Long-term effects of vertical bone augmentation: a systematic review

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ABSTRACT

Extraction, periodontitis, or trauma can cause a reduction on the alveolar ridge. This could result in an insufficient alveolar bone width and height. Different techniques of vertical bone augmentation are described in literature. However, nowadays there is not enough evidence against lateral augmentation procedures to verify if these techniques are stable over a long period of time. Objective: This review analyses the different techniques that are used to vertically augment the bone and evaluate if these techniques are stable over a long period of time. Material and Methods: The MEDLINE-PubMed database was searched from its earliest records until December 22, 2014. The following search term was used: Alveolar Ridge augmentation [MESH]. Several journals were hand searched and some authors were contacted for additional information. The primary outcome measure that was analyzed was marginal bone level change around dental implants in the augmented sites, and the secondary outcomes were survival and success rates of dental implants placed in the augmented sites. Results: The search yielded 203 abstracts. Ultimately, 90 articles were selected, describing 51 studies meeting the eligibility criteria. The marginal bone level change for the inlay technique and vertical guided bone regeneration are in agreement with the success criteria. Alveolar distraction showed more marginal bone level change after the first year of loading, and for the inlay technique very few studies were available. Conclusions: Based on the available data in the current existing studies with a follow-up period of at least 4 to 5 years, one can summarize that there seems to be a trend that the onlay technique, alveolar distraction, and vertical guided bone regeneration are stable for at least 4 to 5 years.

Keywords: Alveolar ridge augmentation. Dental implants. Atrophy. Alveolar bone loss. Bone substitutes.

INTRODUCTION

Since Brånemark introduced a new dental treatment, a machined titanium implant, a new treatment option became available1. If there is sufficient bone quantity and quality, a dental implant could be a predictable treatment option. In literature, a survival rate over 95% in non-compromised patients is reported2. Therefore, dental implants have become a reliable treatment option for patients missing one or multiple teeth. However, unfavourable conditions of the alveolar bone due to periodontitis, extraction, or trauma provoke decrease in the alveolar ridge due to bone atrophy. Such bone atrophy could cause challenging interarch relationship in vertical, transverse, and sagittal planes, which may cause incorrect dental implant placement from a functional and aesthetic point of view19.

To provide adequate bone volume and to assure an adequate aesthetic result, bone augmentation procedures are sometimes a prerequisite for successful dental implant treatment. There are different techniques to augment the bone, such as: 1. Onlay grafting. The graft material will be placed on top of the defect to increase height or
width of the alveolar bone. The graft is immobilised with dental implants, screws, or plates52.

2. Inlay grafting. A part of the alveolar ridge is surgically separated and a graft material is placed between the two sections52.

3. Ridge expansion. A part of the alveolar ridge is longitudinally split to widen the ridge and allow placement of a graft, an oral implant, or both35.

4. Distraction osteogenesis. A gradual, controlled displacement of a surgically prepared fracture. The two bone fragments are slowly pulled apart, and new bone will arise in the gap26.

5. Guided bone regeneration (GBR). A space is maintained by a barrier membrane, which will be filled with new bone57.

Different materials can be used for augmentation:
1. Autogenous bone graft. This bone graft is taken from the same patient in an adjacent or remote site. This material is considered to be the “gold standard”, while it is biologically compatible and provides a scaffold for new bone formation77.

2. Allograft. This bone graft is harvested from human cadavers and processed by methods such as freezing or demineralising and freezing67.

3. Xenograft. This is a graft material derived from animals, usually bovine bone. It is processed to completely remove the organic component13.

4. Alloplastic graft. This bone graft is a synthetic bone substitute made up of bioactive glass or calcium phosphates112.

5. Osteoinductive material. This material stimulates the osteoprogenitor cells to differentiate into osteoblasts and accelerate new bone formation. The most common are bone morphogenetic proteins (BMPs), platelet rich plasma (PRP), and leukocyte platelet rich fibrin (L-PRF)31.

Each type of augmentation material may be used combined with a variety of different surgical techniques.

The rationale for the use of a vertical bone augmentation is to improve the vertical dimension of the bone. If the use of a vertical bone augmentation technique is needed, the clinician needs to decide which technique and which material should be used to vertically augment the bone. When the vertical bone augmentation is successful, one can proceed for dental implant placement. The aim of this review is to analyze the success, survival rates of dental implants, and the marginal bone level change around dental implants placed in the augmented area. Marginal bone level change is most often controlled through x-rays in the maintenance phase to demonstrate and secure implant success.

