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Clinical outcomes of implants following lateral bone augmentation: systematic assessment of available options (barrier membranes, bone grafts, split osteotomy)

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Abstract

Objective: To compare the clinical outcomes related to implants following lateral augmentation procedures (GBR, bone grafts, split osteotomy) with implants placed in pristine sites.

Material and Methods: A systematic review of all prospective studies of implants placed simultaneously or as a second surgery following lateral augmentation compared with implants placed in pristine bone with 6 months of loading was performed.

Results: From 435 potentially relevant publications, 125 full-text publications were screened and four were identified as fulfilling the inclusion criteria. Three studies compared implants placed with simultaneous GBR or with a bone substitute and one with autogenous bone graft as a staged procedure. The implant survival at the augmented sites irrespective of the procedure used varied from 91.7% to 100% and from 93.2% to 100% at the control sites for a period between 12 and 59.1 months.

Conclusions: Within the limits of the systematic review there was evidence that the evaluated augmentation techniques result in similar implant survival between augmented and pristine sites. The small number of retrieved studies fulfilling the inclusion criteria limited the conclusions regarding the success of the augmentation and its effect on the survival of the implants. Properly designed randomized controlled clinical trials on this topic are needed.

Key words: bone grafts; GBR; implant outcomes; implant success; implant survival; lateral augmentation success; lateral ridge augmentation; split osteotomy; systematic review

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The use of titanium dental implants is considered as a successful and predictable treatment of partial and full edentulism (Adell et al. 1981, Albrektsson et al. 1986). However, a prerequisite for the successful placement of implants in the ideal, prosthodontically driven position is a minimum amount of bone width and height of the recipient site that will provide a functional and cosmetic implant borne restoration for the patient.

Lateral bone/ridge augmentation procedures are necessary when the width of the recipient alveolar ridge does not present with the adequate dimensions

for implant placement, which ultimately will provide the masticatory rehabilitation of the patients. As such, a number of surgical procedures have been used for creating adequate bone width, which can be performed either in combination with the implant placement (*one stage/simultaneous approach*) and this would be usually associated with dehiscence or fenestration bone defects or before the surgical placement of the implants and following a period for healing (*two stage/staged approach*) for thin alveolar ridges. These procedures involve the use of bone grafting with different type of grafts (autografts, allografts, xenografts, bone substitutes), Guided Bone Regeneration (GBR) alone or in combination with grafting procedures, as well as the use of ridge expansion techniques utilizing ''split'' ridge osteotomy.

Autogenous bone grafts are currently used for the reconstruction of partial and full edentulism with various degrees of success (Jensen & Sindet-Pedersen 1991, Schliephake et al. 1991, Nyström et al. 1993). Furthermore, successful bone regeneration has also been observed when GBR alone or in combination with bone grafts has been used either for placement of dental implants following ridge augmentation (Buser et al. 1995, 1996) or simultaneously with the placement of implants (Dahlin et al. 1989, Becker et al. 1990, Lorenzoni et al. 1998). These procedures are currently used in the everyday clinical practice with various degrees of success (Hämmerle & Hellem 1999).

In all surgical procedures, one of the essential requirements is the predictability of the successful outcome of the procedure. The success of a lateral ridge augmentation technique could also be based on the survival/success of the dental implants placed on the site because ultimately this would reflect a successful outcome, which is the masticatory rehabilitation of the patient. In the current literature, the survival/success of implants placed in combination with lateral augmentation procedures is not always compared directly with the survival/success rate of implants placed in a conventional manner where lateral augmentation was not undertaken. It is also often assumed that the result of the augmentation procedures would be maintained to similar levels as the inserted implants.

The present systematic review was carried out to compare the clinical outcomes of dental implants in sites treated with different lateral bone augmentation procedures to implants placed in a conventional manner where lateral ridge augmentation was not performed (pristine sites). Through the included studies of the review, the outcomes in terms of implant survival/success as well as of the success of augmentation procedure would have been possible to be evaluated for the different time points and follow-up periods of the different treatments.

Focused Question

''In patients treated with different lateral ridge augmentation procedures (GBR, bone grafts, ridge expansion) what are the clinical outcomes in terms of implant survival/success in comparison with implants placed in sites with no lateral ridge augmentation (pristine site)''.

A secondary objective was also to survey studies from the retrieved publications with implants placed in augmented sites but did not include a control group of implants in pristine sites for providing additional information on clinical outcomes. These studies were not pooled with the comparative studies that included a control group and the limitation of the research design was also taken into account and the results from these studies are clearly identified as being separate from the primary focused question.

Material and Methods

Before commencement of the study, a detailed protocol agreed by all authors was developed.

Design of the study

The protocol of the present systematic review was set out with the following methods: search strategy, eligibility criteria for study inclusion, screening methods, data abstraction, quality control and data synthesis.

Inclusion criteria

1. All prospective longitudinal studies reporting on endosseous dental implant survival and/or success in jaws where laterally augmentation procedures have been performed were included (i.e. randomized controlled trials (RCTs), controlled clinical trials (CCTs), cohort studies, case–control studies, and case series). Data syntheses were stratified by study design. Single arms (subgroup) of studies that presented data separately for implants placed in lateral bone augmentation in one stage (simultaneous) or in two stages (staged approach) and in non-augmented (pristine) sites were also included. These data may be located in different type of studies including clinical trials (e.g. RCTs) and cohort studies, comparing different implant types.
2. Studies needed to report on implants with at least 6 months of loading. This was selected to allow biological complications during function to be observed rather than early implant failures.
3. Patients were partially dentate who had received dental implants in non-augmented bone (control) with a comparison group of patients undergoing a lateral bone augmentation procedure (test). Controlled studies should have included at least five patients per group (control/test) (in total 10 patients). This has been selected arbitrarily to exclude individual case reports. In cases where few of the patients included in the study were edentulous in one of the jaws, these studies were included.
4. In order for case series studies to be included they had to report on a minimum of 15 consecutive patients who were not selected on the basis of bone quality or volume.
5. Studies on smokers were included.
6. Studies utilizing only titanium endosseous implants including different types of surface modification were included.

Exclusion criteria

1. Studies that reported on the results of the lateral augmentation procedures with no consequent implant placement and/or loading (<6 months) were excluded.
2. Studies in medically compromised patients, e.g. cancer, uncontrolled diabetes mellitus, were excluded.
3. Studies involving trans-mandibular implants, zygomatic implants, transitional implants, implants used for anchorage in orthodontic therapy, maxillofacial prosthesis or any other non-dental use were excluded.
4. Studies describing major maxillofacial reconstructions with combined extra-oral vascularized or not bone grafts for the reconstruction of severely resorbed maxillae and/or mandibles were excluded.
5. Studies describing socket preservation techniques for bone augmentation and/or immediately placed implants in extraction sockets were excluded.

6. Studies describing vertical ridge augmentation techniques were excluded.
7. Studies describing treatment of peri-implantitis were excluded.
8. Studies with ridge augmentation procedures carried out in tumour resected jaws; maxillofacial trauma; alveolar clefts, with subsequent implant placement were excluded.
9. Retrospective studies, letters and reviews were excluded.

Additional studies

Studies that derived from the screening process and compared/included different membranes or techniques for lateral augmentation which was followed by dental implant placement with functional loading of at least 6 months and satisfied the above inclusion criteria but did not include a control group with implants placed in pristine sites were also reviewed in order to evaluate possible additional information on implant and augmentation outcomes. However, these studies were not considered to provide direct evidence to the focus question. These studies were categorized as ''additional'' and the same data extraction was used but the results were only reported as a supplement to the main systematic review.

Types of intervention

The following lateral augmentation procedures were considered: (1) GBR, (2) Block and particulate bone grafts (3) ridge expansion techniques utilizing ''split'' ridge osteotomy.

Types of outcome measures

Implant survival

This was presented (when possible) as a percentage cumulative ''survival'' rate indicating that a certain percentage of implants were still present in the mouth (censored) at the end of the observation period. The observation period was classified into cumulative implant survival (when available) from placement or from loading (i.e. post-loading survival rate). The results could have also been presented as incidence of implant loss (''failure'' rate), i.e. number of losses divided by sum of lengths of time at risk for each implant. Any other definition of implant survival as described in the included study was also considered.

Implant success

As there is a lack of consensus regarding a set of universally accepted success criteria, all definitions of implant success (including bone level change) were considered according to the criteria of each included study. However, when possible, the following clinical and radiographic criteria were utilized to define implant success based on a combination of the success criteria previously defined by Albrektsson et al. (1986) and adapted by Buser and co-workers (1997) as well as Karoussis et al. (2004):

1. Absence of mobility (Buser et al. 1990).
2. Absence of persistent subjective complaints (pain, foreign body sensation and/or dysaesthesia) (Buser et al. 1990).
3. Absence of recurrent peri-implant infection with suppuration (Buser et al. 1990).
4. Absence of a continuous radiolucency around the implant (Buser et al. 1990).
5. No pocket probing depth (PPD) $>$ 5 mm (Mombelli & Lang 1994, Bragger et al. 2001).
6. No PPD $\geqslant$ 5 mm and bleeding on probing (BOP) (Mombelli & Lang 1994).
7. During the first year, a 1.5 mm of vertical bone resorption was accepted. After the first year of service, the annual vertical bone loss should not exceed 0.2 mm (mesially or distally) (Albrektsson et al. 1986, Albrektsson & Isidor 1994).

Lateral ridge augmentation success

Definition of Successful Lateral Ridge Augmentation. The authors agreed that the following constituted successful lateral ridge augmentation irrespective of the surgical technique used:

Creation of an alveolar ridge of adequate dimensions to facilitate placement of dental implants that were eventually osseointegrated into the host and regenerated bone and were functionally loaded under a restorative driven protocol for at least 6 months.

When the above parameters were not available or clear, the success/survival of lateral augmentation procedures was considered according to the related criteria of each included study. These comprised clinical and radiological methods to measure bone level changes before and after lateral augmentation procedures including surgical re-entry and for the entire observation period that corresponded to the reported implant survival or success.

Search strategy

The search strategy incorporated searching of electronic databases, supplemented by cross-checking bibliographies of relevant review articles. A search on MEDLINE and EMBASE using the Ovid interface was conducted up to and including the 30th of November 2007.

The search strategy for MEDLINE and EMBASE used a combination of MeSH terms and text words. The initial electronic search strategies formulated for MEDLINE were adapted from Esposito et al. (2005) and later modified as appropriate for EMBASE.

The following keywords/search terms and their combinations (grouped as population/exposure, interventions, type of studies) limited to clinical studies, were used:

''Implants'', ''Dental Implants'', ''Osseointegrated Implants'', ''Oral Implants'', ''Implant Supported Prosthesis'', ''Transmucosal Implants'', ''Alveolar Ridge Augmentation'', ''Lateral Ridge Augmentation'', ''Alveolar Ridge Atrophy'', ''Regeneration'', ''Bone Regeneration'', ''Guided Bone Regeneration'', ''Guided Tissue Regeneration'', ''Barrier Membranes'', ''Membranes'', ''Distraction Osteogenesis'', ''Alveolar Distraction Osteogenesis'', ''Graft'', ''Bone Grafts'', ''Bone Substitutes'', ''Autogenous Bone Grafts'', ''Allograft'', ''Xenograft'', ''Calvarial Bone Graft'', ''Iliac Crest Graft'', ''Chin Bone Grafts'', ''Onlay Bone Grafts'', ''Veneer Bone Grafts'', ''Split Crest Osteotomy'', ''Ridge Expansion'', ''Implant Outcomes'', ''Prospective study'', ''Comparative Study'', ''Randomised Control Trial'', ''Controlled Clinical Trial'', ''Cohort Study'', ''Case Series''.

These were combined as: *Population/Exposure AND (intervention OR types of studies)*. In addition, the bibliographies of relevant review articles were screened for possible inclusions. The references of all included publications were screened for further relevant studies. In addition, reference lists of recent relevant review publications were manually examined for studies that had not been identified by the electronic search.

Studies published in English, German, French and Italian were included

and translated by staff at the Eastman Dental Institute if necessary.

Study eligibility assessment and data extraction methods

Steps in search

Searching for relevant studies. The comprehensive nature of the search methodology resulted in a large volume of published studies in the topic. As such, a three-stage screening process was performed independently and in duplicate to increase accuracy of the extracted data (Fig. 1). Independent duplicate data extraction was done by two reviewers (NM and VC) on a predetermined data extraction form (for the third stage of screening). Data recorded from the included studies were based on the focus question. During each stage, all disagreements were resolved by discussion and if necessary, a third reviewer was consulted (ND). In cases where consensus on excluding an article was not achieved, the article was included in the next stage of screening.

The first stage included screening of titles (NM, VC) to eliminate irrelevant publications, review articles and animal studies.

The second stage of screening (NM, VC) excluded studies based on the number of patients, the nature of the study sample, the intervention and the outcome characteristics.

The third stage of screening of the full text articles (NM, VC) was performed using a predetermined data extraction form to confirm the study eligibility based on the predetermined inclusion and exclusion criteria.

The level of agreement regarding inclusion of potential studies was calculated by κ statistics for the second stage of the screening and for 50 randomly selected publications in the third stage of screening. Any disagreement was resolved by discussion and when necessary a third, internal reviewer (ND) was consulted.

Methodological quality assessment

Quality assessment of all the included studies was conducted independently and in duplicate by two reviewers (NM and VC) as part of the data extraction process.

The methodological quality assessment of included studies has been adapted from Khan et al. (2001) and has been used previously by our group in another systematic review (Ong et al. 2008 in press). It assessed the components of study methodology that might affect the outcomes of a study such as similarity of baseline characteristics between the test and control groups; masking of outcome assessors; completeness of follow-up; reasons, rates of drop-out and explicitness of the inclusion criteria.

