

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

Johan Anton Jochum KEESTRA^{1,2}, Obada BARRY³, Lianne DE JONG⁴, Gerhard WAHL³

1- Ordentall, Rotterdam, Netherlands.

2- Praktijk voor Parodontologie en Implantologie, Tilburg, Netherlands.

3- Universität Bonn, Poliklinik für Chirurgische Zahn-, Mund- und Kieferheilkunde, Bonn, Germany.

4- Dental Clinics Zuidoost, Rotterdam, Netherlands.

Corresponding address: Gerhard Wahl - Department of Oral Surgery, University of Bonn, Welschnonnenstraße 17, 53117 - Bonn, Germany - Fax: +49 228 287 22653 - e-mail: hanskeestra@gmail.com

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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 available³. 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 reported³². 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 bone⁶⁷.

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)³³.

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 review^{46,69}.

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 articles. Studies that fulfilled all the selection criteria were processed for data extraction. Discrepancies regarding the inclusion or exclusion of studies were resolved by discussion between the reviewers (OB and JK). The extracted data included: year of publication, design of the study, number of patients *per* study arm, defect type, surgical procedure, donor site, number of dental implants, timing of implants, follow-up time, primary outcome measure at baseline (placement of the final crown, start loading), year 1, 2, 3, 4, and 5 of loading, and secondary outcomes measures. The quality of the various studies were not considered in the final analysis, therefore, no quality assessment has been done.

Statistical analyses

Data of the included studies were extracted and inserted into a database. Mean values and standard deviations were extracted from the data. If no standard deviation was available, it was recalculated by the formula ($SE=SD/\sqrt{n}$) where n is the sample size. When mean follow-up period was used, it was recalculated, if possible, for every year; if not, the

nearest full year was used. If there were insufficient 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 articles^{2,8,9,12,14,18,23,24,27,28,30,39,41,44,45,48,49,51,56,59,60,62,64,68,73,75,84,89,90,92-94,98,102,103,107,108,111,113} 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 summarized^{1,6,7,10,15,16,20-22,25,29,31,34,36-38,40,42,43,50,53,55,57,58,61,63,65,66,70-72,74,78-86,91,95,96,99,100,104-106,109,110,114}. 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 studies^{10,21,22,25,36,37,40,43,50,57,79,81-83,95,104,114} with alveolar distraction, and one study⁸⁶ used a combination of the inlay technique and alveolar distraction. Eight studies were retrospective while 10 were