MATERIAL AND METHODS

The following analysis was performed in a different way according to the guidelines of the Cochrane Collaboration and the principles of the PRISMA (Preferred Reporting Items for Systemic Reviews and Meta-Analyses) statement for a systematic review46,69.

Focused question (PICO)

We focused on the following question: “Do vertical bone augmentation have a long-term predictable stability?”.

Search strategy

The MEDLINE-PubMed database was searched from its earliest records until December 22, 2014. The following search term was used: Alveolar Ridge augmentation [MESH]. In addition, a manual search was carried out concerning issues from the past 10 years of the following journals: Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, European Journal of Oral Implantology, Implant Dentistry, International Journal of Oral and Maxillofacial Implants, International Journal of Oral and Maxillofacial Surgery, Journal of Oral Implantology, Journal of Oral and Maxillofacial Surgery, Journal of Clinical Periodontology, Journal of Periodontal Research, and the Journal of Periodontology.

Study inclusion and exclusion criteria

The selection process was performed by two masked reviewers (OB and JK). The studies were analyzed according to the following inclusion criteria:

1. All studies in which at least 10 patients were treated and had a follow-up of at least 12 months.

2. Patients presenting deficient edentulous ridges caused by atrophy, periodontal disease, and trauma were considered.

3. The following surgical procedures were considered: onlay bone grafts, split-ridge/ridge expansion techniques/inlay technique (vertical direction), alveolar distraction osteogenesis, and guided bone regeneration procedures.

4. Articles related to dental implants were considered for inclusion.

5. No specific dental implant system was excluded.

6. No specific augmentation material was excluded.

7. Only studies in the English language were included.

The following exclusion criteria were used:

1. Patients with bone defects caused by congenital malformations, after ablation of tumors, or osteoradionecrosis.

2. The following surgical procedures were excluded: sinus floor elevation by a lateral approach, Le Fort I osteotomy with interpositional grafts, revascularized free flaps, socket preservation...
techniques, and correction of dehiscences and fenestrations.

3. Duplicated studies.

Outcome variables

The primary outcome was: marginal bone level change around dental implants in the augmented sites. The following recall moments were noted: baseline (placement of the final crown, start loading), year 1, 2, 3, 4, and 5 of loading. The secondary outcomes were survival and success rates of dental implants placed in the augmented sites. Implant survival was evaluated using Simonis, et al.97 (2010), being implant removal the survival criterion. Implant success was evaluated using Albrektsson, et al.5 (2012), and the success criteria were absence of persistent pain or dysesthesia, absence of peri-implant infection with suppuration, absence of mobility, absence of continuous peri-implant radiolucency, less than 1.5 mm of peri-implant bone resorption during the first year of function, and less than 0.2 mm in subsequent years.

Data extraction

The title and abstract of studies with potential relevance for the review were obtained and screened independently by two masked reviewers (OB and JK). Studies without abstract, but with a title suggesting relevance to the subject of the review, were selected for full text screening. The selected full-text articles were independently read in detail to verify whether they passed the inclusion/exclusion criteria. The references of the full text articles were screened for any relevant additional data available, the corresponding authors were contacted for additional data. The available data were recalculated in order to present the data like marginal bone level change at baseline (placement of the final crown, start loading), year 1, 2, 3, 4, and 5 of loading, and the latest available data for survival and success rates were noted. The data of this review was statistically analyzed using the program SPSS 21.0 (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.).

RESULTS

The initial search resulted in a total of 3248 articles (Figure 1). After screening the titles, 203 abstracts were included for further analysis. Analysis of the abstracts resulted in 90 potential articles. In the third phase, the full-text articles of the remaining 90 articles were evaluated, of which 39 articles2,8,9,12,14,18,23,24,27,30,39,41,44,45,48,49,51,56,59,60,62,64,68,73,75,84,90,92,94,98,102,103,107,108,111,113 did not pass the inclusion criteria (Figure 2). A screening of the reference lists of the full text articles did not result in any additional articles. In Table 1, the main characteristics of the 51 included studies are summarized1,6,7,10,15,16,20-22,25,29,31,34,36-38,40,42,43,50,53,55,57,58,61,63,65,66,70-72,74,78-86,91,95,96,99,100,104-106,109,110,114. Only the treatment groups of interest are represented. For vertical bone augmentation, four different techniques were used and the results will be presented separately. In Table 2, the characteristics of the different vertical augmentation techniques are presented.