Accordingly, an overall risk of bias for each study was provided by the reviewers, which was classified into three categories: *low, medium or high. Low risk* of bias was classified as fulfillment of all the assessed components. On the other hand, *a high risk of bias* was based on studies that have either not fulfilled or only fulfilled a limited number of the assessed components.

Confounding factors

Factors such as smoking, medical history and periodontal status/factors were also assessed to determine whether they were reported and adjusted in the final study analysis.

Data synthesis and analysis

Evidence tables were created with the data of the studies and grouped according to type of treatment. Descriptive analysis (summary) was initially performed to determine the quantity of data, evaluating at the same time for variations in terms of study characteristics (i.e. populations, interventions, outcomes, design, quality and results).

Meta-analysis was not performed due to the significant heterogeneity of the data in the included studies. As such, the synthesis of the data was determined from the evidence tables alone.

Results

Study characteristics

The search resulted in the 5079 studies in total. Following the first stage screening of titles, 435 potentially relevant publications were identified. Independent screening of titles and abstracts (second stage screening) resulted in

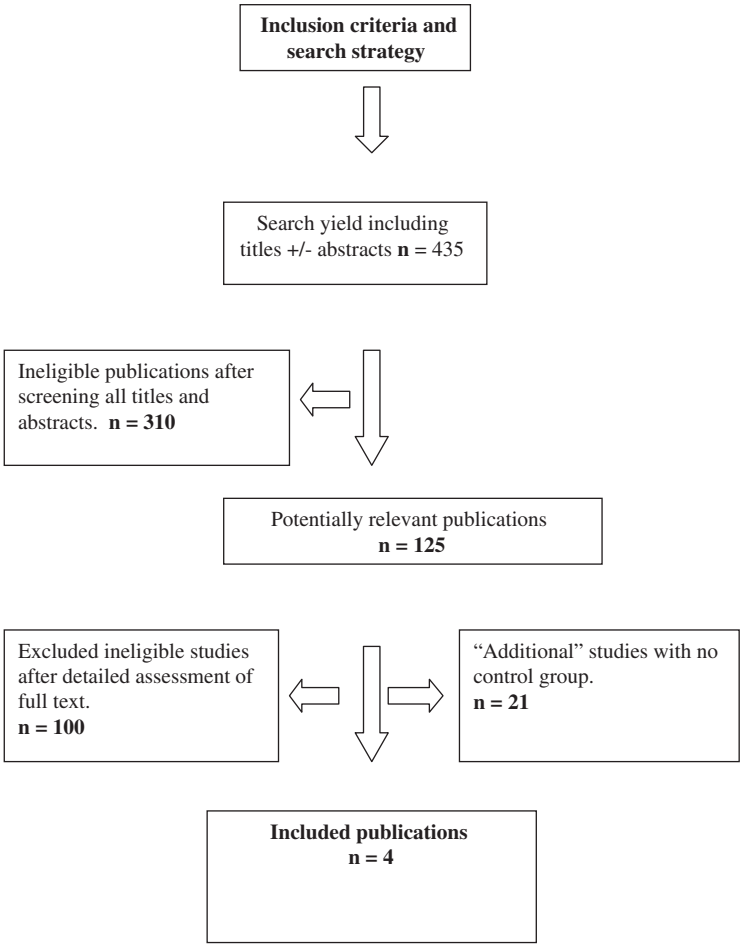

Fig. 1. Flow of studies through the review.

Table 1. Study characteristics and summary of data in the included studies

Author, year and study type	Participants: 1. Patients Number and implant numbers 2. Drop-outs 3. Age-range 4. Source of recruitment 5. Smoking habits	1. Type of procedure and defect Site of implant placement: 2. Maxilla or/and Mandible 3. Anterior/Posterior	Lateral augmentation technique: GBR OR Graft OR Split ridge	Lateral augmentation success % 1. Pre-loading 2. Post-loading Ridge dimensions: 1. Before 2. After 3. Implant placement possible? 4. Initial augmentation adequate?	Follow-up 1. Control 2. Test	Implant outcome augmented sites 1. Survival 2. Success	Implant at control/pristine post-loading 1. Survival 2. Success	No. of implants lost at augmented sites	No. of implants lost at control sites
Corrente et al. (2000) CCT Split mouth	1. 29 patients/112 implants 2. Drop-out: No 3. Age: Unclear 4.Recruitment: Unclear 5. Smoking: Unclear	1. *One stage*: Dehiscence, fenestration, intrabony defects 29 patients/52 implants *Versus* *Pristine sites* in 29 patients/60 implants 2. Jaw: Maxilla/mandible 3. Site: Unclear	*Lateral augmentation technique*: *Graft*: Bone substitute Carbonate (Biocoral Gel) ± fibrin-fibronectin (Tissucol)	*Augmentation success*: 1. Pre-loading: 85.4% 2. Post-loading: Unclear *Ridge dimensions*: 1. Before: Unclear 2. After: Unclear 3. *Implant placement possible?* Yes 4. *Initial augmentation adequate?* No (14.6%) incomplete defect resolution	*Follow-up* 1. *Control*: 59 months post-loading (49–82) *2. Test*: 55 months post-loading (21–76)	*Augmented sites:* 1. *Survival*: 91.7% (after removal of early failures) 2. *Success:* 91.7%(after removal of early failures	*Control:* 1. *Survival:* 93.2% post-loading (after removal of early failures 2. *Success*: 93.2% post-loading (after removal of early failures	*Lost implants/ augmented sites*: 8.3%	*Lost implants/ control*: 1.6% (1 implant) preload 6.6% (4 implants) post-loading
Ozkan et al. (2007) Cohort study	1. 15 patients/35 implants 2. Drop-out: No 3. Age: 19–55 4. Recruitment: University/Hospital 5. Smoking habits: Non-smokers	1. *Two stage*: autogenous block bone graft in 8 patients/17 implants *Versus* *Pristine sites* in 7 patients/18 implants 2. Jaw: Mandible 3. Site: Posterior	*Lateral augmentation technique*: *Graft*: Autogenous mono cortical block+particulate chin graft	*Augmentation success*: 1. Pre-loading: 100% 2. Post-loading: Unclear *Ridge dimensions*: 1. Before: 3.2 ± 0.3 mm 2. After: 6.4 ± 0.4 mm 3. *Implant placement possible?* Yes 4. *Initial augmentation adequate?* Yes	*Follow-up* (control and test): 12 months post-loading	*Augmented sites:* 1. *Survival*: 100%	*Control*: 1. *Survival*: 100%	*Lost implants/ augmented sites*: 0%	*Lost implants/ control*: 0%
Zitzmann et al. (2001)	1. 75 patients/265 implants 2. Drop-out: 9	1. *One stage GBR:* Fenestration and Dehiscence	*Lateral augmentation technique*:	*Augmentation success*: 1. Pre-loading:	*Follow-up* (control and test):	*Augmented sites*: 1. *Survival*: mean: 95.8%	*Control*: 1. Survival: 97.3%	*Lost implants/ augmented sites*: Unclear	*Lost implants/*

Table 1. (Contd.)

Author, year and study type	Participants: 1. Patients Number and implant numbers 2. Drop-outs 3. Age-range 4. Source of recruitment 5. Smoking habits	1. Type of procedure and defect Site of implant placement: 2. Maxilla or/and Mandible 3. Anterior/Posterior	Lateral augmentation technique: GBR OR Graft OR Split ridge	Lateral augmentation success % 1. Pre-loading 2. Post-loading Ridge dimensions: 1. Before 2. After 3. Implant placement possible? 4. Initial augmentation adequate?	Follow-up 1. Control 2. Test	Implant outcome augmented sites 1. Survival 2. Success	Implant at control/pristine post-loading 1. Survival 2. Success	No. of implants lost at augmented sites	No. of implants lost at control sites
CCT Split mouth	patients 3. Age: 19–76 4. Recruitment: Unclear 5. Smoking habits: Unclear	75 patients/153 implants *Versus* *Pristine sites*: 75patients/112 implants 2: Jaw: Maxilla and mandible 3: Site: Anterior and posterior	*Simultaneous GBR*: e-PTFE+Bio-Oss (24 patients/41 implants) and Collagen (Bio-Gide)+ Bio-Oss (75 patients/112 impants)	Unclear 2. Post-loading: Unclear *Ridge dimensions*: 1. Before: Unclear 2. After: Unclear 3. *Implant placement possible?* Yes 4. *Initial augmentation adequate?* Unclear	59.1 months post-loading (range 55–70)	– 95.4% collagen – 92.6% e-PTFE 2. *Success*: Unclear			*control*: Unclear
Mayfield et al. (1998) CCT split mouth	1. 7 patients/38 implants 2. Drop-out: 4 patients/25 implants 3. Age: 57–82 years 4. Recruitment: Private practice 5. Smoking Habits: 1/7 smoker	1. *One stage GBR* Fenestration (11implants) and Dehiscence (10implants) 7patients/21implants *Versus* *Pristine sites*: 7 patients/17implants 2. Jaw: Maxilla and mandible 3. Site: Anterior and posterior	*Lateral augmentation technique*: *Simultaneous GBR*: Copolymer of polyglycolide and polylactide (Resolut)	*Augmentation success*: 1. Unclear 2. Unclear *Ridge dimensions*: 1. Unclear 2. Unclear 3. *Implant placement possible?* Yes 4. *Initial augmentation adequate?* Unclear	*Follow-up* (control and test): 24 months post-loading (25–29)	*Augmented sites:* *1. Survival:* 100%	*Control:* *Survival:* 100%	*Lost implants/augmented sites*: 0%	*Lost implants/control*: 0%

RCT: randomized controlled clinical trial, CCT: controlled clinical trial, CS: case series.
Lateral augmentation success: simultaneous/one stage procedure: complete cover of exposed implant surface, staged approach: restorative driven implant placement with no further augmentation procedure needed

Table 2. Study characteristics and summary of data of the controlled studies

Author and year	Type of implants: 1. System, design and surface topography (as reported by authors) 2. Diameter and length 3. type of implant support prosthesis	Trial characteristics: 1. Location 2. Number of centre 3. Source of funding	Success criteria	1. Experience of operator 2. Antibiotics	Loading of implants:	Complications (Except Loss of Implant): 1. Test 2. Control 3. Comments
Corrente et al. (2000)	1. Type of implant: Screw-vent Paragon unclear surface topography 2. Length: 8–13 mm, Diameter (D): 3.75 mm 3. Single tooth, fixed bridge	1. Location: University of Torino, Italy 2. Single centre 3. Source of funding: Unclear	Success criteria: Albrektsson criteria	1. Experience of operator: Specialist 2. Antibiotics: Amoxicillin 1 g every 8 h, 1 h before and 7 days after	Loading: 1. Delayed Augmented sites: 7 moths Pristine sites: 4–5 months	No complications
Ozkan et al. (2007)	1. Type of implant: SLA Straumann 2. Test: 10–14 mm length, control: L: 12–14 mm length D: 3.3–4.1 mm 3. Fixed bridges	1. Location: University of Marmara, Turkey 2. Single centre 3. Source of funding: Unclear	Success criteria: RFA, Mobility, Subjective complaints, Inflammation, Periimplant radiolucency, Bone loss MBL in standardized radiographs	1. Experience of operator: Specialists 2. Antibiotics: Amoxicillin+Clavulanic acid 1000 mg/12 h intramuscular or clindamycin 600 mg/12 h	Loading: Delayed (4 months)	No complications
Zitzmann et al (2001)	1. Type of implant: Nobel Biocare/ Turned surface 2. Diameter and length: Unclear 3. 6/75 Overdentures single tooth, fixed bridge	1. Location: Switzerland 2. Single centre 3. Source of funding: Unclear	Success criteria: Albrektsson criteria with no 0.2 mm annual vertical bone loss. Radiographical mean marginal bone level	1. Experience of operator: Specialist 2. Antibiotics: Unclear	Loading: Delayed: 4 months maxilla 6 months mandible	Test and control: peri-implant mucosal problems (e.g. redness, hyperplasia, suppuration, pain and swelling.
Mayfield et al. (1998)	1. Type of implant: Brånemark turned surface 2. Diameter and length: Not mentioned 3. Single tooth, fixed bridge	1. Location: Sweden 2. Single centre 3. Source of funding: Academic	Mobility, inflammation, PPD, BOP, peri-implant radiolucency, Marginal bone loss and level	1. Experience of operator: Specialists 2. Antibiotics: Unclear	Loading: Delayed 6–7 moths	1. Test: Exposure of the first thread of the implant (9%)

further consideration of 105 for possible inclusion. The search from the bibliographies of relevant review articles and the references of all included publications resulted in 20 further studies increasing the total number of potentially included studies to 125. Only four publications out of 125 studies met the defined inclusion criteria and presented a control group. This group of studies was called ''controlled'' studies (Fig. 1) (Tables 1–3).

''Additional'' studies

Twenty-one studies were found comparing two different membranes or techniques for lateral augmentation or including a series of cases with different lateral ridge augmentation techniques with consequent dental implant placement and loading for more than 6 months but did not have a control group (implant in pristine sites) and as such they were considered to provide only supplementary evidence to the focused question. These studies were categorized as ''additional'' and the same data extraction process was used but the results were reported only as a supplement to the main systematic review.

The excluded publications and the main reason for exclusion are presented separately in Appendix A.

The κ value for inter-reviewer agreement for study inclusion was 0.82 (titles and abstracts) and 1.0 (full-text articles) indicating ''good'' and ''complete'' agreement, respectively, between reviewers according to the criteria of Landis & Koch (1977).

''Controlled studies'' answering the focus question

The included studies consisted of three CCT (Mayfield et al. 1998, Corrente et al. 2000, Zitzmann et al. 2001) and one cohort study (Ozkan et al. 2007).

