	6–9	3.15 ± 1.12	NE	NE	NE	10 (1/10)	NE	Case series	Two sites were treated with the conventional e-PTFE membrane and pure autog. bone particles

DIB, buser 91, distance between head shoulder and first visible bone-implant contact; ΔDIB, the difference in DIB values between the abutment connection surgery and the examinations during the following years of observation; smoke, > 10 cigarettes/day.

Success/survival are according to Albrektsson et al. (1986).

NE, not evaluable; DBBM, deproteinized bovine bone mineral; TR, titanium reinforced; NB, Nobel Biocare; partic., particulated; mand., mandible; max., maxilla; autog., autogenous; impl., implant; pts, patients.

GBR: implant outcomes

Quality of included studies and study design

The two retrospective studies and one RCT that entered this category are displayed in Table 1.

Two studies use machined Branemark implants (Simion et al. 2001, 2004). Chiapasco et al. (2004a, b) reported the use of Branemark implants, but did not specify if the implant surfaces were machined or rough. Unless specified, all papers referred to the Albrektsson et al. (1986) criteria for implant success.

What is the success, survival and failure rate of implants placed in vertically regenerated bone?

These studies involved 74 patients with a total of 220 implants. Survival rates ranging from 92.1% to 100% over 1–7 years were reported. Success rates of 76.3% to 97.5% were reported in two of the studies (Simion et al. 2001, 2004). One study (Chiapasco et al. 2004b) observed a success rate of 61.5% after a single stage approach, and 75% when a two-stage approach was applied.

GBR: histological outcome

Quality of included studies and study design

18 papers resulted from the literature search and are displayed in Tables 2a and 2b. The articles included in this section include nine human (Table 2b) and nine preclinical animal studies (Table 2a). All human papers are case series and case reports.

Most studies identified utilized a one-stage procedure with simultaneous implant placement while only two recent papers (Canullo et al. 2006, Simion et al. 2007b) report on the use of a two-stage procedure. Most of the studies used machined surface implants, however in the more recent studies, rough surface implants are more often reported given the limited overall current usage in clinical practice with machined surfaces.

An array of biomaterials were used in the study of GBR. Most studies use non-resorbable e-PTFE membranes under which the grafts vary among blood clot, autogenous graft and demineralized freeze-dried bone allograft. Attempts have been proposed using resorbable devices as barrier membranes (Schliephake & Kracht 1997; Schliephake et al. 2000).

What is the amount of new bone formation and the bone-to-implant contact (BIC)?

Four papers within the total 18 studies described GBR by means of an e-PTFE membrane and blood clot in a one-stage procedure. Two of them (Simion et al. 1994, Jovanovic et al. 1995) reported a significant mean vertical bone gain in respect to the control sites, whereas the other two papers (Roos-Jansåker et al. 2002, Stenport et al. 2003) failed to demonstrate such a difference compared with the controls.

Nine papers describing GBR using different types of grafts combined with e-PTFE membranes suggested that the conjunction of a graft with the membrane technique increased the efficacy of such procedure in terms of vertical bone gain and BIC.

Negative values of bone height (-2.7 mm, Schliephake & Kracht 1997; Schliephake et al. 2000) and extremely high values of soft tissue dehiscences were reported when attempts were made to use resorbable membranes in experimental vertical ridge augmentation. Only seven out of 18 publications report values of BIC. Out of these, six can be interpreted in terms of percentage BIC and one refers to linear BIC values. Most of the studies evaluated biopsies of the newly regenerated tissue without histomorphometric data (bone height and/or bone to implant contact), but only with a qualitative analysis. Six out of nine human studies included in this section, did not provide data on BIC or amount of new bone formation. The studies describe qualitatively the hard tissue biopsy.

Distraction osteogenesis: outcome of the procedure

Quality of included studies and study design

A total of 13 articles fulfilled the inclusion criteria and are listed in Table 3. Two studies (Chiapasco et al. 2004b, 2007) were also included in the GBR and onlay block tables due to their study design and inclusion of these techniques. The two largest cohorts are from the studies by Chiapasco et al. (2004a) and Enislidis et al. (2005) reporting 37 patients each. All authors have evaluated distraction osteogenesis in atrophic maxilla and mandibles.

The authors report the use of currently available alveolar design distractors with extrabone or intrabone anchorage and models that are solely distractors or act as distractor-implants.