Alveolar distraction (Table 1, Figure 3)

The 51 included articles provided 17 studies10,21,22,25,36,37,40,43,50,57,79,81-83,95,104,114 with alveolar distraction, and one study86 used a combination of the inlay technique and alveolar distraction. Eight studies were retrospective while 10 were

Figure 1- Search strategy
prospective. A total of 333 patients with a vertical resorption of partially or totally edentulous alveolar ridges were treated with intraoral intraosseous or extraosseous devices. Twelve patients were treated with a combination of inlay technique and vertical distraction. In total, 1011 dental implants were placed after 3 to 6 months, and the mean was 3.8 months after the completion of the distraction. After the start of loading, the follow-up ranged from 1 to 7.1 years and the mean was 2.9 years. The survival rates for the dental implants in alveolar distracted bone ranged from 88 to 100% and the mean was 96.3%.

| Reason for exclusion                                                                 |                                  |
|-------------------------------------------------------------------------------------|----------------------------------|
| Useful clinical results, more information needed. Could not contact the author       |                                  |
| Information available only about the volume of the graft                             |                                  |
| Not enough patients for analyzing vertical augmentation                              |                                  |
| Useful clinical results, more information needed. Could not contact the author       |                                  |
| Sinus elevation was included in study group                                         |                                  |
| Horizontal augmentation                                                              |                                  |
| No difference between horizontal, vertical en socket preservation techniques         |                                  |
| Useful clinical results, more information needed. Could not contact the author       |                                  |
| Information about cost-effectiveness of reconstructive surgery                      |                                  |
| Revascularized free flaps                                                            |                                  |
| No difference between horizontal and vertical techniques                              |                                  |
| Same results Esposito, et al. (2011)                                               |                                  |
| Combination of onlay and sinuslift procedures                                       |                                  |
| Useful clinical results, more information needed but not available                  |                                  |
| Useful clinical results, more information needed but not available                  |                                  |
| Horizontal augmentation                                                              |                                  |
| Useful clinical results, more information needed. Could not contact the author       |                                  |
| Horizontal augmentation                                                              |                                  |
| Le Fort 1 + sinus elevation                                                          |                                  |
| Information available only about graft resorption                                    |                                  |
| Systematic review                                                                   |                                  |
| Only 8 patients                                                                     |                                  |
| Useful clinical results, more information needed but not available                  |                                  |
| Useful clinical results, more information needed but not available                  |                                  |
| Sinus elevation was included in study group                                         |                                  |
| Sinus elevation was included in study group                                         |                                  |
| Usefull clinical results, more information needed. Could not contact the author     |                                  |
| Same results Nyström, et al. (2004)                                                |                                  |
| Horizontal augmentation                                                              |                                  |
| No difference between horizontal and vertical techniques                              |                                  |
| Horizontal augmentation                                                              |                                  |
| No difference were reported between immediate or delayed placement                  |                                  |
| Sinus elevation was included in study group                                         |                                  |
| Usefull clinical results, more information needed. Could not contact the author     |                                  |
| Usefull clinical results, more information needed. Could not contact the author     |                                  |
| No separate information available about inlay/onlay, sinuslift procedures            |                                  |
| Sinus elevation was included in study group                                         |                                  |
| Sinus elevation was included in study group                                         |                                  |
| Sinus elevation was included in study group                                         |                                  |

**Figure 2**- Characteristics of the 39 studies excluded
Table 1- Characteristics of the 51 studies included

| Reference                  | Study design         | Number of patients | Defect type (type of atrophy) | Surgical procedure | Donor materials                               | Number of implants | Timing of implants | Follow-up | Implant survival (%) | Implant success (%) |
|----------------------------|----------------------|--------------------|-------------------------------|--------------------|-----------------------------------------------|--------------------|--------------------|-----------|----------------------|---------------------|
| Sbordone, et al.91         | Prospective study    | 14 Max + Man + Hor + Ver | Alveolar distraction          | Autogenous (Ramus) | 41 Del 4.9 months                            | 7.1 ± 1.7 years    | 97.3               | 92.7      |                      |                     |
| Pérez-Sayáns, et al.61 (2013) | Retrospective study | 14 Max + Man + Hor + Ver | Alveolar distraction          | Autogenous (Ramus) | 61 Del 6.2 months                            | 8.2 ± 2.0 years    | 94.1               | 90.2      |                      |                     |
| Todisco, et al.100 (2010)  | Prospective study    | 20 Max + Man + Hor + Ver | Vertical guided bone regeneration | Allograft          | 64 Del 12 months                             | 1.2 years          | 100                | 97        |                      |                     |
| Fino, et al.114 (2012)     | Prospective study    | 21 Max + Man + Hor + Ver | Vertical guided bone regeneration | Allograft          | 62 Del 6-7 months                            | 1.6 years          | 100                | 93.1      |                      |                     |
| Kranz, et al.53 (2013)     | Randomized control trial | 7 Max + Man + Hor + Ver | Onlay technique               | Autogenous (Ramus) | 29 Del 4-5 months                            | 1.6 years          | 100                | 90.3      |                      |                     |
| Canullo, et al.15 (2010)   | Prospective study    | 20 Max + Man + Hor + Ver | Onlay technique               | Autogenous (Ramus) | 56 Del 4-5 months                            | 1.6 years          | 100                | 97        |                      |                     |
| Almeyda, et al.68 (2012)   | Prospective study    | 15 Max + Man + Hor + Ver | Onlay technique               | Autogenous (Ramus) | 32 Del 4-5 months                            | 1.4 years          | 100                | 98.4      | 96.7                 | 98.2                |