Patient and intervention characteristics

The test group in two studies (Mayfield et al. 1998, Zitzmann et al. 2001) was simultaneous GBR, in one it was bone substitute (Corrente et al. 2000) and in one it was autogenous block and particulate mandibular/chin bone graft (Ozkan et al. 2007). In two studies, the control group consisted of another parallel group of patients (Corrente et al. 2000, Ozkan et al. 2007) and in the remaining two

Table 3. Quality assessment of reviewed controlled studies

Study	Similarity of baseline characteristics: 1. Bone quality 2. Prosthetic needs	Patients consecutively entered (for case series)	Inclusion criteria explicit	Masking of 1. Assessor 2. Operator	Similarity of drop-outs and reasons for drop-outs	Risk of bias	Potential source of heterogeneity and other methodological points
Corrente et al. (2000)	1. Unclear bone quality 2. Similar prosthetic needs	Unclear	Unclear	Unclear masking	No drop-outs	High	– Sample calculation unclear – Bone grafting was combined with fibronectin in some cases – Unclear distribution between type of defects – Different loading periods – Initial implant failures were excluded from the final analysis
Ozkan et al. (2007)	1. Unclear bone quality 2. Similar prosthetic needs	Yes	Yes	Unclear masking	No dropouts	Medium	– Sample size calculation unclear
Zitzmann et al. (2001)	1. Unclear bone quality 2. Different prosthetic needs (single tooth, bridge and overdenture)	Unclear	No	Unclear masking	Similarity of drop-outs: Drop-out: 9 patients • 4 patients died • 3 patients moved • 2 elderly patients declined to continue after the 4-year check-up.	High	– Sample calculation is unclear – No standardized X-rays – The re-entry measurements of the defects were not reported – Different type of membranes were used
Mayfield et al. (1998)	1. Unclear bone quality 2. Similar prosthetic needs	Unclear	Yes	1. Masking of assessor 2. Unclear masking of operator	Similarity of drop-outs: Similar Drop-out: 4/11 original patients Study performed on 7 patients. 2 pts ill, 2 declined to participate	High	– Sample calculation unclear

studies a split mouth design was employed (Mayfield et al. 1998, Zitzmann et al. 2001). In three studies (Mayfield et al. 1998, Corrente et al. 2000, Zitzmann et al. 2001), the implants were placed in both upper and lower jaws and in both anterior and posterior sites. In one study (Ozkan et al. 2007), the lateral augmentation procedures and the dental implants were all performed in the posterior sites of the mandible.

GBR (Mayfield et al. 1998; Zitzmann et al. 2001). In both studies, the treatments were performed in a single centre (Switzerland, Sweden), a total of 87 patients (both test and control) were treated and a total of 303 implants were placed. One hundred and ninety-one (191) Brånemark with a turned surface implants were placed in laterally augmented sites and 129 implants in control sites. The dental implants were used for single tooth and fixed bridge restorations and in 6 cases were used to support implant borne over-dentures (Zitzmann et al. 2001). The implants were loaded in both test and control sites between 4 and 7 months.

In both studies, the test site involved one stage simultaneous lateral ridge augmentation in dehiscence and fenestration defects. In Zitzmann et al. (2001), at the test sites, 41 defects were treated with e-PTFE (Gore-Tex) non-resorbable membrane and demineralized bovine bone particles (Bio-Oss) and 112 defects were treated with a porcine origin collagen membrane (Biogide) and Bio-Oss particles. However, the distribution of the type of the defect between membranes was not clear. In Mayfield et al. (1998), 21 defects around implants were treated with a resorbable polylactic polyglycolic acid membrane (Resolut, Gore-Tex), where the 10 implant defect sites were dehiscence and 11 fenestrations.

Outcomes. In both studies, there were no reentry procedures and the success of lateral ridge augmentation or the changes in ridge dimensions were not reported. In Mayfield et al. (1998), a clinical follow up of 24 months (range 25–29 months) was reported with 100% implant survival both at test and control sites. Clinical parameters and the mean radiographical marginal bone level (number of exposed threads) and marginal bone loss at the mesial and distal site of the implant at 9 months (range 4–15 months) and at 25 months (range

23–27 months) were used as success criteria. At the radiographs during abutment connection the membrane treated fixtures had lower marginal bone levels than the control fixtures, indicating that optimal bone regeneration was not achieved at all defects. At control, pristine sites, the radiographical marginal bone level changed from a mean ± SD of 0.5 ± 0.6 exposed threads at abutment connection (baseline) to a mean ± SD of 1.5 ± 0.6 exposed threads at 25 months after loading. During the same observation period, in fenestration defects the radiographic marginal bone level changed form 1.6 ± 1.5 exposed threads at baseline to 2.6 ± 1.5 exposed threads and from 0.9 ± 0.6 exposed threads at baseline to 2.2 ± 1.5 exposed threads at the dehiscence defects. However, there was no statistically significant difference in terms of radiographic marginal bone loss between control and test (fenestration and dehiscence) fixtures. Also, there were no statistically significant differences in marginal bone loss between fixtures presenting dehiscence or fenestration defects.

In Zitzmann et al. (2001), the follow up was 59 months and the implant survival was 97.3% for the control sites and 95.4% and 92.6% for the collagen and e-PTFE membranes, respectively. The differences between groups were not statistically significant. The Albrektsson criteria and the mean marginal bone level (MBL) at the mesial and distal aspect of the implant in radiographs (parallel long-cone technique) taken after the placement of the supra-structure, at 6 months post-loading and at 1 and 5 years after loading were used as success criteria and for evaluating the marginal bone loss between test and control sites. There was an increase in MBL at the control sites from 0.27 ± 0.52 mm (mean ± SD) at the day of supra-structure placement to 1.73 ± 0.7 mm at 60 month post-loading. At the sites treated with collagen membrane and e-PTFE there was an increase of mean MBL from 0.35 ± 0.68 and 0.39 ± 0.79 mm to 1.83 ± 0.63 mm and 2.21 ± 1.26 mm at 60 months post-loading, respectively, which was statistically significant ($p < 0.0001$). The average MBL values were significantly higher ($p < 0.001$) for the collagen membrane and the e-PTFE sites when compared with controls. At the same time, the e-PTFE MBL values were significantly higher than the collagen membrane.

GBR complications. The complications reported in the studies were presence of peri-implant mucosal problems including redness, hyperplasia, suppuration, pain and swelling (Zitzmann et al. 2001) or exposure of threads in a limited number of fixtures (Mayfield et al. 1998). A positive relationship was found between increased MBL values and mucosal problems or recession ($p < 0.0001$) (Zitzmann et al. 2001).

Autogenous block graft. One cohort study with 15 patients where 8 patients received 17 implants in sites augmented with block bone graft and 7 patients received 18 implants (Straumann, SLA surface) in pristine sites was retrieved (Ozkan et al. 2007). The augmentation procedure resulted in increase of bone width for implant placement. The ridge dimensions before grafting at the test site were 3.2 ± 0.3 mm and after the ridge augmentation procedure it increased to 6.4 ± 0.3 mm.

The implants at the test sites were placed in a second stage procedure (4 months following grafting) and the reported implant survival was 100% after 12 months post-loading for both test and control sites.

The success of the implants was evaluated mainly by Resonance Frequency Analysis (RFA) which showed no statistical significant difference between test and control sites. Other success criteria were the mobility of the implants, presence of inflammation and peri-apical radiolucency. Furthermore, bone loss was evaluated by standardized radiographs which showed a mean value (mesial and distal) of 0.16 mm of bone loss at 12 months at test sites.

Bone substitute. One CCT with a split mouth design reported on the simultaneous use of Calcium Carbonate, with or without the use of a fibrin-fibronectin system in dehiscence, fenestration as well as intrabony defects compared with implants (Screw Vent, Paragon, Carlsbad, CA, USA) placed in pristine sites in 29 patients (Corrente et al. 2000). In total 112 implants were placed in this study (52 test and 60 control) and were followed for 59 (control) and 55 months (test). Seven out of 48 implants (14.6%) presented incomplete bone healing. At the control sites, one implant was lost before loading and four implants were lost at follow up resulting in a survival rate of 93.2% after removing from the final analysis the implants presenting early failures. At the test sites, four implants were lost before loading and four implants at follow up resulting in a survival rate of 91.7% after removing from the final analysis the implants presenting early failures. The success of the implants was based on the Albrektsson criteria without providing any further clarification.

Methodological quality of all included studies. There was satisfactory agreement between reviewers concerning the study quality issues as summarized in Table 3. Most of studies were rated as high risk of bias because they did not fulfill most of the quality assessment criteria. The study by Ozkan et al. (2007) and the study by Zitzmann et al. (2001) provided explicit inclusion criteria but most of the remaining quality assessment criteria were unclear.

Confounding factors. Ozkan et al. (2007), did not include smokers in the study. Mayfield et al. (1998) included one smoker out of the total seven patients and the in the remaining studies the smoking habits were unclear.

The sources of heterogeneity and other critical methodological issues included: small numbers of recruited patients (Mayfield et al. 2001, Ozkan et al. 2007), unclear methodology for sample size calculation based on the primary outcome (all studies), use of the implant as the unit of analysis (all studies), removal of failed implants from the final statistical analysis (Corrente et al. 2000), lack of standardized radiographs (Mayfield et al. 1998, Zitzmann et al. 2001), lack of initial radiograph measurements immediately after implant placement (Mayfield et al. 1998, Zitzmann et al. 2001), inclusion of use of two types of membranes within the same patients (Zitzmann et al. 2001) and unclear number of patients where added biomaterial (Tissucol) was used (Corrente et al. 2000).

"Additional studies" (lack of control-pristine site group)

Twenty-one studies were included in this category. Two studies were randomized CCTs (Ferrigno & Laureti et al. 2005, Zitzmann et al. 1997), one was a prospective cohort study (Christensen et al. 2003), one study was CCT (Chiapasco et al. 1999) and one was arm of a CCT (Thor et al. 2005). Sixteen included studies were case series

Table 4. Result of study characteristics selected ''additional'' studies

Author, year and study type	Participants: 1. Number of patients and implants 2. Drop-outs 3. Smoking habits	Type of procedure and type of defect:	Material and Treatment Group	Lateral augmentation Success % 1. Preload 2. Post-loading Ridge/defect dimensions: 1. Before 2. After 3. Implant placement possible? 4. Initial augmentation adequate	Follow-up	Implant outcomes at lateral augmented sites post-loading 1. Survival 2. Success	1. Augmentation complication 2. Number of implants lost at augmented sites
				GBR			
Keith et al. (2006) Case Series	1. 73 patients/97 implants 2. Drop-outs: None 3. Smokers included ($n = 2$)	1. *Staged* GBR and block allograft	– Resorbable collagen membrane (79% defects) Mineralized block allograft and particulate bone allograft or DFDBA (83%defects) and/or PRP in 23% defects.	*Lateral augmentation* *Success %* 1. Preload: Unclear 2. Post-loading: 93% graft survival (1year) and 91% (2 years) *Ridge Dimensions* 1. Before: 1–5 mm 2. After: Unclear 3. *Implant placement possible:* 97 implants in 63% of grafted defects 4. *Initial augmentation adequate*: Unclear	*Follow-up*: 0–36 months post-augmentation	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 99% (24 months post-grafting)	1. Flap dehiscence 6/82 defects–(7.3%) –Loss of graft 8/82 defects (9.7%). 2. 1/97 implants lost (1.03%)
Blanco et al. (2005) Case Series	1. 19 patients/26 implants 2. Drop-outs: None 3. Smokers included	*Simultaneous GBR*+combination bone graft Fenestration ($n = 6$ implants) Dehiscence ($n = 20$ implants)	GBR (GTAM, Gore Tex)+Autogenous particulate ($n = 5$ patients GBR (GTAM, Gore Tex)+ DFDBA or mixture autogenous particulate+DFDBA ($n = 12$ patients)	*Lateral augmentation* *Success %* 1. *80.7% of the sites presented 100% defect resolution* – 97.3% of implants *in non-exposed membranes* showed 100% defect resolution and – 0% implants *in exposed membranes* showed 100% defect resolution 2. NA *Ridge Dimensions* *non-exposed membranes* ($n = 23$ implants) Before: 6.23 ± 2.26 mm After: 0.17 ± 0.5 mm *exposed membranes* ($n = 3$ implants) Before: 8.33 ± 4 mm After: 1.6 ± 0.5 mm 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate*: unclear	*Follow-up:* 5 years post-implantation	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 96.1%	1. Membrane exposure/early retrieval in 3/26 implants (11.5%) 2. 1/26 implants lost (3.84%)
Peleg et al. (2004) Arm of Case Series	1. 37 patients/41 implants 2. Drop-outs: None 3. Smoking habits: Unclear	*Simultaneous GBR* Fenestration and Dehiscence	*GBR Collagen* (BioMend Extend) or Lyophilized Dura Mater (University of Miami tissue bank) *+Autogenous bone chips*	*Lateral augmentation* *Success %* 1. Pre-loading: 100% 2. Post-loading: Unclear *Ridge Dimensions* 1. Unclear 2. Unclear	*Follow-up:* 16 months (range: 8–24) post-implantation	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 100% 2. Success: 100%	1. No complications reported 2. No implants lost