What is the efficacy of the procedure in terms of vertical bone gain, bone stability and complications?

Nine out of 13 studies did not provide measurements of crestal bone levels over time. Vertical bone gain, on the other hand, was reported by most authors, even though the methods used to extrapolate such data are difficult to discern with a high level of confidence. An overall reported range of 5–15 mm of vertical bone gain was reported.

High percentages (10–75.7%) and a broad spectrum of complications were reported with DO. These varied from fractures of the distractor, infection of the distraction chamber, fractures of transported or basal bone, premature or delayed consolidation and fibrous non-union, slight resorption of the transported fragment, neurological alterations, deviations from the correct distraction vector and soft tissue dehiscences. The nature of some of these complications appeared to be quite severe. Five patients experienced a basal bone fracture that was further treated with an additional surgery to place ostheosynthesis plates. Enislidis et al. (2005) described a fracture of the transport segment in a patient and Türker et al. (2007) reported a complete resorption of the transport segment at the consolidation period requiring secondary grafting procedures.

The most common complication was a progressive lingual/palatal inclination. Additional bone regenerative procedures to allow dental implant placement were mandatory in 42 patients out of a total of 191 patients included in these papers.

Distraction osteogenesis: implant outcome

What is the success, survival and failure rate of implants placed in vertically regenerated bone?

Five out of 13 papers report information about implant survival and/or success. The data presented are homogenous considering the survival rate ranged

Table 2a. Histologic outcome criteria assessed in guided bone regeneration animal studies

Author	Model	# pts/ # sites	Anatomical area	One/ two stage	Graft	Barrier	Impl. surface	Time interval before biopsy (months)	Supracrestal defect at baseline	Mean height gain (mm)	BIC (%)	Complications (%)	Level of evidence	Comments
Jovanovic et al. (1995)	Dog	5/10	Mand.	One	Blood clot	TR e-PTFE e-PTFE No barrier	Machined (NB)	6	2.69	1.82	NE	30% 3/10 membrane exp. 1–2 weeks	Experimental study	Newly formed bone around the impl. was evident in the histo sections with clear demarcation between basal and reg bone
Jensen et al. (1995)	Dog	4/24	Mand.	One	Canine DFDBA Iliac autog. Blood clot No graft	TR e-PTFE or No barrier	Machined (NB)	6	3 impl. threads	1.90 0.53 3	80 (graft+membrane) 86.3% (blood+membrane) 20% (graft)	25% 6/24 membrane exp.	Experimental study	Inferior border of mand. chosen
Renvert et al. (1996)	Dog	4/8	Mand.	One	Autog. bone partic.	Titanium dome alone or + TR e-PTFE	Machined (NB)	3	6 impl. threads	1.91	NE	0	Pilot study	
Schliephake & Kracht (1997)	Dog	10/20	Mand.	One	No graft	Polylactic or No barrier	ITI Bonefit	3	2.8	3.08 − 2.7	26.1	96.7% 29/30 impl. membrane exp. 40% 12/30 soft tissue exp.	Experimental study	
Schliephake et al. (2000)	Dog	6/24	Mand.	One	Autog. partic. No graft	Polylactic acid No barrier	NE (NB)	5 5	5	0.6 0.29–1.08	33 NE	41.7% 10/24 tissue dehisc. at 2 weeks–3 months	Experimental study	
Roos-Jansåker et al. (2002)	Dog	4/8	Mand.	One	Blood clot	Titanium mesh+ e-PTFE	Machined (NB)	3	5 threads	NE	0	0	Experimental study	No cortical perofrations BIC of 22%in threads in native bone
Stenport et al. (2003)	Dog	6/12	Mand.	One	S300 BMP+bone matrix carrier	Titanium mesh+ e-PTFE	Turned	4	5 threads	0	19	0	Experimental study	
Simion et al. (2006)	Dog	6/8	Mand.	One	DBBM block+rh-PDGF-BB	Collagen barrier No barrier	TiUnite (NB)	4	10	NE	NE	25% 2/8 a fistula and a soft tissue dehisc.	Experimental study	
Simion et al. (2007a)	Dog	3/6	Mand.	One	Blood clot	TR e-PTFE No barrier	Machined (NB)	6	4.09	2.89	0.52 mm	16.7% 1/6 membrane exp. at 2 weeks	Experimental study	Bone fill with TR e-PTFE 57% No barrier 11% BIC linear measurement only is reported

Smoke, >10 cigarettes/day.