Continue in the next page
Table 1 - Continuation

| Reference | Study design | Number of patients | Defect type (type of atrophy) | Surgical procedure | Donor materials | Number of implants | Timing of implants | Follow-up | Implant survival (%) | Implant success (%) |
|-----------|--------------|-------------------|------------------------------|--------------------|----------------|-------------------|------------------|-----------|---------------------|---------------------|
| Ettl, et al.14 (2010) | Retrospective study | 30 | Max + Man + Hor + Ver | Alveolar distraction | | 82 | Del 4.5 months | 4.2 years | 95.1 | X |
| Nissan, et al.71 (2011) | Prospective study | 31 | Max + Hor + Ver | Onlay technique | Allograft | 63 | Del 6.0 months | 2.8 ± 1.3 years | 98.1 | X |
| Felice, et al.42 (2009) | Prospective study | 10 | Man + Hor + Ver | Inlay technique | Autogenous (iliac) | 20 | Del 3-4 years | 1.5 years | 100 | 90 | 86.9 |
| Nissan, et al.70 (2011) | Prospective study | 21 | Man + Hor + Ver | Onlay technique | Allograft | 85 | Del 6.0 months | 3.1 ± 1.4 years | 95.1 | X |
| Urban, et al.19s (2009) | Prospective study | 28 | Man + Hor + Ver | Vertical guided bone regeneration | Autogenous (Ramus, Chin) | 54 | Del 6-9 months | 2.8 years | 100 | 94.7 |
| Carinci, et al.16 (2009) | Retrospective study | 21 | Man + Hor + Ver | Onlay technique | Allograft | 63 | Del 6.0 months | 1.7 years | 96.8 | X |
| Robioni, et al.44 (2008) | Retrospective study | 12 | Man + Hor + Ver | Inlay technique + Inlay technique | Autogenous (iliac) | 47 | Del 6.0 months | 5 years | 97.9 | 91.5 |
| Pieri, et al.56 (2008) | Prospective study | 16 | Max + Man + Hor + Ver | Vertical guided bone regeneration | Autogenous (Ramus) + Xenograft | 44 | Del 8-9 months | 2 years | 100 | 93.1 |
| Bianchi, et al.70 (2008) | Prospective study | 5 | Man + Hor + Ver | Inlay technique | Autogenous (iliac) | 21 | Del 3-4 months | 1.8 years | 100 | 95.2 |
| Chiapasco, et al.24 (2007) | Prospective study | 8 | Man + Hor + Ver | Onlay technique | Autogenous (Ramus) | 19 | Del 4-5 months | 2-4 years | 100 | 89.5 |
| Chiapasco, et al.25 (2007) | Retrospective study | 30 | Max + Hor + Ver | Alveolar distraction | | 138 | Del 3-6 months | 2.8 years | 100 | 94.2 |
| Chiapasco, et al.24 (2004) | Prospective study | 5 | Max + Man + Hor + Ver | Vertical guided bone regeneration | Autogenous (Ramus) | 12 | Del 6-7 months | 1-3 years | 100 | 75 |
| Chiapasco, et al.24 (2004) | Prospective study | 10 | Max + Man + Hor + Ver | Alveolar distraction | | 34 | Del 3-4 months | 100 | 94.1 |
| Raghoebar, et al.59 (2002) | Prospective study | 10 | Man + Hor + Ver | Alveolar distraction | | 20 | Del 2-3 months | 0.9 years | 95 | X |
| Jensen, et al.50 (2002) | Prospective study | 28 | Max + Man + Hor + Ver | Alveolar distraction | | 84 | Del 3-4 months | 1-4.4 years | 90.4 | X |
| Rachmiel, et al.52 (2001) | Retrospective study | 14 | Max + Man + Hor + Ver | Alveolar distraction | | 23 | Del 2-3 months | 0.5-1.7 years | 95.7 | X |

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Unfortunately, only nine studies evaluated the implant success rate. This ranged from 92.7 to 100.0%, and the mean was 95.5%.