			(zygomaticomaxillary buttress, ramus, lateral mandibular wall)	3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Yes			
Christensen et al. (2003) prospective cohort	1. 45 patients/55 implants 2. Drop-outs: None 3. Non-smokers	*Simultaneous* *GBR* ± combination bone grafting Fenestration and Dehiscence 28 pts/32 implants *Versus* *Staged* *GBR* ± combination bone graft 17 pts/23 implants.	*GBR* 1. e-PTFE, (Gore-Tex) 2. e-PTFE titanium reinforced 3. resorbable polylactic acid (Guidor) 3. collagen membranes (Bio-Gide) ± a.Autogenous ± Bio-Oss b. Bio-Oss	*Lateral augmentation* *Success %* 1. Pre-loading: Unclear 2. Post-loading: Unclear *Ridge Dimensions* 1. Before: Unclear 2. After: Unclear 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Unclear	*Follow-up*: 2 years post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 100%	1. No complications reported 2. No implants lost
Buser et al. (2002) Case Series	1. 40 patients/66 implants 2. Drop-outs: 3 patients/5 implants 3. Smoking habits: Unclear	1. *Staged* GBR ± autogenous block bone grafts	e-PTFE (Gore-Tex)+ autogenous block bone graft (retromolar, chin)	*Lateral augmentation* *Success %* 1. Pre-loading: 95% *5% (2/40) patients presented compromised results* 2. Post-loading: Unclear *Ridge dimensions* 1. Before: 3.53 ± 0.73 mm 2. After: 7.06 ± 1.24 mm 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Yes	*Follow-up*: 5 years post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 100% 2. Success: 98.3%	1. Flap dehiscence 1/40 patients (2.5%) 2. No implants lost
Chiapasco et al. 1999 CCT	1. 30 patients/74 implants 2. Drop-outs: None 3. Non-smokers	1. *Staged* GBR+ autogenous particulate bone ($n = 15$ patients) *Versus* *Staged* augmentation with autogenous block bone graft ($n = 15$ patients)	e-PTFE (Gore-Tex)+ autogenous bone chips (Chin, retro molar) *Versus* Autogenous bone block graft (ramus, chin, iliac crest, calvarial bone graft)	*Lateral augmentation* *Success %* 1. Pre-loading: 87% (13/15 patients) in GBR group 100% in block graft group 2. Post-loading: Unclear *Ridge Dimensions*: 1. GBR: 3.2 mm; Block graft: 2.7 mm 2. GBR: 7.7 mm Block graft: 8.07 mm 3. *Implant placement possible:* Not always in the GBR group *In 1/15 patient width of ridge insufficient In 1/15 patients pt (GBR) implants inserted with buccal dehiscence Yes in the block graft group 4. *Initial augmentation adequate* No in the GBR group Yes block graft group	*Follow-up:* 22.4 months (range: 18–36 months) post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 100% 2.Success: – GBR: 93.3% – Block graft: 90.9%	– Membrane exposure/early removal 2/15 patients (13.3%) –Transient paraesthesia of the lower lip in 8/15 patients (53.3%). – Paraesthesia of frontal mandibular teeth: 12/15 patients (80%) chin grafts.
Gaggl & Schultes (1999) Case Series	1. 42 patients/42 implants 2. Drop-outs: None 3. Smoking habits: Unclear	*Simultaneous* GBR ± combination bone grafting	Titanium foil (TISIS-Implant, SIS Inc, Austria)+autogenous bone chips (retro molar) + Demineralized freeze dried bone	*Lateral augmentation* *Success %* 1. Pre-loading: – 30/42 (71.4%) patients achieved desirable augmentation dimensions – 5/42 (12%) patients the augmentation failed. – 7/42 patients (16.6%) desired augmentation dimensions was not achieved	*Follow-up*: 12 months post-implantation	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 100%	1. Soft tissue dehiscence in 9/42 patients (21.4%) 2. No implants lost

Table 4. Contd.

Author, year and study type	Participants: 1. Number of patients and implants 2. Drop-outs 3. Smoking habits	Type of procedure and type of defect:	Material and Treatment Group	Lateral augmentation Success % 1. Preload 2. Post-loading Ridge/defect dimensions: 1. Before 2. After 3. Implant placement possible? 4. Initial augmentation adequate	Follow-up	Implant outcomes at lateral augmented sites post-loading 1. Survival 2. Success	1. Augmentation complication 2. Number of implants lost at augmented sites
				2. Post-loading: Unclear *Ridge dimensions:* 1. Before: 4.7 mm (3.9–5) 2. After: Unclear 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* No (28.6%)			
Becker et al. (1999) Arm of Case Series Same population as Dahlin et al. (1995)	1. 44 patients/55 implants 2. Drop-outs: 10 patients 3. Smoking habits: Unclear	*Simultaneous* GBR+autogenous bone graft Fenestration and Dehiscence	e-PTFE+autogenous bone chips	*Lateral augmentation* *Success %* 1. Pre-loading: Unclear 2. Post-loading: Unclear *Ridge dimensions* 1. Before: Unclear 2. After: Unclear 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Yes	*Follow-up:* 1–5 years post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. 76.8% maxilla 83.8% mandible	1. None reported 2. 11/55 implants lost (20%)
Lorenzoni et al. (1999) CS	1. 63 patients/91 implants 2. Drop-outs: 4 patients/6 implants 3. Smoking habits: Unclear	*Simultaneous GBR* Buccal dehiscence (80%) and mesio-distal combination defects (20%)	e-PTFE, (Gore-Tex)	*Lateral augmentation* *Success %* 1. Pre-loading: Unclear 2. Post-loading: Unclear *Ridge dimensions* 1. Before: Unclear 2. After: Unclear 3. *Implant placement possible:* Yes (one stage) 4. *Initial augmentation adequate* Unclear	*Follow-up*: 2 years post-implantation	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 100% 2. Success: 100%	1. Flap dehiscence and membrane exposure (9 patients) 2. No implants lost
Zitzmann et al. (1997) RCT Split mouth design	1. 25 patients/84 implants 2. Drop-outs: No 3. Smokers included ($n = 10$)	*Simultaneous GBR* dehiscence (78 implants), fenestrations (3 implants) combination defects (3 implants)	*GBR with Collagen membrane* (Bio-Gide)+Bio-Oss*($n = 43$ implants) *Versus* *GBR with ePTFE membrane* (Gore-Tex)+Bio-Oss* ($n = 41$ implants) *Bio-Oss mixed with sterile sodium solution+anesthetic (Articain)+tetracycline powder (30 mg/0.5 g, Bio-Oss)	*Lateral augmentation* *Success %* 1. Pre-loading: *collagen membrane mean defect reduction: 92%* (long-term delayed implants: 90%; short-term delayed implants: 97%) *Versus* *e-PTFE mean defect reduction: 78%* (long-term delayed implants: 80%; short-term delayed implants: 94%) 2. Post-loading: N/A *Ridge dimensions* 1. In Bio-Gide group Initial defect size: $15.8 \pm 9.52\,mm^2$ (mean value ± SD)	*Follow-up*: 321 days (range:50–604 days) post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. Overall survival *97.6%* (100% in Bio-Gide and 95.2% in e-PTFE)	1. Flap dehiscence and membrane exposure: 16.3% Biogide and 24.4% e-PTFE 2. 2/41 (4.9%) (e-PTFE) lost implants

				In Gore-Tex group; Initial defect size: $15.7 \pm 11.74\,mm^2$ 2. In Bio-Gide group Final defect size: $1.1 \pm 2.84\,mm^2$ (mean value ± SD); In Gore-Tex group: Final defect size $2.1 \pm 6.40\,mm^2$ (mean value ± SD); 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Unclear		
Fugazzotto (1997) Arm of CS	1. 208 patients/ 432 implants 2. Drop-outs: Unclear 3. Smoking habits: Unclear	*Simultaneous* GBR ± various graft combinations Fenestration (77 implants/25 patients) Dehiscence (172 implants/84 patients) *Two stage* GBR ± various graft combinations (183 implants/99 patients)	e-PTFE+DFDBA+TCP	*Lateral augmentation* *Success %* 1. Pre-loading: Unclear 2. Post-loading: N/A *Ridge dimensions* 1. Before: Dehiscence dimensions range from <2–12 mm; Fenestrations: <2 mm-14 mm 2. NA 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Yes	*Follow-up*: 6–51 months post-loading	*Implant outcomes at lateral augmented sites post-loading* 1.Survival: Dehiscence: 99.4% Fenestration:100% Two stage: 97.3% 2. Success: Dehiscence: 98.9% Fenestration: 100% Two stage: 97.3%	1. Membrane exposure/ infection ($n = 64$ membranes) 2. 7/432 lost implants (1.6%)
Dahlin et al. (1995) Case Series	1. 45 patients/55 implants 2. Drop-outs: 1 patient 3. Smoking habits: Unclear	*Simultaneous GBR* Fenestration (15 implants) and Dehiscence (40 implants) Group A: sites covered with membrane for entire healing period ($n = 48$) Group B: sites exposed during healing ($n = 6$)	e-PTFE (Gore-Tex, GTAM)	*Lateral augmentation* *Success %* 1. Pre-loading: Unclear 82% mean defect size reduction 2. Post-loading: Unclear Defect dimensions 1. Before: Group A: 4.6 mm Group B: 5.3 mm 2. After: Group A: 1.2 mm Group B: 0.6 mm 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* No	*Follow-up*: 2years post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 95% mandible 84.7% maxilla	1. Membrane exposure and early removal (11%) 2. 6/55 Implants (11%) lost (4 at 2nd stage and 2 post-loading)
			Bone Graft				
Thor et al. (2005) Arm of CCT	1. 19 patients/ 152 implants (76 implants placed in anterior areas were included) 2. Drop-outs: none	*Staged* augmentation with Autogenous iliac particulate bone with PRP (19 test sites) *Versus* *Staged* augmentation with Autogenous iliac Block bone graft without	Autogenous iliac particulate bone with PRP (19 test sites) *Versus* Autogenous iliac Block bone graft without PRP (19 control sites)	*Lateral augmentation* *Success %* 1. Pre-loading: Unclear marked resorption of bone graft seen at time of implant installation 2. Post-loading: Unclear Ridge Dimensions 1. Before: Unclear 2. After: Unclear	*Follow-up*: 1 year post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 100%	1. No complications reported 2. No implants lost

Table 4. Contd.

Author, year and study type	Participants: 1. Number of patients and implants 2. Drop-outs 3. Smoking habits	Type of procedure and type of defect:	Material and Treatment Group	Lateral augmentation Success % 1. Preload 2. Post-loading Ridge/defect dimensions: 1. Before 2. After 3. Implant placement possible? 4. Initial augmentation adequate	Follow-up	Implant outcomes at lateral augmented sites post-loading 1. Survival 2. Success	1. Augmentation complication 2. Number of implants lost at augmented sites
	3. Smokers < 10 cigarettes/day were included ($n = 1$) Former smokers: $n = 12$ Non-smokers: $n = 6$	PRP (19 control sites)		3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Unclear			
Hellem et al. (2003) CS	1. 30 patients/82 implants 2. Drop-outs: 3 patients/8 implants 3. Smokers < 20 cigarettes/day were included	*Staged* lateral augmentation with Autogenous particulate bone and Bio-Oss	Autogenous particulate bone (Chin, Ramus, Iliac) and Bio-Oss(50–50%)+Tiseel (Fibrinogen)	*Lateral augmentation Success %* 1. Pre-loading: 92.6%* (patient level) 2. Unclear *Ridge Dimensions* 1. Before: Unclear 2. After: Unclear: 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* No* (7.4%) * –In 1/27 patients the 3 planned implants could not be inserted in the intended position	*Follow-up*: 3 years post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: – 95.9% at implant level – 96.3% at patient level	1. Dehiscence 1/27 patients (3.7%) –Post-operative embolus iliac donor site 1/27 patients (3.7%) – Discomfort iliac donor site 3/27patients (11.1%) –Fracture of abutment screw 1/27 patients (3.7%) –Fracture of facings 2/27 patients (7.4%) 2. 3 implants lost (4.1%) in 1patient
McCarthy et al. (2003) Case Series	1. 17 patients/35 implants 2. Drop-outs: None 3. Smokers ($n = 3$)	1. *One stage* autogenous bone ± GBR Fenestration and Dehiscence $n = 2$ patients and *Two stage* GBR ± block bone grafts $n = 15$ patients	Autogenous (symphisis) block bone graft (covered ($n = 4$) or not ($n = 13$) with –ePTFE Gore-Tex ($n = 3$) – collagen membrane (Bio-Gide) ($n = 1$)	*Lateral augmentation Success %* 1. Pre-loading: Unclear 2. Post-loading: Unclear *Ridge Dimensions* Before and After: Unclear 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Unclear	*Follow-up*: 35.6 months (range: 17–66) post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 97.1%	1. Paraesthesia donor site 4/17 patients (23.5%) 2. 1/35 implants lost (2.9%)

Cordaro et al. (2002) CS	1. 15 patients/40 implants 2. Drop-outs: None 3. Smoking habits: Unclear	2. *Two stage* lateral ridge augmentation with autogenous block bone grafts	*Autogenous block bone grafts* (Ramus, Chin)	*Lateral augmentation* *Success %* 1.–Preload: Unclear A marked resorption (23.5%) of bone graft seen at implant installation 2. Unclear *Ridge dimensions* 1. Before: 6.5 ± 0.33 mm 2. After: 5.0 ± 0.23 mm 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Unclear	*Follow up:* 12 months (range: 4–38) post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 100% 2. Success: 100%	1. Numbness (in 1 patient) 2. No implants lost
Hising et al. (2001) Arm of CS	1. 39 patients/ 107 implants 2. Drop-outs: 10 patients in the whole study, unclear number in the included CS arm 3. Smokers included	1. *Simultaneous with Bio-Oss* Fenestration and Dehiscence 3 patients/7 implants and *Staged augmentation* with Bio-Oss ± Autogenous particulate bone	1. Bio-Oss, 2. Autogenous particulate bone (chin). 3. Autogenous blood 4. Tisseel Duo Quick (Immuno AG)	*Lateral augmentation* *Success %* 1. Preload: Unclear 2. Post-loading: Unclear *Ridge dimensions* 1. Before: Unclear 2. After: Unclear 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Unclear	*Follow-up*: Up to 113 months post-loading	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 84.1%	1. No complications reported 2. 17/107 implants lost (15.9%)
			Split-Osteotomy				
Chiapasco et al. (2006a) CS	1. 45 patients/ 110 implants 2. Drop-out: 1 patient 3. Smokers < 15 cigarettes/day were included	*1. Simultaneous split osteotomy*+immediate implant placement ($n = 86$ implants) 2. *Staged with split osteotomy*+delayed implant placement after 7 days ($n = 24$ implants)	*Split crest osteotomy* with an expansion device (Extension Crest®)	*Lateral augmentation* *Success %* 1. Pre-loading: 97.8% (overall) (44/45 patients) – Width gain: 2–5 mm 2.Post-loading: Unclear *Ridge Dimensions:* 1. Before: 3–7 mm (median: 4 mm) 2. After: 6.5–10 mm (median: 8 mm) 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Yes	*Follow-up*: 20.4 months (range12–36 months) post-loading in 42patients with 106 implants	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 97.3% 2. Success: 95.4%	1. Fractured buccal bone plate 1/45 (2.2%), paraesthesia 1/45 (2.2%) Continuous pain for a month 1/45 (2.2%) patients 2. 3 Implants lost (2.7%) in 3/45 patients (6.6%)
Ferringo et al. 2005 RCT	1. 40 patients/82 implants 2. Drop-outs: None 3. Smokers < 5 cigarettes/day were included	*Simultaneous* augmentation with splitting osteotomy+immediate *TE* implants, ($n = 20$ patients/42 implants) *Versus* *Simultaneous* splitting osteotomy+immediate Standard implants, ($n = 20$ patients/40 implants)	*Split osteotomy* +GBR Collagen (Bio-Gide)+Autogenous bone chips+Bio-Oss	*Lateral augmentation* *Success %* 1. Pre-loading: *90% in total* *(100% with TE and 87.5% Standard implants) 2. N/A *Ridge Dimensions* 1. Before: 3–5 mm 2. After: Unclear 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* No* (10%) –* In 1 patient with 2 standard implants augmentation failed due to buccal bone fracture –Minor fractures of the ridge in another 3	*Follow-up:* 18 months post-implantation	*Implant outcomes at lateral augmented sites post-loading* 1. 100% for TE implants and 95% for Standard implants 2. 100% TE implants 95% (Standard implants)	1. Major or minor buccal bone fracture in 4 patients (10%) with 6 standard implants 2. 2/82 (2.4%) implants lost in 1 patient (control) after 4 months post-implantation

Table 4. Contd.