Success/survival are according to Albrektsson et al. (1986).

NE, not evaluable; NB, Nobel Biocare; DBBM, Deproteinized Bovine Bone Mineral; TR, titanium reinforced; partic., particulated; BIC, Bone to implant contact; mand., mandible; max., maxilla; impl., implant; pts, patients; exp., exposure; dehisc., dehiscence.

Table 2b. Histologic outcome criteria assessed in guided bone regeneration human studies

Author	Model	# pts/ # sites	Anatomical area	One/ two stage	Graft	Barrier	Impl. surface	Time interval before biopsy (months)	Supracrestal defect at baseline	Mean height gain (mm)	BIC (%)	Complications (%)	Level of evidence	Comments
Simion et al. (1994)	Human	5/6	Max. & Mand.	One	Blood clot	TR e-PTFE	Machined (NB)	9	4–7	4	42.5	16.7% 1/6 abscess after 1 month	Case series	2.2 .m of connective tissue surrounded the coronal portion of screws. No clear demarcation between native and new bone Protocol description
Tinti et al. (1996)	Human	6/6	Max. & Mand.	One	Autog. bone partic.	TR e-PTFE	Machined (NB)	12	3–7	4.95	NE	16.7% 1/6 membrane exp. at 11 days	Case series	Protocol description
Piattelli et al. (1996)	Human	1/1	Max.	One	DFDBA	Resorbable freeze-dried dura mater membrane	Impl. Innovation	6	2.5	2.5	Not possible- only bone hravested	0	Case report	
Tinti et al. (1997)	Human	2/2	Mand.	One	No graft	Gold mesh+ e-PTFE	(NB)	12	3	NE	Not possible- only bone hravested	0	Case report	
Tinti & Parma-Benfenati (1998)	Human	18/22	Max. & mand.	One	Autog. bone partic.	TR e-PTFE	Machined (NB)	12	2–7	NE	NE	13.6% 3/22 membrane exp. at 15 days, 2 and 5 months	Retrospective study	Vital bone with regularly formed bone cells. But no data/image of histology
Simion et al. (1998)	Human	20/22	Max. & mand.	One	Autog. bone partic. DFDBA	TR e-PTFE	Machined (NB)	7–11	5.09	5.02	63.2	18% 2/12 membrane exp. & abscess 2/10 membrane exp.	Case series	Regenerated bone was hardly distinguishable from native bone BIC of 63–67% in threads in native bone
Parma-Benfenati et al. (1999)	Human	6/6	Mand.	One	Autog. partic.	TR e-PTFE	Machined (NB)	12	2.68 5–7	3.14 NE	56.4 22	NE	Case series	BIC of 44%in threads in native bone
Canullo et al. (2006)	Human	1/1	Mand.	Two	DBBM partic.	TR e-PTFE	Ti-Unite (NB)	6	NE	NE	NE	0	Case report	No BIC due to hard tissue sample only, with no screw retrieved
Simion et al. (2007b)	Human	7/10	Mand.	One 5/10 Two 5/10	Autog. partic. +DBBM	TR e-PTFE	Ti-Unite (NB)	6–9.5	2–7	3.15	Not possible- only bone harvested	10% 1/10 membarne exp. at 3 weeks	Case series	Two sites were treated with the conventional e-PTFE membrane and pure autog. bone particles

Smoke, >10 cigarettes/day.
Success/survival are according to Albrektsson et al. (1986).
NE, not evaluable; NB, Nobel Biocare; DBBM, deproteinized bovine bone mineral; TR, titanium reinforced; partic., particulated; BIC, Bone to implant contact; mand., mandible; max., maxilla; exp., exposure; autog., autogenous.