Only seven studies out of the 17 which used alveolar distraction as a treatment presented the marginal bone level change in their results. The marginal bone level change is shown in Figure 3. Only four studies presented the results for a follow-up period of 4 or 5 years. At baseline, the marginal bone level change is around -0.20 – -0.50 mm, 1st year of loading -0.65 – -1.17 mm, 2nd year of loading -1.00 – -1.32 mm, 3rd year of loading -1.00 – -1.41 mm, 4th year of loading -1.30 – -1.46 mm, and 5th year of loading -1.49 – 1.55 mm.

Inlay technique (Table 1, Figure 4)

The 51 articles included provided four studies with inlay technique, and one study used a combination of onlay and inlay techniques. Of these, two were prospective studies; one, a split mouth study; and one, a randomized clinical trial. A total of 57 patients with a vertical resorption of partially or totally edentulous alveolar ridges were treated with the inlay technique. Seventeen patients were treated with a combination of onlay and inlay techniques. Three different donor materials for the bone where used: autogenous (iliac, ramus), xenografts, and alloplastic grafts. In total, 206 dental implants were placed after 3 to 6 months, and the mean was 4.6 months after the healing of the inlay technique. After the start of loading, the follow-up ranged from 1 to 3 years, and the mean was 1.7 years. Survival rates for the dental implants in bone from the inlay technique ranged from 95.9 to 100.0%, and the mean was 98.5%.

Unfortunately, only four studies evaluated the implant success rate, which ranged from 90.9 to 100.0%, and the mean was 93.4%.

Only three studies out of the four which used the inlay technique presented the marginal bone level change in their results. One study has different treatment groups, therefore, it is shown twice in the figure. None of the studies showed a long-term follow-up. At baseline, the marginal bone level change is around -0.71 – -1.21 mm, 1st year of loading -0.90 – -1.65 mm, and 3rd year of loading -2.43 mm.

Table 1- Continuation

| Reference               | Study design | Number of patients | Defect type (type of atrophy) | Surgical procedure | Donor materials | Number of implants | Timing of implants | Follow-up | Implant survival (%) | Implant success (%) |
|-------------------------|--------------|--------------------|-------------------------------|--------------------|-----------------|--------------------|-------------------|-----------|----------------------|---------------------|
| Simion, et al. (2001)   | Retrospective study | 6 11 32 | Max + Man + Hor + Ver | Vertical guided bone regeneration | Allograft         | 17 26 82          | Imm              | 5.3 years | 94.1         | 94.1               |
| Gaggl, et al. (2000)    | Prospective study | 34 | Max + Man + Hor + Ver | Alveolar distraction |                | 62                | Imm              | 1 year     | 96           | X                   |
| Keller, et al. (1999)   | Retrospective study | 28 4 | Max + Hor + Ver | Onlay technique | Autogenous (iliac) | 183 21          | Imm Del 4-6 months | 5.6 years | 86.3         | X                   |
| Verhoeven, et al. (1997)| Prospective study | 13 | Max + Hor + Ver | Onlay technique | Autogenous (iliac) | 72                | Imm              | 2.4 ± 0.9 years | 100         | X                   |
| McGrath, et al. (1996)  | Retrospective study | 18 | Max + Hor + Ver | Onlay technique | Autogenous (iliac) | 36                | Imm              | 1.4 years   | 91.6         | 91.6               |
| Vermeeren, et al. (1996)| Retrospective study | 31 | Max + Hor + Ver | Onlay technique | Autogenous (iliac) | 78                | Imm              | 5 years     | 89.7         | X                   |
| Astrand, et al. (1994)  | Retrospective study | 17 | Max + Hor + Ver | Onlay technique | Autogenous (iliac) | 92                | Imm              | 3-5 years   | 75           | X                   |
| Donovan et al. (1994)   | Retrospective study | 24 | Max + Man + Hor + Ver | Onlay technique | Autogenous (Calvarium) | 43 50          | Imm Del 6-8 months | 1.5 years | 97.7         | X                   |

Table 2- Characteristics of the different vertical augmentation techniques

|                  | Alveolar distraction | Inlay technique | Onlay technique | Vertical guided bone regeneration |
|------------------|----------------------|-----------------|-----------------|----------------------------------|
| Patients (n)     | 345                  | 74              | 700             | 138                              |
| Implants (n)     | 1011                 | 206             | 2155            | 347                              |
| Survival rate (%)| 97.1                 | 98.5            | 94.7            | 99.3                             |
| Success rate (%) | 95.5                 | 93.4            | 93.2            | 90.7                             |
Onlay technique (Table 1, Figure 5)