Author, year and study type	Participants: 1. Number of patients and implants 2. Drop-outs 3. Smoking habits	Type of procedure and type of defect:	Material and Treatment Group	Lateral augmentation Success % 1. Preload 2. Post-loading Ridge/defect dimensions: 1. Before 2. After 3. Implant placement possible? 4. Initial augmentation adequate	Follow-up	Implant outcomes at lateral augmented sites post-loading 1. Survival 2. Success	1. Augmentation complication 2. Number of implants lost at augmented sites
				patients with 4 standard implants were treated with additional GBR			
Sethi & Kaus (2000) CS	1. 150 patients/ 449 implants 2. Drop-outs: 24 patients/78 implants 3. Smokers included, but habits unclear	*Simultaneous* lateral augmentation with split osteotomy and immediate implants	*Split osteotomy* and ridge expansion with osteotomes (no osteotomy) + Hydroxyapatite (Osteograf 300 μm or 700 μm) $\pm$ autogenous bone	*Lateral augmentation* *Success %* 1. Pre-loading: Unclear 2. Post-loading: Unclear *Ridge Dimensions* 1. Before: 2–4 mm 2. After: Unclear 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Unclear An increase in the width of maxillary ridge was achieved that allowed the placement of implants. However only 49/ 449 implants placed at an angle to the long axis of the proposed restoration.	*Follow-up*: 27 months post-implantation (0–93 months)	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 97%	1. Minor fractures at the crest 2. 12/449 implants lost (2.7%)
Engelke et al. (1997) CS	1. 44 patients/ 121 implants 2. Drop-outs: 2 patients/3 implants 3. Smoking habits: Unclear	*Simultaneous* augmentation with split osteotomy and ridge expansion with a micro plate fixation	*Split osteotomy* with a micro-plate fixation combined with+ Hydroxyapatite or GTR (e-PTFE in 7patients)	*Lateral augmentation* *Success %* 1. Pre-loading: Unclear 2. Post-loading: Unclear Ridge dimensions 1. Before: Unclear 2. After: Unclear 3. *Implant placement possible:* Yes 4. *Initial augmentation adequate* Unclear	*Follow-up:* 34.3 months post-loading (6–68 months)	*Implant outcomes at lateral augmented sites post-loading* 1. Survival: 86.2% (5 year CSR)	1. Fracture of micro screws in 2 (4.5%) patients –Loss of graft through mucous membrane in 4 (9.9%) patients –Membrane exposure (number of patients not mentioned –Loosening of micro screw in 7 (3.08%) patients 2. 12/121 implants lost (9.9%)

RCT: randomized controlled clinical trial, CCT: controlled clinical trial, CS: case series. Lateral augmentation success: simultaneous/one stage procedure: complete cover of exposed implant surface, staged approach: restorative driven implant placement with no further augmentation procedure needed.

(Dahlin et al. 1995, Engelke et al. 1997, Fugazzotto 1997, Becker et al. 1999, Gaggl & Schultes 1999, Lorenzoni et al. 1999, Sethi & Kaus 2000, Hising et al. 2001, Buser et al. 2002, Cordaro et al. 2002, Hellem et al. 2003, McCarthy et al. 2003, Peleg et al. 2004, Blanco et al 2005, Chiapasco et al. 2006a, b, Keith et al. 2006) (for the related study characteristics see Tables 4 and 5).

Patient and intervention characteristics

GBR. There were 656 patients that were treated with some form of GBR and 1059 implants placed in total, in both anterior and posterior areas of both the upper and lower jaw.

Outcomes:
Simultaneous lateral augmentation in dehiscence and fenestration defects. In an RCT with a split mouth design (Zitzmann et al. 1997) comparing two types of membranes (collagen and e-PTFE), the reported mean defect reduction was 90%/97% for the use of Bio-Gide and Bio-Oss and 80%/94% for the use of e-PTFE and Bio-Oss at 4 (mandible) or 6 months (maxilla) following GBR in implants placed more than 6 months after extraction or implants placed between 6 weeks and to 6 months after extraction, respectively. In another study though, an 82% defect reduction was observed (Dahlin et al. 1995). The overall implant survival rate was different between studies. It varied from 97.6% for the 2 years follow up (Zitzmann et al. 1997) and 96.1% at 5 years post-implantation (Blanco et al. 2005) to 76.8% and 83.8% for the maxilla and mandible, respectively, in an observation period up to 5 years (Becker et al. 1999).

Staged (GBR) lateral augmentation. Significant increase of the ridge dimensions (87%–95%) was observed following this procedure which enabled the placement of implants and presented with an implant success rate of 93.3% at 22.4 months post-loading (Chiapasco 1999) to 98.3% at 5 years following implantation (Buser et al. 2002). In the study by Chiapasco et al. (1999), the control group used for lateral augmentation was different types of autogenous bone block graft (chin, ramus, iliac crest, calvarial) which resulted in 100% success in terms of lateral augmentation and 90.9% implant success at 22.4 months post-loading.

Complications. The most common complication was the flap dehiscence/membrane exposure (Dahlin et al. 1995, Zitzmann et al. 1997, Becker et al. 1999, Gaggl & Schultes 1999, Blanco et al. 2005) which was present at 16.3% of the implants treated with a collagen membrane (Bio-Gide) and varied from 11.1% (Dahlin et al. 1995) and 11.5% (Blanco et al. 2005) to 24.4% of the implants treated with e-PTFE (Zitzmann et al. 1997). When the exposed e-PTFE membranes and the early removed e-PTFE membranes were grouped, the 44% of the treated sites were negatively affected (Zitzmann et al. 1997).

Furthermore, e-PTFE membranes combined with autogenous bone block grafts as a staged approach presented higher risk of infection due to flap dehiscence and membrane exposure than the use of autogenous block bone grafts alone (Chiapasco et al. 1999).

Loss of osseointegration in the augmented sites has been observed and varied from a small number of implants affected (2/84) (Zitzmann et al. 1997) to 11/55 (44 patients) of the implants.

Quality assessment, sources of heterogeneity and other methodological issues

Apart from the use of the implant as the unit of analysis, unclear methodology for sample size calculation based on the primary outcome (all studies) other methodological issues and sources of heterogeneity were summarized at Table 6.

Bone grafts

Patient and intervention characteristics

There were four included studies with 64 patients in total that had lateral ridge augmentation with bone grafts and 198 implants were inserted (Hising et al. 2001, Cordaro et al. 2002, Hellem et al. 2003, Thor et al. 2005) (for further details see Tables 4 and 5).

Outcomes

In the included studies, staged lateral ridge augmentation was evaluated by comparison of autogenous iliac particulate bone with PRP to autogenous iliac block bone graft without PRP (Thor et al. 2005), or use of autogenous block bone grafts (ramus, chin) (Cordaro et al. 2002), autogenous particulate graft (chin, ramus, iliac crest) and deproteinized bovine bone mineral (Bio-Oss) and Fibrinogen (Tiseel) (Hellem et al. 2003) or autogenous particulate graft (chin) with or without deproteinized bovine bone mineral (Bio-Oss) and Tisseel Duo Quick (Hising et al. 2001). The outcomes of the augmentation procedure at the time of implant placement either were not reported (Hising et al. 2001) or varied from 92.6% success (Hellem et al. 2003) to marked resorption of the autogenous iliac crest bone graft (Thor et al. 2005) or of the chin bone graft (23.5%) (Cordaro et al. 2002). In terms of implant survival, it varied from 100% at 1 year post-loading (Thor et al. 2005) to 84.1% at a follow-up of up to 113 months (Hising et al. 2001).

Complications. The loss of implants in the augmented sites varied from 0% (Cordaro et al. 2002, Thor et al. 2005) to 3/82 (4.1%) implants (Hellem et al. 2003) and 17/107 implants (15.9%) (Hising et al. 2001) during observation periods that varied from 12 months (Cordaro et al. 2002) post-loading to 113 months post-loading (Hising et al. 2001). Other complications involved discomfort at the iliac crest donor site area, post-operative embolus at iliac crest donor site and fracture of the abutment screw (Hellem et al. 2003).

Quality assessment and other methodological aspects. For detailed review of each study see Table 6.

Split osteotomy technique

In the four included studies, there were 279 patients treated with split osteotomy techniques and 1090 implants placed in total in both anterior and posterior areas of the upper and lower jaw (Engelke et al. 1997, Sethi & Kaus 2000, Ferrigno & Laureti et al. 2005, Chiapasco et al. 2006a, b). In three of the above studies the implants were placed simultaneously with the augmentation procedure while in the fourth study (Chiapasco et al. 2006a, b) 24 out of the 110 implants were placed in a delayed mode, at 7 days after the ridge expansion.

Outcomes

In all studies, the procedure resulted in a significant increase (range 87.5%–100%) in the width of the alveolar ridge

Table 5. Result of study characteristics ''additional'' selected studies

Author and year	Type of implants: 1. System, design and surface topography 2. Diameter and length 3. type of implant support prosthesis	Trial characteristics: 1. Location 2. Number of centre 3. Source of recruitment 4. Source of funding	Success criteria	1. Experience of operator 2. antibiotics	Loading of implants: 1. Delayed 2. immediate
			GBR		
Keith et al (2006)	1. Unclear type of implants 2. D: 3.25–6 mm L: Unclear 3. Single tooth, fixed bridge	1. Location: USA 2. Multicentre 3. Recruitment: Private Practice. 4. Funding: Unclear	Unclear success criteria	1. *Experience of operator*: Specialists 2. Antibiotics: Unclear	1. Delayed loading 2 months in mandible, and 4 months in maxilla
Blanco et al. (2005)	1. Brånemark system Surface topography not mentioned 2. Unclear diameter and length 3. Single tooth, fixed bridge	1.. Location: Spain 2. Three centres 3. Recruitment: 3 Private practices 4. Funding: Unclear	Albrektsson criteria without the 0.2 mm annual marginal bone loss. MBL in standardized radiographs at baseline and 5 years	1. *Experience of operator*: Specialist 2. Antibiotics: Unclear	1. Delayed 8.5 months (6–13)
Peleg et al. (2004)	1. Zimmer Dental, Carlsbad, CA Surface topography not mentioned 2. D: 3.25, 3.75 mm L: 15 mm 3. Single tooth, fixed bridge	1. Location: USA 2. Unclear 3. Recruitment: NA 4. Funding: Unclear	Albrektsson success criteria and MBL in non-standardized panoramic and periapical radiographs	1. *Experience of operator*: Specialists 2. Antibiotics: Yes (antibiotics not specified)	1. Delayed 4–8 months
Christensen et al. (2003)	1. ITI ® Dental Implant System; TPS surface 2. D: 4.1 mm L: 8–12 mm 3. Single tooth, fixed bridge	1. Location: Switzerland 2. Single centre 3. Recruitment: University/ Hospital 4. Funding: Unclear	No clear success criteria mentioned BOP, mPI, attachment level, mucosal margin to implant shoulder measurement MBL in non-standardized peri-apical radiographs	1. *Experience of operator*: Specialists 2. Antibiotics: Unclear	1. Delayed after 3 months
Buser et al. (2002)	1. ITI Straumann TPS surface 2. Unclear diameter and length 3.Single crowns/Fixed prosthesis	1. Location: Switzerland 2. Single centre 3. Recruitment: University/ Hospital 4. Funding: Unclear	Buser success criteria	1. *Experience of operator*: Specialist 2. Antibiotics: Amoxicillin	1. Delayed 6–9 months
Chiapasco et al. (1999)	1. Brånemark ($n = 50$) and ITI ($n = 24$); design/surface topography not mentioned 2. D: 3.75–4.1 mm L: Unclear 3. Single tooth, fixed bridge	1. Location: Italy 2. Single centre 3. Recruitment: Unclear 4. Funding: Unclear	Albrektsson criteria Radiographic examination	1. *Experience of operator*: Specialist 2. Antibiotics: Patients treated under local anesthesia received 2 g ampicillin per os, 1 h before surgery, whereas – patients treated under general anesthesia received 2 g ampicillin IV at time of induction. Oral ampicillin (1 gr) was administered 6 h after surgery in patients of both groups	1. Delayed 6–8 months
Gaggl & Schultes (1999)	1. SIS (SIS-Implant, SIS Inc, Austria) Conical titanium implants ($n = 42$) surface topography not mentioned 2. D: Up to 4 mm	1. Location: Austria 2. Single centre 3. Recruitment: Unclear 4. Funding: Unclear	No clear success criteria Radiographic examination with standardized peri-apical X-rays and OPG.	1. *Experience of operator*: Specialist 2. Antibiotics: Unclear.	1. Delayed 6 months