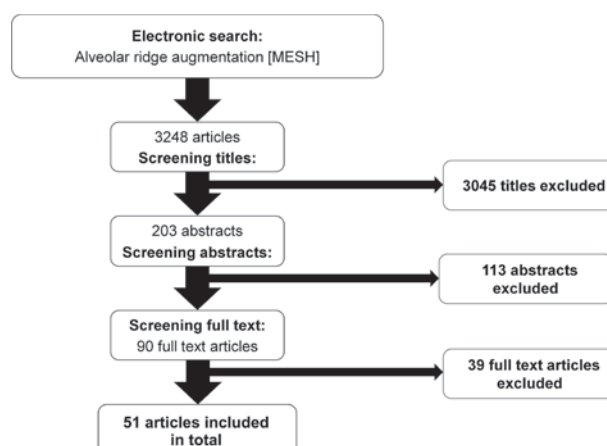


Figure 1- Search strategy

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

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. ³⁸ (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
Useful clinical results, more information needed. Could not contact the author
Same results Nyström, et al. ⁷⁴ (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
Useful clinical results, more information needed. Could not contact the author
Useful 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 (%)
Kim, et al. ⁵⁷ (2013)	Retrospective study	14	Max + Man + Hor + Ver	Alveolar distraction	Autogenous (Ramus)	41	Del 4.9 months	7.1 ± 1.7 years	97.3	92.7
		28	Max + Man + Hor + Ver	Onlay technique		61	Del 6.2 months	8.2 ± 2.0 years	94.1	90.2
Pérez-Sayáns, et al. ⁷⁹ (2013)	Retrospective study	14	Max + Man + Hor + Ver	Alveolar distraction		50	Del 3.0 months	3 years	100	96
Korpi, et al. ⁵⁸ (2012)	Prospective study	22	Man + Hor + Ver	Onlay technique	Autogenous (Iliac)	48	Imm	3-9 years	100	96
De Riu, et al. ³¹ (2012)	Prospective study	15	Man + Hor + Ver	Onlay technique	Autogenous (Coronoid)	40	Del 6.0 months	2 years	95	96.7
Zwetyenga, et al. ¹¹⁴ (2012)	Retrospective study	37	Man + Hor + Ver	Alveolar distraction		127	Del 5.8 months	5.2 years	100	96.2
Sezer, et al. ⁹⁵ (2012)	Prospective study	10	Man + Hor + Ver	Alveolar distraction		40	Del 4.0 months	3 years	100	100
Kawakami, et al. ⁵³ (2013)	Controlled split mouth study	12	Man + Hor + Ver	Inlay technique	Autogenous (Ramus)	22	Del 6.0 months	1 year	95.5	90.9
				Inlay technique	Alloplastic graft	22			95.5	90.9
Annibali, et al. ⁶ (2012)	Retrospective study	5	Man + Hor + Ver	Vertical guided bone regeneration	Autogenous (Ramus) + Allograft	16	Imm	1.0 ± 0.1 years	100	81.3
Nissan, et al. ⁷² (2012)	Prospective study	40	Max + Hor + Ver	Onlay technique	Allograft	83	Del 6.0 months	4.0 ± 1.8 years	98.8	X
Esposito, et al. ³⁸ (2012)	Randomized control trial	30	Man + Hor + Ver	Inlay technique	Xenograft	61	Del 5.0 months	3 years	100	X
Chiapasco, et al. ²⁰ (2012)	Prospective study	11	Max + Man + Hor + Ver	Onlay technique	Autogenous (Ramus)	29	Del 4-5 months	1.6 years	100	93.1
		7	Man + Hor + Ver		Autogenous (Calvarium)	31		Del 6-7 months	100	90.3
Acocella, et al. ¹ (2012)	Prospective study	16	Max + Hor + Ver	Onlay technique	Allograft	34	Del 6.0 months	1.5-2.5 years	100	X
Ludovichette, et al. ⁶⁵ (2011)	Prospective study	19	Max + Man + Hor + Ver	Onlay technique	Alloplastic graft	49	Imm	3 years	100	100
Rigo, et al. ⁸⁵ (2011)	Retrospective study	17	Max + Man + Hor + Ver	Inlay/onlay technique	Allograft	60	Del 6.0 months	2.2 years	100	100
Canullo, et al. ¹⁵ (2010)	Prospective study	20	Max + Man + Hor + Ver	Onlay technique	Alloplastic graft	42	Imm	2 years	100	100
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
Corinaldesi, et al. ²⁹ (2009)	Retrospective study	24	Max + Man + Hor + Ver	Onlay technique	Autogenous (Ramus)	56	Imm / Del 8-9 months	3-8 years	100	96.4
Le, et al. ⁶¹ (2010)	Prospective study	15	Max + Man + Hor + Ver	Vertical guided bone regeneration	Allograft	32	Del 4-5 months	1.4 years	100	100
Pelo, et al. ⁷⁸ (2010)	Prospective study	19	Man + Hor + Ver	Onlay technique	Autogenous (Ramus)	141	Del 4.0 months	4.0 years	96	91
Sbordone, et al. ⁹¹ (2009)	Retrospective study	40	Max + Man + Hor + Ver	Onlay technique	Autogenous (Ramus, Iliac)	109	Del 3-5 months	3.0 years	99.1	X
Elo, et al. ³⁶ (2009)	Retrospective study	65	Max + Man + Hor + Ver	Onlay technique	Autogenous (Iliac, Chin, Retromolar, Tibia)	184	Del 4-5 months	3-5.1 years	98.4	96.7
		17	Man + Hor + Ver	Alveolar distraction		56			98.2	98.2