The 51 articles included provided 27 studies with onlay technique, and one study used a combination of inlay and onlay techniques. Thirteen studies were retrospective while 14 were prospective. A total of 683 patients with a vertical resorption of partially or totally edentulous alveolar ridges were treated with the onlay technique. Seventeen patients were treated with a combination of onlay and inlay techniques. Three different donor materials for the bone where used: autogenous (iliac, ramus, calvarium, chin, tibia, and coronoid), allografts, and alloplastic grafts. In total, 910 dental implants were placed immediately, 1245 dental implants were placed after 3 to 9 months, and the mean was 5.5 months.
after the healing of the onlay technique. After the start of loading, the follow-up ranged from 1.4 to 10 years, and the mean was 3.5 years. Survival rates for the dental implants in bone from the onlay technique ranged from 72.8 to 100.0%, and the mean was 94.7%. Unfortunately, only 14 studies evaluated the implant success rate, which ranged from 86.9 to 100.0%, and the mean was 93.2%.

Only eight studies out of the 27 which used the onlay technique as a treatment presented the marginal bone level change in their results. The marginal bone level change is shown in Figure 5. One study has different treatment groups, therefore, it is shown twice in the figure. Only four studies presented the results for a follow-up period of 4 or 5 years. At baseline, the marginal bone level change is around -0.30 – -2.24 mm, 1st year of loading -0.85 – -3.70 mm, 2nd year of

**Figure 5** - Onlay technique. Mean and Standard Deviation are indicated

**Figure 6** - Vertical guided bone regeneration. Mean and Standard Deviation are indicated
Vertical guided bone regeneration (Table 1, Figure 6)

The 51 articles included provided seven studies with vertical bone regeneration. Three studies were retrospective while 4 were prospective. A total of 138 patients with a vertical resorption of partially or totally edentulous alveolar ridges were treated with vertical guided bone regeneration. Two different donor materials for the bone were used: autogenous (ramus²²,⁹⁶,¹⁰⁵ and chin⁹⁶,¹⁰⁵) and allografts⁶¹,¹⁰⁰. Moreover, combinations of different donor materials for the bone were used - autogenous+allograft⁶ and autogenous+xenograft⁸⁰. In total, 141 dental implants were placed immediately, 206 dental implants were placed after 4 to 12 months, and the mean was 7.8 months after the healing of the vertical bone regeneration. After the start of loading, the follow-up ranged from 1.0 to 5.3 years, and the mean was 2.4 years. The survival rates for the dental implants in bone from the vertical bone regeneration ranged from 94.1 to 100.0%, and the mean was 99.3%. The implant success rate ranged from 75.0 to 100.0%, and the mean was 90.7%. The implant success rate ranged from 94.1 to 100.0%, and the mean was 99.3%. The survival rates for the bone were used: autogenous (ramus²²,⁹⁶,¹⁰⁵ and chin⁹⁶,¹⁰⁵) and allografts⁶¹,¹⁰⁰. Moreover, combinations of different donor materials for the bone were used - autogenous+allograft⁶ and autogenous+xenograft⁸⁰. In total, 141 dental implants were placed immediately, 206 dental implants were placed after 4 to 12 months, and the mean was 7.8 months after the healing of the vertical bone regeneration. After the start of loading, the follow-up ranged from 1.0 to 5.3 years, and the mean was 2.4 years. The survival rates for the dental implants in bone from the vertical bone regeneration ranged from 94.1 to 100.0%, and the mean was 99.3%. The implant success rate ranged from 75.0 to 100.0%, and the mean was 90.7%.

All the seven studies which used vertical bone regeneration as a treatment presented the marginal bone level change in their results. The marginal bone level change is shown in Figure 5. One study has different treatment groups, therefore, it is shown three times in the figure. Only two studies presented the results for a follow-up period of 5 years. At baseline, the marginal bone level change is around 0.41 – -1.29 mm, 1st year of loading -0.85 – -2.64 mm, 2nd year of loading -1.35 – -2.64 mm, 3rd year of loading -1.27 – -2.64 mm, 4th year of loading -1.00 – -2.64 mm, and 5th year of loading -1.00 – -2.86 mm.