Table 3. Outcome criteria for implant success assessed in distraction osteogenesis studies

Author	# pts/# alveolar segments/ # impl.	Smoke	Anatomical area	Distractor design	Technique	Impl. surface	Time of impl. placement (distractor removal) (months)	Time interval before abutment connection (months)	Reported follow-up period (years)	Mean height gain (range mm)	Impl. success (%)	Impl. survival (%)	Impl. failure (%)	Complications (%)	Marginal bone loss (ΔDIB)	Level of evidence	Comments
Klug et al. (2001)	10/13/NE	NE	Mand.	TRACK 1.0 Distractor (Martin)	Distractor+ titanium membrane in 4/13 sites	NE	2.5	NE	2–19 months	7.5 (6–9)	NE	NE	NE	23% (3/13)	NE	Case series	Yes histo
McAllister (2001)	7/10/16	0	Max. & mand.	OGD Distractor (ACE)	Endoosseous distractor	NE	2–4	6–7	1–2.5	7 (5–9)	NE	NE	0	30% (3/10)	NE	Case series	Yes histo
Rachmiel et al. (2001)	14/14/23	NE	Max. & mand.	LEAD Distractor (Leibinger)	Endoosseous distractor	NE	2	6	6–20 months	10.3 (8–13)	NE	NE	4.3% (1/23)	14.3% (2/14)	NE	Case series	
Jensen et al. (2002)	28/28/84	NE	Max.	3i Implant - distarctor	Transcortical distractor Distractor implant	NE	2–4	6	5	6.5 (3–15)	NE	90.4%	9.6% (8/84)	50% (14/28)	1 ± 1.3	Case series	
Raghoebar et al. (2002)	10/10/20	NE	Edentulous mand. Cawood class VI	GDD distarctor (Martin)	Distractor	ITI Bonefit (12) Branemark (8)	2	3	6–20 months	NE (6–8)	NE	NE	5% (1/20)	10% (1/10)	NE	Case series	Yes histo
Chiapasco et al. (2004a)	37/37/138	No	Mand. & max.	TRACK 1.0 Distractor (Martin)	Intra-oral distractor	Branemark, 3i, Frialit, ITI	2–3	3–6	1–4.6	9.9 (4–15)	94.2%	100%	0	21.6% (8/37)	1.4 ± 0.4	Case series	The mean DIB is at 4 years
Chiapasco et al. (2004b)	10/10/34	No	Max. & mand.	Distractor (Martin)	Intra-oral distractor	Branemark, 3i, Frialit, ITI	2–3	3–6	1–3	NE	94.1%	100%	0	20% (2/10)	1.93	Randomized control trial	
Kunkel et al. (2005)	10/10/28	NE	Mand.	Mainz-distarctor (Medicon)	Intraosseous impl. shaped distractor	Branemark, Ankylos, Astra-tech, Frialit	NE	4–6	4	7.3	59	90	7% (2/28)	30% (3/10)	NE	Case series	Yes stat analysis
Iizuka et al. (2005)	7/7/21	NE	Anterior mand. & max.	V2- alveolar distraction system (Medartis)	Bidirectional distractor	ITI	2–3	3	1	NE (10–15)	NE	NE	NE	28.6% (2/7)	NE	Case series	Yes stat analysis yes histo
Enislidis et al. (2005)	37/45/94	NE	Mand.	LEAD Distractor (Leibinger) TRACK 1.0 Distractor (Martin)	Intraosseous distractor (14) Subperiosteal distractor (31)	NE	3	6 (19 impl. were inserted 5 months after distraction removal)	3	8.2 (5–15)	NE	95.7%	NE	75.7%	NE	Case series	Major complications represented for both distractors 50% of the complications reported
Türker et al. (2007)	10/10/15	NE	Mand.	LEAD Distractor (Leibinger)	Intraosseous distractor	NE	3	NE	1	NE (6–12)	NE	NE	NE	20% (2/10)	NE	Case series	Yes stat analysis
Schleier et al. (2007)	21/21/59	No	Mand. & max.	Martin Medartis	Unidirectional (10) Bidirectional (11)	ITI	3	2.5	2.5	5.3 ± 1.8		94%	1.7% (1/59)	70% (7/10)		Retrospective study	Yes stat analysis Complications refer to additional bone graft required
Chiapasco et al. (2007)	9/9/21	No	Mand.	Martin	Intraoral extraosseous distractor	ITI	2–3	3–5	3.5	6.1 ± 2.3 5.3 (2–8)	94.7%	100%	NE	27.3% (3/11) 33.3% (3/9)	1.3		

DIB, Buser 91, distance between head shoulder and first visible bone-implant contact; ΔDIB, the difference in DIB values between the abutment connection surgery and the examinations during the following years of observation; smoke, >10 cigarettes/day; mand., mandible; max., maxilla; impl., implant.
NE, not evaluable; Success/survival are according to Albrektsson et al. (1986).

from 90% to 100%. Success rate was reported only by two papers. Kunkel et al. (2005) reported a lower success rate (59%) as compared with the other study (Chipasco et al. 2004a, success rate of 94.2%).