	L: 13 mm ($n = 13$) and 15 mm ($n = 29$) 3. Single tooth		BOP, PPD at 3-, 6- and 12-month period		
Becker et al. (1999)	1. Nobel Biocare Surface topography unclear. 2. Unclear diameter and length 3. Single tooth, fixed bridge	1. Location: USA, Sweden, Belgium 2. Multicentre (4 centres) 3. Recruitment: University/ Hospital; Specialist practice 4. Funding: Unclear	No clear success criteria MBL in non-standardized periapical radiographs	1. *Experience of operator*: Specialists 2. Antibiotics: Unclear	1. Delayed 3–4 months-mandible; 6 months-maxilla
Lorenzoni et al. (1999)	1. Frialit-2 Surface topography not mentioned 2. Unclear diameter and length 3. Single tooth, fixed prosthesis, Tooth – implant bridge	1. Location: Austria 2. Single centre 3. University/Hospital 4. Funding: Unclear	Spiekermann criteria (1995) PPD, BOP Perio test values MBL in non-standardized periapical radiographs	1. *Experience of operator*: Specialists 2. Antibiotics: Unclear	1. Delayed (6 months)
Zitzmann et al. (1997)	1. Brånemark system (Nobel Biocare) Surface topography not clarified 2. Unclear diameter and length 3. Fixed prosthesis 38 implants for removable prosthesis	1. Location: Switzerland 2. Single centre 3. Recruitment: Uni/Hospital 4. Funding: Unclear	No clear success criteria Perio test values	1. *Experience of operator*: Specialists 2. Antibiotics: Amoxicillin 750 mg 1 h pre-operative and 375 mg 3/day for 5 days	Delayed (re-entry at 4 months in the mandible and 6months in the maxilla)
Fugazzotto (1997)	1. IMZ (titanium plasma spray) $n = 510$ Interpore (titanium plasma spray) $n = 114$ 2. D = 3..3–4.25, L = 8–15 3. Unclear	1. Location: USA 2. Single centre 3. Recruitment: Private practice 4. Funding: Unclear	Immobile implant, Absence of pain/suppuration, No peri-implant radiolucency, Vertical bone loss less than 1.5 mm in the 1st year	1. *Experience of operator*: Specialist 2. Antibiotics Amoxicillin 500 mg 4/day for 10 days or erythromycin 400 mg 3/day for 10 days.	Delayed 6–9 months
Dahlin et al. (1995)	1. Brånemark system (Nobel Biocare) Surface topography not clarified 2. Unclear diameter and length 3. Unclear	1. Location: USA, Sweden, Belgium 2. Multicentre (four centres) 3. Recruitment: University/ Hospital, private practice 4. Funding: Unclear	Albrektsson success criteria (not reported in the study)	1. *Experience of operator*: Specialists 2. Antibiotics: Yes (but type, dose and period of antibiotics not specified)	Delayed (3–4 months mandible 5–6 months maxilla)
			Bone Grafts		
Thor et al. (2005)	1. Tioblast™, (AstraTech AB,) – Blasted surface 2. D: 3.5 mm L: 9–17 mm 3. Fixed bridge	1. Location: Sweden 2. Single centre 3. Recruitment:Hospital 4. Funding: Unclear	1. Clinical examination 2. RFA 3. Marginal bone level assessment in non-standardized periapical radiographs at completion of prosthetic treatment and 1 year in function	1. *Experience of operator*: Specialist 2. Antibiotics For augmentation operation: Pre-operative: penicillin (3gr × 3) or clindamycin (600 mg × 3) Post- operative: penicillin (1gr × 3)+metronidazole (400 mg × 3) or clindamycin (300 mg × 3) × 10 days For implant operation Pre-operative: penicillin (2gr × 3) or clindamycin (600 mg × 3) Post- operative: penicillin (1gr × 3 or clindamycin (300 mg × 3) × 5 days	1. Delayed 6 months after implant placement
Hellem et al. (2003)	1. Brånemark (MK II), Turned surface 2. D: 3.75 mm	1. Location: Sweden 2. Single centre 3. Recruitment: University/	No clear success criteria MBL in non-standardized	1. *Experience of operator*: Specialists 2. Antibiotics Penicillin V 2g × 2/day	1. Delayed 6 months after implant placement

Table 5. Contd.

Author and year	Type of implants: 1. System, design and surface topography 2. Diameter and length 3. type of implant support prosthesis	Trial characteristics: 1. Location 2. Number of centre 3. Source of recruitment 4. Source of funding	Success criteria	1. Experience of operator 2. antibiotics	Loading of implants: 1. Delayed 2. immediate
	L: 7–18 mm 3. Single tooth, fixed bridge	Hospital 4. Funding: Unclear	Panoramic and periapical radiographs		
McCarthy et al. (2003)	1. Brånemark (MK II), Turned surface 2. Unclear diameter and length 3. Single tooth, fixed bridge	1. Location: United Kingdom 2. Single centre 3. Recruitment: University/ Hospital 4. Funding: Unclear	No success criteria mentioned	1. *Experience of operator*: Specialists 2. Antibiotics: Unclear	1. Delayed, 7.1 months after implant placement (range:3–7.4 months)
Cordaro et al. (2002)	1. In 15 sites 4.1 mm diameter Straumann solid screws In 3 sites = 3.75 mm self-tapping screw implants with external hexagonal head (Implant Innovation Inc., USA) 2. D: 3.75–4.1 mm L: min 10 mm 3. Fixed bridge prosthesis/single crowns	1. Location: Italy 2. Single centre 3. Recruitment: University/ Hospital 4. Funding: Unclear	Albrektsson success criteria	1. *Experience of operator*: Specialists 2. Antibiotics: Unclear	1. Delayed 6 months
Hising et al. 2001	1. Multiple systems e.g. Astra, Cresco; IMZ; Nobel Biocare; Sterngold-ImplaMed; Straumann; Swede-vent. Various surfaces 2. D: Unclear L: 10–15 mm 3. Single tooth, fixed bridge, overdentures	1. Location: Sweden 2. Single centre 3. Recruitment: Specialist practice 4. Funding: Industry	Albrektsson success criteria +panoramic radiographs (no radiographic evaluation of crest width could be done)	1. *Experience of operator*: Specialists 2. Antibiotics: At the time of the augmentation procedure = 500 mg of floxacillin; Post-operative: floxacillin (500 mg × 3) × 8 and 9 days, Before implant placement: phenoximethylpenicillin 2 g × 10 days	1. Delayed 6 months – maxilla 3 months – mandible
			Split Osteotomy		
Chiapasco et al. (2006a, b)	1. TE implants (Straumann), –Blasted and etched surface (SLA) 2. D: 3–4.8 mm; L: 8–14 mm 3. Single tooth, fixed bridge	1. Location: Italy 2. Three centers 3. Recruitment: University/ Hospital+Sp practice 4. Funding: Unclear	Albrektsson success criteria	1. *Experience of operator*: Specialist 2. Antibiotics Amoxicillin+clavulonic acid 2gr/day 1 h before surgery, and post-operative × 6 days	1. Delayed 3–4 months after implant placement
Ferringo et al. (2005)	1. Standard solid screw and TE® implants (Straumann), SLA surface 2.TE: d:3.3/4.8 and Standard plus: 4.1 mm L: Unclear 3. Single tooth, fixed bridge	1. Location: Italy 2. Two centres 3. Recruitment:Private practice 4. Funding: Unclear	1. Buser success criteria 2. MBL in non-standardized periapical radiographs	1. *Experience of operator*: Specialists 2. Antibiotics: Yes (but type of antibiotics not specified)	1. Delayed 3 months after implant placement

Sethi & Kaus (2000)	1. Unclear type of implants 2. D: 2.75–4.5 mm L: 9–20 mm 3. Single tooth, fixed bridge	1. Location: United Kingdom 2. Single centre 3. Recruitment: Speciality Practice 4. Funding: Unclear	No clear success criteria mentioned Radiographic examination in non-standardized radiographs- no specific measurements reported	1. *Experience of operator:* Specialists 2. Antibiotics: Unclear	1. Delayed, ca. 7 months
Engelke et al. (1997)	1. 97 Straumann and 24 Brånemark system. Straumann: TPS surface and Brånemark: Polished turned surface) Straumann L: 10–14 mm Brånemark L: 10–18 mm D: Not specified 3. 74 implant supported prosthesis, 38 implants served as support for removable prosthesis	1. Location: Germany 2. Single centre 3. Recruitment: University/ Hospital 4. Funding: Unclear	No clear success criteria PPD MBL in non-standardized periapical radiographs	1. *Experience of operator:* Specialists 2. Antibiotics: Amoxicillin 3gr IV. pre-operative	1. Delayed (4 – 6 months+3 weeks)

that allowed the placement of implants into the osteotomy created by expansion. The implant survival rates varied from 95% to 100% at 18 months post-loading (Ferrigno & Laureti et al. 2005), 97.3% at 20.4 months post-loading (range 12–36 months) (Chiapasco et al. 2006a, b) and 86.2% at 5 years after implant placement (Engelke et al. 1997) to 97% (cumulative survival rate) at 60 months post-loading (Sethi & Kaus 2000).

Complications. The most common complication was the fracture of buccal bone plate during the ridge expansion in a limited number of patients (Chiapasco et al. 2006a, b, Ferrigno & Laureti et al. 2005, Sethi & Kaus 2000). Other minor complications related with the split osteotomy/ridge expansion included loosening or fracture of micro screw (Engelke et al. 1997), prolonged pain or paraesthesia (Chiapasco et al. 2006a, b) and membrane exposure and/or graft loss (Engelke et al. 1997).

Loss of osseointegration has been observed in relatively small number of patients (Engelke et al. 1997, Sethi & Kaus 2000, Ferrigno & Laureti et al. 2005, Chiapasco et al. 2006a, b).

Quality assessment, sources of heterogeneity and other methodological issues. For detailed review of each study see Table 6.

Discussion

Key findings

The aim of the present review was to evaluate if different lateral ridge augmentation procedures result to the same outcome in terms of implant survival and success as implants placed in pristine sites. At the same time, the success of the augmentation procedure per se was evaluated by the changes in ridge dimension over time.

The present systematic review produced only 4 publications of prospective study designs for all procedures, two for GBR (Mayfield et al. 1998, Zitzmann et al. 2001), one for autogenous bone grafts (Ozkan et al. 2007) and one for bone substitute (Corente et al. 2000).

Main findings

Success of lateral augmentation procedure and implant survival/success

GBR. In the two included studies where simultaneous GBR was used, the reported survival of the implants varied from 95.8% to 100% and was similar to the implant survival at pristine sites (97.3–100%) with an observation period extending from 24 to 59.1 months post-loading. These findings are in agreement with the survival rates reported in recent systematic reviews in this field (Hämmerle et al. 2002, Fiorellini & Nevins 2003, Chiapasco et al. 2006a, b).

In the current literature in the field of implantology, the survival and success rate of the implants are the most commonly used implant related outcomes. Van Steenberghe et al. (1999) defined as survival rate ''the proportion of implants still in place in a specific time, even if they do not have any function''. Furthermore, the established Albrektsson criteria of implant success (Albrektsson et al. 1986, Albrektsson & Isidor 1994) have included apart from a series of clinical measures, the evaluation of the radiographical marginal bone loss which should present an average of 1.5 mm for the first year of function and for the following years it should not exceed 0.2 mm per year. More recently, it has also been proposed to accept a maximal radiographic bone loss of 2 mm between the period of prostheses installation and the 5th year of clinical evaluation with the majority of bone loss to occur during the first year of function (Wennström & Palmer 1999). As such, lack of progressive marginal bone loss over the years becomes an important success criterion when different implant systems and augmentation procedures are to be compared (Van Steenberghe et al. 1999).