DISCUSSION

In the literature, evidence is available about the stability of vertical bone augmentation. A wide range of different techniques was used to vertically augment the bone. This review tried to systematically evaluate the current evidence and to compare the different vertical augmentation techniques as well as their marginal bone level change on the long-term. In total, 51 articles could be included, from which the data were obtained. Only 21 articles out of 51 contained information about the marginal bone level change. Line graphs with standard deviation were used to present the marginal bone level change over a long period of time.

Few articles showing the marginal bone level change around a successful implant are available in literature. In order to assess the stability of an implant in augmented bone, it is important to know the marginal bone level change around a successful implant in non-augmented bone. The most recent data about marginal bone level change around non-augmented implants were discussed at the Third EAO consensus conference. In this article, data of implants in an augmented side were collected and compared with the EAO consensus conference conclusions.

Alveolar distraction

The analysis shows that the implant survival and success rates are comparable with dental implants which are placed in non-augmented bone. The line graph (Figure 2) shows an overview of the marginal bone level change for the first 5 years. Only three studies present the results for a follow-up period of 4 or 5 years. Unfortunately, it was not possible to combine those results. The marginal bone level change between abutment connection and 1st year of loading varies between -0.60 – -0.97 mm. After the 2nd year, it varies between -0.1 – -0.3 mm; after the 3rd year, between -0.06 – -0.17 mm; after the 4th year, between 0 – -0.2 mm; and after the 5th year of loading it is -0.09 mm. These data are in agreement with the present success criteria for the 1st year of loading, which allows a marginal bone loss of 1-1.5 mm. In the 2nd, 3rd, 4th, and 5th year, the bone loss is, in most of the studies, more than 0.1 mm. This could indicate that the resorption rate is more rapidly progressing compared to non-augmented bone.

Alveolar distraction initiates natural bone formation between the distracted segment and the basal bone. Therefore, there is no need for bone grafting, but for a narrow ridge instead. For a narrow ridge, a bone grafting is better to use, since it can rebuild the horizontal and vertical components. Alveolar distraction seems to be only indicated for the mandible because of the pneumatisation of the sinus in the maxilla. A disadvantage of this technique is the early resorption of the distracted bone. It is essential to consider some overcorrection during treatment planning for directly avoiding surgical relapse and another surgical intervention for additional augmentation. Alveolar distraction undergoes a more active remodeling process because of the better vascularization when compared to a block graft. For the long-term, the marginal bone level change might be more stable.

Inlay technique

The analysis shows that implant survival and success rates are comparable with dental implants which are placed in non-augmented bone. The
line graph (Figure 3) shows an overview of the marginal bone level change for the first 5 years. Only one study\textsuperscript{38} presents a follow-up period of 3 years. Unfortunately, it was not possible to draw any conclusion.

The inlay technique is a technique in which a new graft is placed between the cranial bone segment and the basal bone. The inlay technique in the maxilla is usually seen as a sinus floor augmentation. This part is excluded from this review. For a narrow ridge, a horizontal bone grafting is sometimes needed. A difficulty for the inlay technique is the management of soft tissues. The soft tissues need to maintain sufficient blood supply to the bone segment which is cranially displaced. The risk of wound dehiscence could arise when there is too much tension after wound closure. Unfortunately, no long-term follow-up studies are available. Therefore, a comparison with dental implants in non-augmented bone is not possible.

### Onlay technique

The analysis shows that implant survival and success rates are comparable with dental implants which are placed in non-augmented bone. The line graph (Figure 4) shows an overview of the marginal bone level change for the first 5 years. Only four studies present the results for a follow-up period of 4 or 5 years\textsuperscript{25,29,57,74}. Unfortunately, it was not possible to combine those results. The marginal bone level change between abutment connection and 1st year of loading varies between -0.60 – -1.46 mm; after the 2nd year, between -0.03 – -0.30 mm; after the 3rd year, between -0.03 – -1.03 mm; after the 4th year, between 0.2 – -0.06 mm; and after the 5th year of loading, between 0.08 – -0.27 mm. These data are in agreement with the present success criteria for the 1st year of loading, which are placed in non-augmented bone. The implants were used to determine the survival and success rates of dental implants in non augmented bone. Therefore, the decision is made to show all the data which criterion or statistical analysis has been used. This could be a disadvantage, but it gives the clinician a complete overview of the available literature.