Onlay bone grafts: outcome of the procedure

Quality of included studies and study design

A total of five papers were identified and included on onlay bone grafting for vertical ridge augmentation (Table 4). The vast majority of the excluded studies presented case reports or case series with a limited number of patients. Many publications were also excluded due to a difficult interpretation of the data presented and ambiguous documentation of vertical and horizontal bone augmentation. Often, the follow-up was less than the minimum 12 months of prosthetic loading required.

Three case series, a prospective and a retrospective study were analysed for onlay bone grafting. Intra-oral and extra-oral autogenous bone grafts were both considered for onlay bone grafting. The two main intraoral donor sites were the mandibular symphysis and the mandibular ramus. The extra-oral sites included the iliac crest or the cranium. In all papers, the bone blocks were firmly secured to the recipient site by means of osteosynthesis screws without the use of barrier membranes.

Different surgical approaches were proposed to achieve vertical ridge augmentation in edentulous patients by means of onlay bone grafts; extraoral bone blocks positioned at the same time of implant placement (Nyström et al. 1996, Bahat et al. 2001), extraoral bone blocks positioned before implant placement (Bahat et al. 2001), or intraoral bone blocks positioned 4–6 months before the insertion of the implant fixtures (Cordaro et al. 2002, Chiapasco et al. 2007). All authors reported that patients treated with OBG were not allowed to wear removable provisional prostheses after the reconstruction procedure for a period of at least 2 months.

What is the efficacy of the procedure in terms of vertical bone gain, bone stability and complications?

Only one paper (Cordaro et al. 2002) reported changes in vertical dimension

Table 4. Outcome criteria for implant success assessed in onlay bone graft studies

Author	# pts/ # impl.	Smoke	Anatomical area	One stage/ two stage (pts)	Graft	Barrier	Impl. surface	Time interval before abutment connection (one stage) (months)	Time interval before abutment connection (two stage) months	Reported follow-up period (years)	Mean height gain (mm)	Impl. success (%)	Impl. survival (%)	Impl. failure (%)	Complications	Marginal bone loss (ΔDIB)	Level of evidence	Comments
Nyström et al. (1996)	30/177	NE	Max.	One	Onlay bicortical from iliac crest	No	NE	NE	NE	3	NE	NE	76%	24%	NE	4.9 ± 0.17 mm at 3 years	Case series	No mean height gain No info about prosthesis and impl.
Bahat & Fontanessi (2001)	25/67	NE	Max. & mand.	4pts one stage 21pts two stages	21 iliac crest 2 torus 1 cranio 1 chin	No	Nobel Biocare Branemark	NE	NE	34.4 months max. 19 months mand.	4.22 (0–15 mm)	–	–	0%	4%	NE	Case series	Difficult data interpretation
Cordaro et al. (2002)	9/20	NE	Max. & mand.	Two	Intraoral bone block	No	ITI/3I No info about surface	–	11–12	4–38 months (mean 12)	3.4 ± 0.66 at OBG 2.2 ± 0.66 at impl. insertion	100%	–	0	0	NE	Case series	42% loss of bone volume at impl. insert
Chiapasco et al. (2007)	8/19	Not >15 cigarettes	Mand.	Two	Intraoral bone block from ramus	No	ITI (SLA surface)	–	7–9	38 months of prosthetic loading (24–48 range)	4.6 mm (3–6 range)	100% CSuR	89.5% CSR	–	1 paresthesia 1 partial graft lost	1.3 ± 0.4 mm at 3 years	Prospective study	
Levin et al. (2007)	50/129	9 pts (18%)	Max. & mand.	Two	Intraoral bone block	No	NE	NE	NE	6–67 months (mean 24.3)	NE	NE	96.9% 88% CSR	NE	NE	0–3.3 (mean 0.22 mm)	Retrospective study	No diff between horiz and vert No prosthesis info

DIB, Buser 91, distance between head shoulder and first visible bone-implant contact; ΔDIB, the difference in DIB values between the abutment connection surgery and the examinations during the following years of observation; smoke, >10 cigarettes/day.

Success/survival are according to Albrektsson et al. (1986).