It has been also advocated that the follow up period for validation of an implant system placed in pristine bone should be at least 5 years (Wennström & Palmer 1999). It could be argued that similar observation periods are needed for implants placed in sites following a lateral augmentation procedure. In one of the included studies of the present review (Zitzmann et al. 2001), the follow up was 59 months and even though the MBL values at the GBR treated fenestration and dehiscence defects presented to be statistically significant increased, the survival of the implants in these sites has not been affected in comparison with the control sites. Therefore, there was no clear evidence from this study that the simultaneous GBR procedure in fenestration or dehiscence defects affected the survival per se of the implants. Similarly, from the

Table 6. Results of quality assessment of selected ''additional'' studies

Study	Similarity of baseline characteristics- 1. Bone quality 2. Prosthetic needs	Patients consecutively entered (for case series)	Inclusion criteria explicit	Masking: 1. Assessor 2. Operator	Similarity of drop-outs and reasons for drop-outs	Risk of bias	Other potential source of heterogeneity and methodological points
				GBR			
Keith et al. (2006)	1. Unclear bone quality 2. Unclear prosthetic needs	Yes	Explicit inclusion criteria	Unclear masking	No drop-outs	High risk of bias	– Implants were placed only in 63% of grafted defects – Variable follow-up post-grafting –Various grafting combinations and augmentation techniques –Unspecified implant systems/surfaces – No adjustment for smoking
Blanco et al. (2005)	1. Unclear bone quality 2. Various (single tooth and fixed bridge)	Yes	Explicit inclusion criteria	Unclear masking	No drop-outs	Medium risk of bias	– Type of bone augmentation: – Various grafting combinations – No adjustment for smoking – No clear success criteria – Dehiscence and Fenestration defects were pooled together
Peleg et al. (2004)	1. Similar bone quality 2. Various (single tooth and fixed bridge)	Yes	No	Unclear masking	No drop-outs	High risk of bias	– variable follow-up (range 8–24 months) –Dehiscence and Fenestration defects were pooled together
Christensen et al. (2003)	1. Similar bone quality 2. Various (single tooth and fixed bridge)	Yes	Unclear	Unclear masking	No dropouts	High risk of bias	– Study design (lack of randomization) –Various grafting combinations and augmentation techniques – No standardized radiographs
Buser et al. (2002)	1. Unclear bone quality 2. Similar prosthetic needs	Yes	Unclear	Unclear masking	Unclear	High risk of bias	– No standardized radiographs
Chiapasco et al. (1999)	1. Similar bone quality 2. Various (single tooth and fixed bridge)	Unclear	Explicit inclusion criteria	No masking	No drop-outs	High risk of bias	– Surgical factors (choice of treatment by the clinician, different donor sites and extension of the defect, different implant types) – Variable follow-up
Gaggl & Schultes (1999)	1. Unclear bone quality 2. Similar prosthetic needs	Unclear	Unclear	Unclear masking	No drop-outs	High risk of bias	– Smoking and medical history not reported – No success criteria were reported
Becker et al. (1999)	1. Unclear bone quality 2. No	Unclear	No	Yes	Drop-outs: 10 patients, similarity and reasons unclear	High risk of bias	– 10 patients lost in follow-up – Various grafting combinations and augmentation techniques
Lorenzoni et al. (1999)	1. Unclear bone quality 2. Unclear prosthetic needs	Unclear	No	Unclear masking	Drop-outs: 4 patients, similarity and reasons unclear	High risk of bias	– No success criteria were reported
Zitzmann et al. (1997)	1. Different type of bone quality 2. Unclear prosthetic needs	Unclear	No	Unclear masking	No drop-outs	High risk of bias	No standardized radiographs
Fugazzotto (1997)	1. Unclear bone quality 2. Unclear prosthetic needs	Yes	Explicit inclusion criteria	Unclear masking	No drop-outs	High risk of bias	– Various grafting combinations and augmentation techniques

							– Different implant types and surfaces) – Variable follow-up
Dahlin et al. (1995)	1. Unclear bone quality 2. Unclear prosthetic needs	Yes	Unclear	Unclear masking	Drop-outs: 1 patient, clear reason.	High risk of bias	– Unclear calibration between centres – Different operators
				Bone Graft			
Thor et al. (2005)	1. Unclear bone quality 2. Fixed prosthesis	Yes	Explicit inclusion criteria	Unclear masking	No drop-outs	Medium risk of bias	– No adjustment for smoking and medical history – No standardized radiographs
Hellem et al. (2003)	1. Similar bone quality 2. Various (single tooth and fixed bridge)	Unclear	Explicit inclusion criteria	No masking	Drop-outs: 3 drop-outs; not similar.	High risk of bias	– No adjustment for smoking – Surgical factors (use of Tiseel) – Outcome measurements: no clear success criteria, no exact number of implants and patients that did not fulfill any success criteria
McCarthy et al. (2003)	1. Unclear bone quality 2. Unclear prosthetic needs	Yes	No	Unclear masking	No drop-outs	High risk of bias	-Variable follow-up (range: 17–66 months post-loading). – No clear success criteria
Cordaro et al. (2002)	1. Unclear bone quality 2. Various (single tooth and fixed bridge)	Yes	No	No masking	No drop-outs	High risk of bias	– Variable follow-up
Hising et al. (2001)	1. Unclear bone quality 2. Various (single tooth and fixed bridge)	Yes	Unclear	Unclear masking	Drop-out: 10 patients for the whole study (unclear for the included arm of the CS)	High risk of bias	– Different implant types and surfaces – Various grafting combinations and augmentation techniques – Several different type of implants were used – Variable follow-up
				Split-Osteotomy			
Chiapasco et al. (2006a, b)	1. Unclear bone quality 2. Various (single tooth and fixed bridge)	Unclear	Explicit inclusion criteria	Unclear masking	Drop-out: 1 patient	High risk of bias	– Type of bone augmentation(both one and two stage procedures pooled together) – No calibration between the centres or assessors is reported – No adjustment for smoking.
Ferrigno el al. 2005	1. Unclear bone quality 2. Similar prosthetic needs	Yes	Explicit inclusion criteria	Unclear masking	No drop-outs	Medium risk of bias	– No adjustment for smoking – Variable follow-up period post-grafting.
Sethi & Kaus (2000)	1. Unclear bone quality 2. Various (single tooth and fixed bridge)	No	No	Unclear masking	Drop outs: 24 patients (16%) with a total of 78 implants (17%) were lost to follow-up –16 patients did not attend the recall –4 patients did not comply with requests to attend for monitoring –2 patients moved –2 patients died	High risk of bias	– No specified implant system – No success criteria were reported – Variable follow-up
Engelke et al. (1997)	1. Unclear bone quality 2. Unclear prosthetic needs	Yes	Unclear	Unclear masking	Drop-outs: 2 patients, no similarity or reasons given	High risk of bias	– Various grafting combinations and augmentation techniques – Different types of implants

current evidence, it is not possible to conclude that the initially augmented sites maintained their increased dimensions which ultimately provided a functional role to the loading and survival of the implants. This could have been evaluated if a third group of patients presenting dehiscence and/or fenestration defects following implant placement where no simultaneous GBR was performed, were also followed up for the same period. However, such a clinical trial might not be possible to perform for ethical reasons.

In the included studies of the present systematic review, re-entry procedures after loading of the implants has not been performed and the radiographical marginal bone loss/level was used to access the success of the simultaneous GBR with a resorbable membrane alone (Mayfield et al. 1998) or with a combination of a collagen membrane or an e-PTFE membrane and deproteinized bovine bone mineral (Zitzmann et al. 2001). However, in these studies, the use of GBR aimed to laterally augment dehiscence and fenestration defects that cannot be evaluated by radiographical means. Instead, it was evaluated the marginal bone level stability at the mesial and distal aspects of a GBR treated implants and not the effect of the GBR procedure at the buccal sites of the implants per se. It was still interesting though to observe that both studies demonstrated less marginal bone loss at the pristine sites than at the GBR treated sites at 24 and 59 months following loading, even though in Mayfield et al. (1998) this difference did not reach statistical significance. The clinical significance of this outcome though in terms of evaluating the long-term success of the augmentation procedure is not clear and does not necessarily allow any final conclusions to be drawn regarding the marginal bone level changes in the augmented sites following implant loading in comparison with pristine sites.

From the included studies, it is difficult to identify a clear effect of the different barrier membranes on the clinical and radiographical success of the GBR procedure or the survival of the implants. From Zitzmann et al. (2001), it could be suggested that the combined use of a collagen membrane and deproteinized bovine bone mineral resulted in lower MBL values than the use of e-PTFE membrane. By the fact that lateral augmentation has been observed at the time of abutment connection, it could also be suggested that both e-PTFE or collagen membranes combined with deproteinized bovine bone mineral resulted in resolution of the fenestration and dehiscence defects with bone regeneration. However, the use of a resorbable co-polymer polyglycolic and polylactic acid membrane alone for the treatment of these defects might not be as effective because it was reported that the membrane treated fixtures had significantly lower marginal bone levels at the radiographs taken during abutment connection indicating that optimal bone regeneration was not achieved at all defects (Mayfield et al. 1998). This observation could suggest that for achieving optimal augmentation in this type of defects with simultaneous/one stage GBR procedures, a bone graft for maintaining the space under the membrane is necessary.

In the literature, the timing for loading of the implants following simultaneous GBR procedures has not been specified and different authors reported different time points. In the included studies, the implants placed in the pristine sites and the implants placed in GBR treated sites were loaded at 4 months in the mandible and at 6–7 months in the maxilla. It is not clear if this timing reflected the loading protocol of the turned surface implants which were used in the included studies or if the current osteoconductive surfaces which present faster osseointegration rate than turned surfaces (Abrahamsson et al. 2004, Buser et al. 2004) would require shorter healing periods when combined with GBR.

In terms of reported complications, it was demonstrated that flap dehiscence associated with barrier exposure resulted to marginal bone loss (Zitzmann et al. 2001). Furthermore, it was reported that the use of e-PTFE membranes was associated with higher MBL probably due to the higher exposure rate (Zitzmann et al. 2001).

Delayed/staged approach. It is important to emphasize that in the current systematic review no prospective studies were retrieved where implants placed in laterally augmented sites following the staged approach with GBR were compared with implants placed in pristine sites. Even though, in the literature it has been reported that this procedure can result in significant amounts of regenerated bone following lateral augmentation (Buser et al. 2002), in the present literature search there were no studies retrieved that compared the survival/success of these implants following a staged GBR approach to implants placed in control pristine sites following a loading period of at least 6 months.

Bone graft. Only one included study (Ozkan et al. 2007), compared the use of autogenous bone grafts for lateral ridge augmentation with implants placed in pristine sites. This was also the only included study where a staged approach procedure was performed. It was shown that there was an increase in the ridge dimensions following the use of autogenous block grafts. Furthermore, the survival of the implants was similar between augmented and pristine sites at 12 months. This suggests that the technique is of value to clinical practice, although the results are short-term and longer follow-up is needed.

Bone substitute. The use of a calcium carbonate bone substitute with or without fibrin-fibronectin system resulted in 85.4% success in terms of ridge augmentation and in comparable implant survival to pristine sites. There were a number of methodological aspects in this study that rendered the making of further conclusions difficult.

Strength of evidence (all studies)

Sample size calculations based on subjects have not been included in any of the studies and this could be considered as a shortcoming (Felechosa et al. 1999). The same applies for lack of randomization, which, if not performed is likely to introduce selection bias. Furthermore, masking of the assessor is important and in the included studies it was confirmed that was performed (direct contact with the author) in Mayfield et al. 1998 but it was not clear in all other studies (Corrente et al. 2000, Zitzmann et al. 2001, Ozkan et al. 2007).

All studies were analyzed on the implant rather than the patient level. This has reported to favour the implant survival in comparison with subject based analysis due to the fact that the prevalence calculated from implant-based results becomes diluted from the large number of implants included in the subject sample (Fransson et al. 2005). When more than one implant in the same individual is used for analysis,

each implant is not independent and this might have an effect on the survival confidence interval in survival analysis (Chuang et al. 2001) and it could introduce a risk of spurious statistically significant results arising from standard errors that are smaller than they should be (Chuang et al. 2002).

In terms of methodology for the evaluation of the outcomes, the lack of proper standardized radiographs (Mayfield et al. 1988, Zitzmann et al. 2001), as well as the lack of initial radiograph measurements immediately after implant placement (Mayfield et al. 1998, Zitzmann et al. 2001) inserted a possibility for measurement error. These measurement errors are likely to occur at random and are therefore likely to dilute any statistical comparisons between groups within a study. It has been demonstrated that radiographic assessments of marginal bone height around implants might present with errors due to deviations from parallelism between the fixture axis and the film plane as well as between differences in alveolar bone width and position of the fixture in a bucco-lingual direction (Sewerin 1990).

Other factors that could affect the outcome was the placement of implants in different areas (anterior/posterior; upper/lower jaw) which have different prognoses (Weber et al. 1997). In only one study, the implants were placed always in the same region (posterior) and jaw (mandible) following augmentation with autogenous bone grafts (Ozkan et al. 2007). Furthermore, the removal of the number of failed implants from the final statistical analysis (Corrente et al. 2000) would have affected the survival rate.

Other aspects that rendered difficulties in the description of the studies and the evaluation of the results was the lack of specific, universally accepted success criteria for the augmentation procedure as well as for success of the implants.

''Additional'' studies with no comparison at pristine sites

The reviewers added this category as a supplement of publications in order to evaluate if any valuable clinical information or trend could be found that was not included in the publications that addressed the focused question. In the ''additional'' studies, the same inclusion criteria and methodology was applied as in the included ''controlled'' studies. The only change was the comparison group of implant outcomes in pristine sites that was no longer included. During the data synthesis, it was apparent that in this group of ''additional studies'' there was a great variety of treatments applied and it was difficult to classify or categorize them in a manner that any ''group'' outcome could be achieved. Furthermore, in terms of quality assessment there was a substantial number and variation of heterogeneity sources and methodological aspects to be addressed. As such, the authors decided to merely present data from the included studies that were relevant to informing on the survival of the implants and the success of the augmentation procedure.

GBR

In the included studies there was a great variation on the techniques and materials used for GBR and the various methodological aspects of each study rendered the creation of any significant conclusions for the clinical practice difficult.

The cumulative survival rate of implants placed with simultaneous GBR in fenestration and dehiscence defects varied from 96.1% at 5 years post-implantation (Blanco et al. 2005) to a significantly reduced survival rate of 76.8% for the maxilla and 83.8% for the mandible (Becker et al. 1999) indicating variation on the outcomes following simultaneous GBR procedure.

For the staged GBR lateral augmentation, the success of the implants varied from 93.3% (Chiapasco et al. 1999) to 98.3% (Buser et al. 2002) at 22.4 months and 5 years post-loading, respectively. At the same time the success of the augmentation procedure varied from 87% (Chiapasco et al. 1999) to 95% (Buser et al. 2002). The above results indicate that in the majority of the cases high success rate of the two stage GBR procedure in terms could be expected.

A common complication was the flap dehiscence and barrier exposure which affected the amount of regeneration/lateral augmentation that was achieved. This was irrespective of factors such as the simultaneous or staged approach or the type of membrane used (Dahlin et al. 1995, Zitzmann et al. 1997, Becker et al. 1999, Chiapasco et al. 1999, Blanco et al. 2005). These observations seem to be in agreement with the results reported from the two included studies addressing the focus question (Mayfield et al. 1998, Zitzmann et al. 2001).