### Vertical guided bone regeneration

The analysis shows that the implant survival is comparable whereas the success rate is not comparable with dental implants which are placed in non-augmented bone. The line graph (Figure 5) shows an overview of the marginal bone level change for the first 5 years. Only two studies present the results for a follow-up period of 5 years\textsuperscript{96,105}. Unfortunately, once again it is not possible to combine those results. The marginal bone level change between abutment connection and 1st year of loading varies between -1.01 – -1.86 mm; after the 2nd year, between 0.05 – -0.02 mm; after the 3rd year, between 0.11 – -0.06 mm; after the 4th year, between 0.27 – -0.02 mm; and after the 5th year of loading, between 0 – -0.22 mm. These data are in agreement with the present success criteria for the 1st year of loading, which allows a marginal bone loss during the first year of 1-1.5 mm, and of 0.1 mm for the 2nd, 3rd, 4th, and 5th year\textsuperscript{5,17}. However, one study\textsuperscript{96} has a different amount of dental implants during the follow-up period, which could influence the outcome.

Vertical guided bone regeneration implies that the regeneration of osseous defects is predictably attainable via the application of occlusive membranes, which mechanically exclude non-osteogenic cell populations from the surrounding soft tissues. In the past, non-resorbable membranes were used, but nowadays resorbable membranes are common. The defect is always filled with particulate autogenous bone, and sometimes mixed with xenograft or allograft. Wound dehiscence is often seen as a complication. Therefore, it is important to get as little traction on the wound as possible. For the long-term, it seems that the marginal bone level loss is comparable with dental implants in non augmented bone.

In the literature, a lot of different criteria is used to determine the survival and success rates of dental implants. The lack of universally accepted success criteria makes the interpretation and comparison of the data really difficult\textsuperscript{96}. In addition, a statistical problem is perceived. There is a discrepancy in reported outcomes when the primary unit of analysis is the patient instead of the dental implant\textsuperscript{87,88}. Therefore, the decision is made to show all the data which criterion or statistical analysis has been used. This could be a disadvantage, but it gives the clinician a complete overview of the available literature.
Some new guidelines were proposed in the VIII European Workshop on Periodontology. A successful dental implant has to meet criteria concerning tissue physiology (osseointegration), function (chewing), absence of pain, and user satisfaction. The first criteria for marginal bone loss exist since 1986. This review shows that the marginal bone loss after abutment connection and the first year of loading varies between 1.0 and 1.5 mm. This is called saucerisation, and is caused by the establishment of the biological width. Recent studies allow a mean marginal bone loss of 1.0 mm in the first year of loading, and an annual of 0.1 mm bone loss can be expected in the following years. The criteria are divided into three domains that are important for identifying the success of a dental implant. These domains are: patient-reported outcome measures (health-related quality of life and general satisfaction), peri-implant health (marginal bone level, bleeding on probing, and probing depth), and implant-supported restorations (longevity of the restoration, function/occlusion related outcomes, and technical complications).

To give a complete overview about the different techniques, every type of grafting material was included. Depending on the grafting material used, a different resorption occurs. That is why the results are presented in graphs and tables, which facilitates the decision of clinicians regarding what type of grafting material must be used. No distinction is made between the different durations of the follow-up period, even though there was a wide range of it. The follow-up period needs to be of at least one year. These different lengths of follow-up periods are included in the calculations. However, an implant success rate of 100% after one year cannot be compared with a success rate after 10 years. Furthermore, different follow-up periods per patient in a study are pooled together. This could lead to a complete different outcome. This review is designed to give a complete overview, thus, the clinician can decide what the best treatment is.

After analysis of the articles about vertical bone augmentation, the main conclusion was that a wide range of different techniques and materials were used, and also different patient groups, study designs, antibiotic prescriptions, and follow-up regimes. Because of this, no meta-analysis was conducted, for once a meta-analysis is performed, it causes a bias. Another limitation of this review is that it was not possible to separate the data for single tooth gap, multiple missing teeth, or an edentulous ridge in the different articles used. These different clinical situations were mostly pooled together; therefore, it was hard to analyze a specific technique for a specific clinical condition. For most defect and especially in the atrophic jaws, the description of the seize of the defect was hardly present, which was also a topic in the last ITI Consensus Conference.

Based on our previous findings, it is hard to state which vertical bone augmentation is the best to use. However, when only considering those vertical bone augmentation techniques for which studies exist with a follow-up period of at least 4 to 5 years, there seems to be a trend that the onlay technique, alveolar distraction, and vertical guided bone regeneration are stable for at least 4 to 5 years. Since it was not possible to carry out meta-analytic procedures, a conclusion about stability is not justified, but a trend is still visible. However, further research is necessary to clarify this finding. More studies that follow the marginal bone level change for a longer period are necessary, in addition to better description and ridge measurements of the clinical situation before and after the augmentation procedure. This will enable a better interpretation of the results and allow the clinician to conclude which specific augmentation is recommended and in which clinical situation.

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