NE, not evaluable; CSR, cumulative survival rate; CsuR, cumulative success rate; OBG, onlay bone grafting; mand., mandible; max., maxilla; impl., implant.

of the bone block from baseline to implant placement. The intra-oral block was reduced by 42% suggesting a strong tendency to a remodelling of the grafted bone when left unprotected by a membrane in vertical ridge augmentation procedures. The other two papers (Bahat & Fontanessi 2001, Chiapasco et al. 2007) report mean vertical bone values of 4.22 mm using iliac crest grafts and 4.6 mm using intra-oral grafts, respectively.

A discrepancy in bone stability data could be found in the three papers reporting graft shrinkage over time. Nyström et al. (1996) showed a mean bone loss of 4.88 mm at 3 years (iliac bone graft), Chiapasco et al. reported 1.3 mm at 4 years (mandibular ramus) and Levin et al. (2007) report 0.22 mm with a range of 0–3.3 mm at 2 years (intraoral graft).

Minor complications were reported with onlay bone grafting. Chiapasco et al. (2007) described transient paresthesia of the area innervated by the inferior alveolar nerve experienced in three out of eight patients. In the study conducted by Cordaro et al. (2002), all but one patients who underwent bone harvesting from the chin reported paresthesia for a period of 3–4 months. No information was given about the morbidity of extra-oral bone grafts at the iliac donor site for onlay bone grafting in these papers.

Onlay bone graft: implant outcomes

What is the success, survival and failure rate of implants placed in vertical regenerated bone?

The survival rate overall ranged from 76% to 100% in the studies analysed for vertical ridge augmentation using OBGs.

Success rate is reported only by two papers; Cordaro et al. (2002) with a success rate of 100% for 40 implants inserted at 12 months and Chiapasco et al. (2007) with 89.5% of implant success rate at 5 years.

Other techniques: outcome of the procedure

Study exclusion, quality of included studies and study design

Table 5 displays the three included articles for other specific techniques to vertically augment bone allowing dental implant placement. These studies included the use of a titanium mesh (TM) in combination with a bone graft

Table 5. Outcome criteria for implant success assessed in studies regarding other techniques for vertical ridge augmentation

Author	# pts/ # impl.	Smoke	Anatomical area	One stage/ two stage (pts)	Technique	Graft	Impl. surface	Time interval before abutment connection (one stage) months	Time interval before abutment connection (two stage) months	Reported follow-up period (years)	Mean height gain(mm)	Impl. success (%)	Impl. survival (%)	Impl. failure (%)	Compli-cations (%)	Marginal bone loss (ΔDIB)	Level of evidence	Comments
Von arx et al. (1998)	18 pts/ 27 impl.	NE	Max. & mand. class B, C, C-W Misch '90	Two	TiM+graft	Autog. bone block+aut bone partic.	ITI	–	12–13 months	1–3 (mean 21 months)	NE	NE	NE	NE	NE	Δ DIB 1 year 1.0 mm ΔDIB 2 year+0.1 m	Case series	
Artzi et al. (2003)	10 pts/ 20 impl.	No	Max. & mand.	Two	TiM+graft	DBBM	Plasma-sprayed Nobel Biocare	–	12–15	2	5.2 ± 0.79	100%	100%	NE	20	NE	Case series	Yes histo
Jensen et al. (2006)	10 pts/ no	NE	Anterior max.	Two	Segmental osteotomy+ interpositional bone graft	Aut bone graft from ramus	NE	–	NE	5	3–6	NE	NE	NE	NE	NE 1 mm postimpl.	Case series	No info about impl. #

DIB, Buser 91, distance between head shoulder and first visible bone-implant contact; ΔDIB, the difference in DIB values between the abutment connection surgery and the examinations during the following years of observation; smoke, >10 cigarettes/day.
Success/survival are according to Albrektsson et al. (1986).
NE, not evaluable; DBBM, deproteinized bovine bone mineral; partic., particulated; TiM, titanium mesh; mand., mandible; max., maxilla; impl., implant; autog.,autogenous.

and an osteotomy combined to interpositional bone grafting. All are case series.

What is the efficacy of the procedure in terms of vertical bone gain, bone stability and complications?

TM and autogenous bone grafting

The only vertical bone gain result is reported by Artzi et al. (2003) (mean height gain 5.2 mm). No information could be extrapolated from the Von arx et al. (1998) study.

The same can be stated for bone stability. Von arx et al. calculated a peri-implant bone loss of 1.0 mm for the first year of loading and 0.1 mm for the second year. The Artzi et al. paper did not report this information.