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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. ⁴⁰ (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 10	Man + Hor + Ver	Inlay technique Onlay technique	Autogenous (Iliac)	20 23	Del 3-4 months	1.5 years	100 100	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. ¹⁰⁵ (2009)	Retrospective study	28	Max + 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
Robiony, et al. ⁸⁶ (2008)	Prospective study	12	Man + Hor + Ver	Alveolar distraction + Inlay technique	Autogenous (Iliac)	47	Del 6.0 months	5 years	97.9	91.5
Pieri, et al. ⁸⁰ (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. ¹⁰ (2008)	Prospective study	5 6	Man + Hor + Ver	Inlay technique Alveolar distraction	Autogenous (Iliac)	21 16	Del 3-4 months Del 4-5 months	1.8 years 2.5 years	100 100	95.2 93.7
Chiapasco, et al. ²⁵ (2007)	Prospective study	8 9	Man + Hor + Ver	Onlay technique Alveolar distraction	Autogenous (Ramus)	19 21	Del 4-5 months Del 3 months	2-4 years	100 100	89.5 94.7
Uckan, et al. ¹⁰⁴ (2007)	Retrospective study	21	Max + Man + Hor + Ver	Alveolar distraction		42	Del 3-4 month	2.7 years	88	X
Polo, et al. ⁸¹ (2007)	Prospective study	10	Man + Hor + Ver	Alveolar distraction		34	Del 3-4 months	1.0 ± 0.3 years	100	X
Levin, et al. ⁶³ (2007)	Retrospective study	50	Max + Man + Hor + Ver	Onlay technique	Autogenous (Ramus, Iliac)	129	Del 4-6 months	2.0 ± 0.9 years	96.9	91.9
Smolka, et al. ⁹⁹ (2006)	Prospective study	10	Man + Hor + Ver	Onlay technique	Autogenous (Calvarium)	20	Del 6.0 months	2.5 years	95	X
Enislidis, et al. ³⁷ (2005)	Retrospective study	32	Man + Hor + Ver	Alveolar distraction		94	Del 3-5 months	3.0 years	95.7	X
van der Meij, et al. ¹⁰⁶ (2005)	Retrospective study	17	Man + Hor + Ver	Onlay technique	Autogenous (Calvarium)	34	Imm	4.3 years	88.2	88.2
Nyström, et al. ⁷⁴ (2004)	Retrospective study	30	Max + Hor + Ver	Onlay technique	Autogenous (Iliac)	177	Imm	10 years	72.8	X
Chiapasco, et al. ²¹ (2004)	Prospective study	37	Max + Man + Hor + Ver	Alveolar distraction		138	Del 3 months	2.8 years	100	94.2
Chiapasco, et al. ²² (2004)	Prospective study	5 10	Max + Man + Hor + Ver	Vertical guided bone regeneration Alveolar distraction	Autogenous (Ramus)	12 34	Del 6-7 months Del 3-4 months	1-3 years	100 100	75 94.1
Raghoobar, et al. ⁸³ (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. ⁸² (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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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. ⁹⁶ (2001)	Retrospective study	6	Max + Man + Hor + Ver	Vertical guided bone regeneration	Allograft Autogenous (Ramus, Chin)	17	Imm	5.3 years	94.1	94.1
		11				26		3.3 years	100	96.1
		32				82		2.5 years	100	100
Gagl, et al. ⁴³ (2000)	Prospective study	34	Max + Man + Hor + Ver	Alveolar distraction		62	Imm	1 year	96	X
Keller, et al. ⁵⁵ (1999)	Retrospective study	28 4	Max + Hor + Ver	Onlay technique	Autogenous (Iliac)	183 21	Imm Del 4-6 months	5.6 years	86.3 91	X
Verhoeven, et al. ¹⁰⁹ (1997)	Prospective study	13	Man + Hor + Ver	Onlay technique	Autogenous (Iliac)	72	Imm	2.4 ± 0.9 years	100	X
McGrath, et al. ⁶⁶ (1996)	Retrospective study	18	Man + Hor + Ver	Onlay technique	Autogenous (Iliac)	36	Imm	1.4 years	91.6	91.6
Vermeeren, et al. ¹¹⁰ (1996)	Retrospective study	31	Man + Hor + Ver	Onlay technique	Autogenous (Iliac)	78	Imm	5 years	89.7	X
Astrand, et al. ⁷ (1996)	Retrospective study	17	Max + Hor + Ver	Onlay technique	Autogenous (Iliac)	92	Imm	3-5 y	75	X
Donovan et al. ³⁴ (1994)	Retrospective study	24	Max + Man + Hor + Ver	Onlay technique	Autogenous (Calvarium)	43	Imm Del 6-8 months	1.5 years	97.7	X
						50		2.6 years	86	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