All these studies presented with a substantial number of potential sources of heterogeneity and other methodological issues. This is perhaps not surprising in view of the wide variety of study types. For cohort studies there was unclear methodology for sample size calculation based on the primary outcome and the unit of analysis was the implant rather than the subject. Also, most studies were not of comparative design. Furthermore, in the multicenter studies there were no clear calibration procedures of the operators or examiners. In terms of treatment, in the included case series, there were a number of variations of GBR procedures included within the same study or between studies, which rendered the conclusions for a specific procedure difficult. In some cases, the staged and the simultaneous procedures were pooled and analyzed as one group. In terms of implant survival, different success criteria were used in different studies, creating difficulties in reaching a conclusion.

Bone grafts

A limited number of studies were found where bone grafting (block graft or particulate) was evaluated. Similar difficulties as in the GBR publications in terms of drawing final conclusions, were encountered especially due to the variety of included combinations of grafting procedures. A common observation was that the bone grafts presented a percentage of resorption which varied but did not prevent the subsequent placement of implants. Similar methodological issues as in GBR were present in these studies as well.

Split osteotomy

A significant increase in lateral ridge dimensions was reported in all studies that allowed the simultaneous placement of implants into the osteotomy site created by the expansion and presented with implant survival rates that varied from 97% at 60 months post-loading (Sethi & Kaus 2000) to 86.2% at 5 years after implant placement (Engelke et al. 1997). The most common complications with these procedures were the fracture of the buccal bone plate during the ridge expansion and the occasional loss of osseointegration. Similar sources of heterogeneity and methodological issues were reported as in the studies with GBR and

bone grafts. Nevertheless, these techniques would seem worthy of further proper clinical evaluation.

Conclusions

The present systematic review resulted in a limited number of publications that addressed the focus question and none of them was an randomized CCT which is considered to be the most appropriate study design for primary research to test the effectiveness of interventions because it is less prone to the effect of bias or confounding as other study designs.

Within the limits of these findings the following conclusions can be made:

1. Data from two studies including a small number of patients reported that implants placed in sites simultaneously augmented with GBR exhibit survival rates similar to implants placed in pristine bone. The range of implant survival was 95.8–100% for the augmented sites and 97.3% to 100% for the control sites at 24–59.1 months post-loading.
2. In the same two studies, an increased radiographical marginal bone loss/level over time at implants placed in sites simultaneously augmented with GBR compared with implants placed in pristine sites was reported. However, this could be associated with different baseline bone levels.
3. Conventional radiographic evaluation is not an appropriate method for evaluating augmentation procedures in buccal sites.
4. In one included study, lateral augmentation with autogenous bone grafts as a staged approach resulted in successful augmentation of the deficient alveolar ridges enabling implant placement. In this study, similar survival rates between implants placed in augmented sites and pristine sites were reported for a period up to 12 months.
5. Methodological issues in the included studies limited the amount of conclusions that could be provided for clinical practice.

Taking into consideration a number of methodological and study design elements, the surveyed ''additional'' studies where the inclusion criteria of the systematic review were satisfied but did not include control groups (implants placed in pristine sites) provided some additional information for the different treatment concepts.

Within the limits of the data in the included studies the following can be reported:

1. For localized bone augmentation to cover exposed threads, clinical data supporting its use were found. The approaches considered in this review encompassed GBR by the placement of membranes and various membrane supporting materials. The survival rate varied from 100% at 2 years post-implantation to 76.8% for the maxilla and 83.8% for the mandible post-loading for an observation period of up to 5 years. The success rate of the augmentation procedure expressed as complete coverage of the exposed implant surface, ranged from 71.4% to 100% for observation periods ranging from 12 months to 5 years.
2. For staged lateral ridge augmentation to enable dental implant placement there are clinical data supporting its use. The approaches considered in this review encompassed GBR and bone grafts. For staged GBR, the survival rate of the implants was 99–100% for observation periods ranging from 22.4 months to 5 years post-loading. The success rate of the augmentation procedure, measured as the achievement of adequate ridge dimensions for placement of implants at the site, varied from 87% to 95% from 22.4 months to 5 years post-loading, respectively. For staged approach with bone grafts the survival rate of implants varied from 100% to 84.1% at 12–113 months post-loading, respectively.
3. For implants placed in sites augmented with split ridge osteotomy, clinical data to support its use were found. The survival rate of the implants varied from 86.2% to 100% for a follow up period between 12 months and 5 years in different studies. The success rate of the split osteotomy, measured as the achievement of adequate ridge dimensions for placement of implants at the site, varied from 87.5% to 97.8% from 18 to 20.4 months post-loading, respectively.

Recommendations for research

1. From the present systematic review, it was evident that few, properly deigned clinical trials have been performed where the outcomes of implants between augmented and pristine sites, as a control group, were compared. On the other hand, due to ethical reasons, it is not possible to conduct clinical trials with dental implants where fenestration and dehiscence defects or thin alveolar ridges are left untreated without simultaneous or staged lateral augmentation procedure. As such, it is important that further pragmatic randomized CCTs are performed where clinical outcomes of implants placed following different lateral augmentation techniques will be compared. These studies must follow the guidelines by the 3rd European Workshop in Periodontology (Felechosa et al. 1999, Wennström & Palmer 1999) for achieving improved methodological quality. More specifically: a control group should be present; appropriate sample size calculation should be performed according to the evaluated primary outcome; allocation to treatment arms must be randomized; when possible the patient should be the unit of analysis; standardized assessments and masking of the examiner (if possible) and the assessor to minimize measurement bias should take place; a follow-up period of at least 5 years post-loading should be included; confounding factors should be taken into account and be adjusted at the final analysis (when appropriate); when possible cumulative survival rates should be reported and appropriate statistical analysis should be performed (Kaplan and Meier life table statistics).
2. The above factors should be fully reported in each publication (in accordance with the CONSORT guidelines).
3. The lack of universally accepted implant and ridge augmentation success criteria is a significant obstacle in comparing the different studies and surgical techniques. As such, a consensus of the success criteria to be universally used is recommended.

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Clinical Relevance

Scientific rationale for the study: Lateral ridge augmentation techniques are routinely used in the clinical practice but there is little information regarding the comparison of clinical outcomes of implants placed in augmented and pristine sites.

Principal findings: Limited number of prospective comparative studies between implants in augmented and pristine sites were retrieved. It was suggested that the survival of implants in augmented and pristine sites is similar.

Practical implications: In clinical practice, the patients treated with simultaneous or staged lateral augmentation procedures would need to be informed of the lack of comparative studies on the clinical outcomes of implants placed in augmented sites.

Table A1. Reasons for exclusion of full-text articles

Author	Reasons for exclusion
Antoun et al. (2001)	No implant survival/success with 6 months follow-up post-loading
Arvidson et al. (1998)	No survival/success of implants & data for augmentation procedure reported
Assenza et al. (2001)	No implant survival/success with 6 months follow-up post-loading
Bahat & Fontanessi (2001)	Case report/series with $n<15$; sinus-augmentation
Barber et al. (2007)	Case report/series with $n<15$
Barone & Covani (2007)	No implant survival/success with 6 months follow-up post-loading
Becker et al. (2005)	No bone augmentation performed
Becktor et al. (2002)	Retrospective study
Becktor et al. (2004)	Extensive reconstruction including vertical augmentation with inlay/onlay grafts and/or sinus lift
Block et al. (1996)	Combination of grafting techniques (vertical/horizontal)

Table A1. (Contd.)

Author	Reasons for exclusion
Brunel et al. (2001)	Case report/series with $n<15$
Buser et al. (1996a)	Case report/series with $n<15$
Buser et al. (1996b)	No survival/success of implants reported
Buser et al. (1997)	No survival/success of implants reported
Carlson Mann et al. (1996)	Case report/series with $n<15$
Carpio et al. (2000)	No implant survival/success with 6 months follow-up post loading
Carrion & Barbosa (2005)	Case report/series with $n<15$
Cecchinato et al. (2004)	No bone augmentation performed
Chavrier (1997)	No implant survival/success with 6 months follow-up post loading
Dahlin et al. (1991)	No augmentation & survival/success of implants reported
Dortbudak et al. (2002)	No implant survival/success with 6 months follow-up post loading
Ekert et al. (1999)	Retrospective study
Ersanli et al. (2004)	Case report/series with $n<15$
Filho et al. (2007)	No implant survival/success with 6 months follow-up post loading
Fugazzotto et al. (1997)	No implant survival/success with 6 months follow-up post loading
Fugazzotto (2003)	No implant survival/success with 6 months follow-up post loading
Fugazzotto et al. (2004)	No augmentation & survival/success of implants reported
Fugazzotto (2005)	Retrospective study
Ganz & Valen (2002)	Case report/series with $n<15$
Hakobyan (2005)	No implant survival/success with 6 months follow-up post loading
Happe (2007)	No implant survival/success with 6 months follow-up post loading
Herford (2005)	Case report/series with $n<15$
Hernandez et al. (2007)	Case report/series with final analysis on 11 patients ($n<15$); post loading follow-up not clear.
Higuchi et al. (1995)	No survival/success of implants & data for augmentation procedure reported
Johansson et al. (2004)	Extensive reconstruction including vertical augmentation with inlay/onlay grafts and/or sinus lift
Jovanovic et al. (1992)	Case report/series with $n<15$
Jung et al. (2003)	No implant survival/success with 6 months follow-up post loading
Karoussis et al. (2004)	No bone augmentation performed
Keller (1995)	Retrospective study
Keller et al. (1999)	Retrospective study
Lang et al. (1994)	No implants placed
Leghissa et al. (1999)	Case report/series with $n<15$
Lemmerman & Lemmerman (2005)	Implants placed in mixed clinical situations e.g. sinus lift, extraction sockets. No clear number of patients/ implants in each clinical situation.
Leonhardt et al. (2002)	No data on implants placed in augmented sites
Levin et al. (2007)	Retrospective study
Lindquist et al. (1996)	No data on implants placed in augmented sites
Lorenzoni et al. (1998)	No implant survival/success reported with a follow-up of 6 months post-loading
Lundgren et al. (1999)	Case report/series with $n<15$
Maiorana et al. (2002)	Case report/series with $n<15$ (on lateral augmentation)
Majzoub et al. (1999)	No implant survival/success with 6 months follow-up post loading
Malchiodi et al. (2006)	Extensive reconstruction including vertical augmentation
Matsumoto et al. (2002)	Case report/series with $n<15$
Mattout et al. (1995)	No implant survival/success with 6 months follow-up post loading
Mayer et al. (2002)	No bone augmentation performed
Mehlisch (1989)	Only vertical augmentation, no implants placed
Miller et al. (1999)	Case report/series with $n<15$
Misch (1997)	No implant survival/success with 6 months follow-up post loading
Morris et al. (2004)	No bone augmentation performed
Moses et al. (2005)	No implant survival/success with 6 months follow-up post loading
Motamedi et al. (1999)	Retrospective study
Naitoh et al. (2005)	Controlled clinical trial with <5 patients per group
Nemcovsky & Artzi (2002)	No implant survival/success with 6 months follow-up post loading
Neyt et al. (2001)	Case report/series with $n<15$
Nkenke et al. (2001)	No implant survival/success with 6 months follow-up post loading
Palmer et al. (1994)	Case report/series with $n<15$
Pappalardo et al. (2004)	No implant survival/success with 6 months follow-up post loading
Park & Wang (2007)	No implant survival/success with 6 months follow-up post loading
Petrungaro (2005)	No implant survival/success with 6 months follow-up post loading
Petrungaro & Amar (2005)	Case report/series with $n<15$
Piattelli et al. (1996)	No implant survival/success with 6 months follow-up post loading
Rabies & Chary (2000)	Case report/series with $n<15$
Raghoebar et al. (2001)	Retrospective study
Raghoebar et al. (2003)	Case report/series with $n<15$
Raghoebar et al. (2006)	Case report/series with $n<15$
Randow et al. (1999)	No bone augmentation performed
Richardson & Cawood (1991)	Case report/series with $n<15$

Table A1. (Contd.)

Author	Reasons for exclusion
Rominger & Triplett (1994)	No implant survival/success with 6 months follow-up post loading
Schlegel et al. (1998)	No implant survival/success with 6 months follow-up post loading
Schliephake et al. (1997)	Extensive reconstruction including vertical augmentation
Schliephake et al. (1999)	Extensive reconstruction in tumour resected and irradiated jaws
Schuler & Verardi (2005)	No augmentation and survival/success of implants reported
Scipioni et al. (1994)	No implant survival/success with 6 months follow-up post loading
Shanaman et al. (2001)	Case report/series with $n<15$
Simion et al. (1997)	Case report/series with $n<15$
Sjostrom et al. (2006)	No implant survival/success with 6 months follow-up post loading
Smiler (2000)	Case report/series with $n<15$
Stellingsma et al. (2004)	Extensive reconstruction including vertical augmentation
Tal et al. (1997)	Case report/series with $n<15$
Tawil et al. (2001)	No implant survival/success with 6 months follow-up post loading
Triplett & Schow (1996)	Retrospective study
Umberto et al. (2007)	Study population had a genetic disorder/condition
Valen & Ganz (2002)	Study on animals
Van der Zee et al. (2004)	No 6 months follow-up post loading
Veis et al. (2004)	No implant survival/success with 6 months follow-up post loading
von Arx et al. (1998)	Retrospective study
von Arx & Kurt (1999)	No implant survival/success with 6 months follow-up post loading
Weber et al. (2000)	No implant survival/success with 6 months follow-up post loading
Widmark et al. (1998)	Case report/series with a number of patients receiving lateral augmentation <15 ($n=10$). The rest of patients treated with a combination of procedures such as sinus lift etc
Widmark et al. (2001)	Case report/series with a number of patients receiving lateral augmentation <15 ($n=10$). The rest of patients treated with a combination of procedures such as sinus lift etc