The sole complication reported was a spontaneous exposure of the TM for two of the 10 patients reported in the Artzi et al. study.

Osteotomy combined to an interpositional bone grafting

No information could be drawn from the study (Jensen et al. 2002) due to the small patient sample size (10 patients) and lack of data.

Other techniques: implant outcomes

What is the success, survival and failure rate of implants placed in vertical regenerated bone?

The only data available on implant outcome derives from the Artzi et al. (2003) study reporting that all 20 implants were integrated and prosthetically functional after a follow-up of at least 2 years.

Discussion

This review was based on the focused question of what is the predictability of vertical ridge augmentation techniques for patients, who were diagnosed with insufficient alveolar bone volume for the placement of dental implants.

There are several reviews available in the literature, however there is limited systematic information available. Fiorellini & Nevins (2003) report the implant survival rates in patients treated with localized ridge augmentation or preservation. This review included all available techniques at the time, as long as bone was augmented or preserved allowing for subsequent implant installation. No distinction was made regarding the baseline defect of the patient and/or the treatment plan. Esposito et al. (2006) questioned whether and when bone augmentation procedures were necessary and which was the most effective technique for specific clinical indications. The authors divided their trials into the following areas: (a) major vertical or horizontal bone augmentation or both; (b) implants placed in extraction sockets; and (c) fenestrated implants. An exhaustive search was narrowed down to the selection of only RCTs. An extensive amount of information can be gleaned from systematic reviews, however the quality of data to answer specific queries is sometimes not provided. If controlled studies or high quality studies were to be considered alone, the amount of data and the number of these studies would be so small to prevent any conclusion. Out of a total of 26 studies fulfilling the inclusion criteria in our review, only two were randomized control trials (RCTs). In order to accomodate more of the available clinical information, the level of evidence in this review was designed to be inclusive of case series to RCTs. Thus, at times it was challenging to reconcile inconsistent and incomplete materials found in some of the studies identified. Sample sizes of all studies were relatively small (although minimum patient sample size was 5 or greater). Thus, many of these studies were underpowered to demonstrate any significant difference in outcome measures between groups. Nevertheless the identified papers did provide limited but useful clinical information and clinical indications that can be evaluated by clinicians when managing vertical bone defects. Furthermore, therapeutic options for strategic implant placement as well as consideration of procedural complications were provided.

Our review evaluated three surgical techniques to augment bone vertically (GBR, distraction osteogenesis and onlay bone grafting) and a fourth group of alternative approaches (TM and osteotomy). The variability within the papers did not allow us to perform a meta-analysis.

Guided bone regeneration

Because of the limited number of patients (128) treated by few centers (4), vertical ridge augmentation can be achieved successfully using GBR, but it cannot be considered a generalizable intervention. This technique appears to be highly technique-sensitive, hence, the applicability of these data to a wider array of operators and clinical settings remains unclear at this time.

Data on bone stability was found on three papers only, reporting that the regenerated bone appears to remain stable through a follow-up period of up to 7 years. These limited data suggest that vertically augmented bone responds to implant placement similar to native, non-regenerated bone. There is no information allowing us to consider the outcomes of one and two staged GBR procedures separately.

The papers have shown that the conjunction of a graft to the membrane technique increases the efficacy of such procedure and its BIC.

Distraction osteogenesis

These studies reported insufficient and unclear information on the methods used to assess vertical bone gain. Lack of information regarding bone stability over time is present in the included papers, however, the only two studies reporting this data show that bone is stable throughout a follow-up period up to 4 years. High percentages of complications were registered, some of which can be considered severe. One of the major drawbacks of this technique appears to be the possibility to regenerate bone strictly in a vertical direction.

Onlay bone grafting

Not enough data is available in the literature about vertical bone gain and its stability over time. However, the few studies available appear to indicate that the intra-oral bone grafts remain more stable than grafts from the iliac crest over time.

Other techniques

Insufficient information is present dealing with this category.

Conclusion

For the concept of vertical ridge augmentation to enable dental implant placement, there are clinical and histological data supporting its potential use. The approaches considered in this

review encompassed GBR, distraction osteogenesis, and onlay bone grafts. Given the confined number of investigators using these techniques and the low number of patient treatments reported in the literature, the generalizability of this approach is limited at this time.

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