97.1%. 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^{21,22,25,57,79,81,86} 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^{10,38,42,53} with inlay technique, and one study⁸⁵ 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 were used: autogenous (iliac^{10,42}, ramus⁵³), xenografts³⁸, and alloplastic grafts⁵³. 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^{38,42,53} out of the four which used the inlay technique presented the marginal bone level change in their results. The marginal bone level change is shown in Figure 4. One study⁵³ 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.

Onlay technique (Table 1, Figure 5)

The 51 articles included provided 27 studies^{1, 7, 15, 16, 20, 25, 29, 33, 35, 41, 54, 56, 57, 62, 64, 65, 69-71, 73, 77, 85, 91, 99, 106, 109, 110} with onlay technique, and one study⁸⁴ 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 were used: autogenous (iliac^{7, 36, 42, 55, 58, 63, 66, 74, 91, 109, 110}, ramus^{20, 25, 29, 36, 57, 78}, calvarium^{20, 34, 99, 106}, chin³⁶, tibia³⁶, and coronoid³¹), allografts^{1, 16, 70-72, 85}, and alloplastic grafts¹⁵. 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

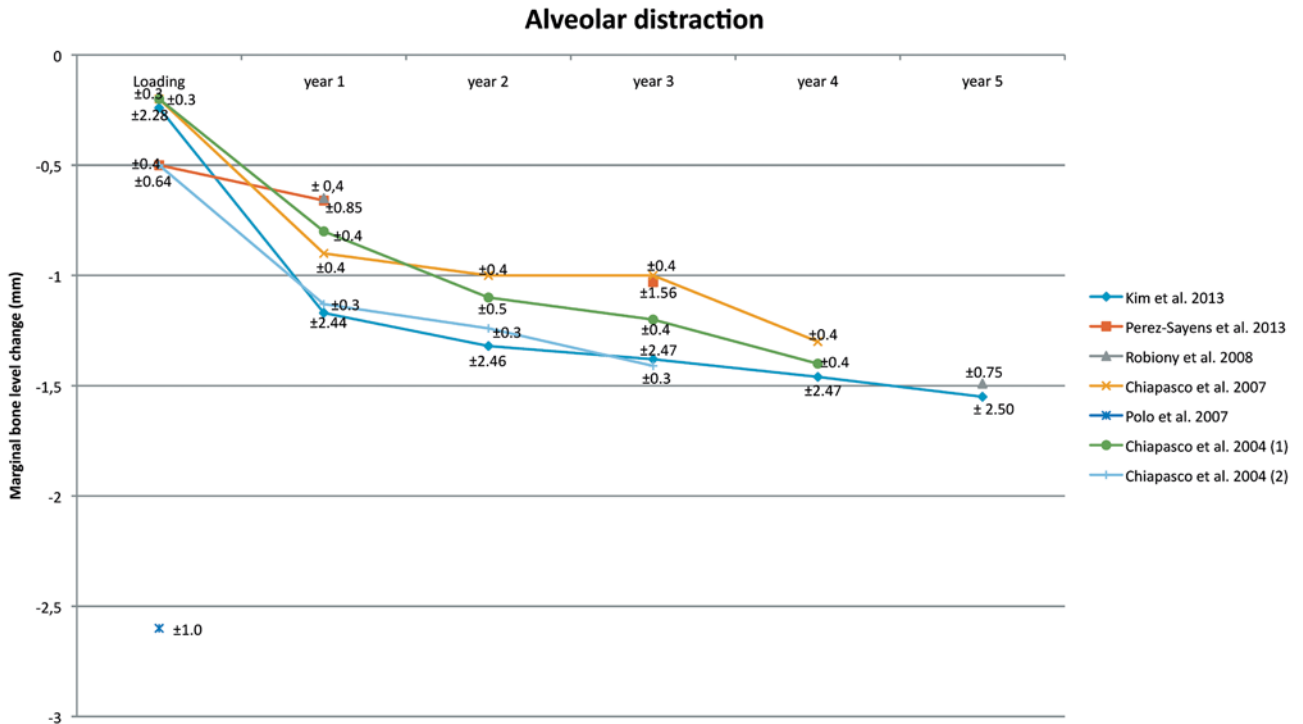


Figure 3- Alveolar distraction. Mean and Standard Deviation are indicated

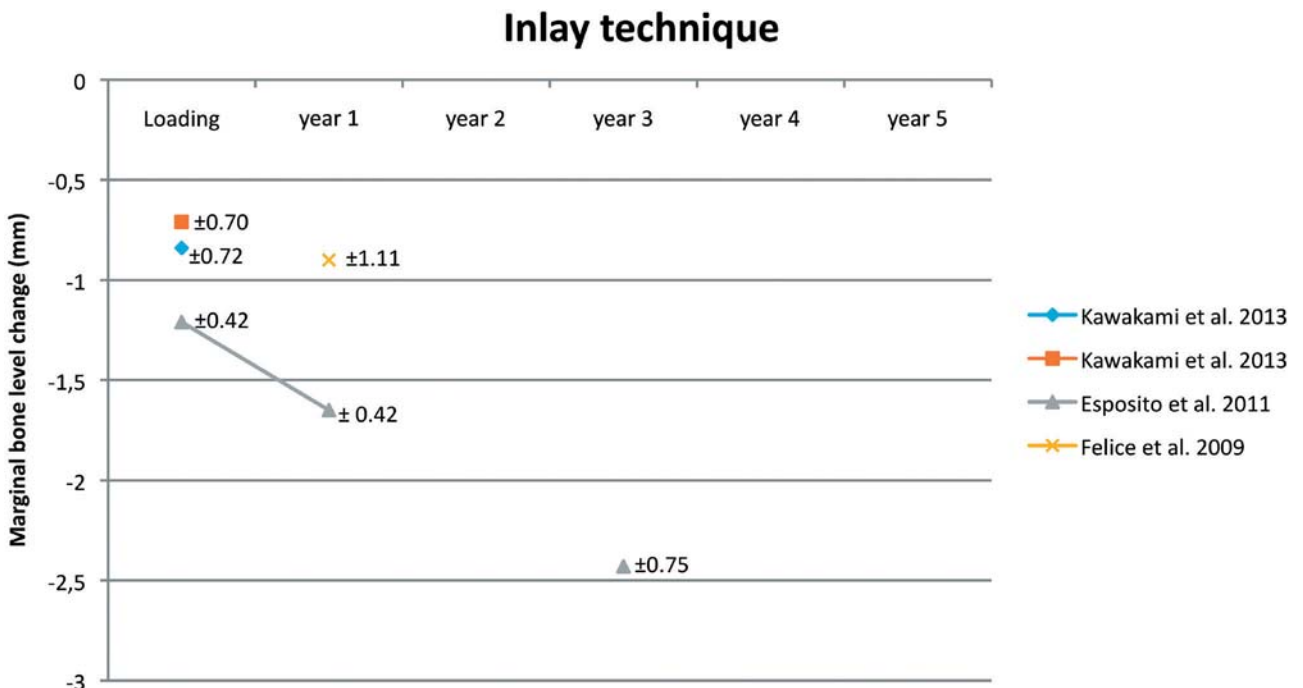


Figure 4- Inlay technique. Mean and Standard Deviation are indicated

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^{15,20,25,29,31,42,57,74} 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 study²⁰ 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

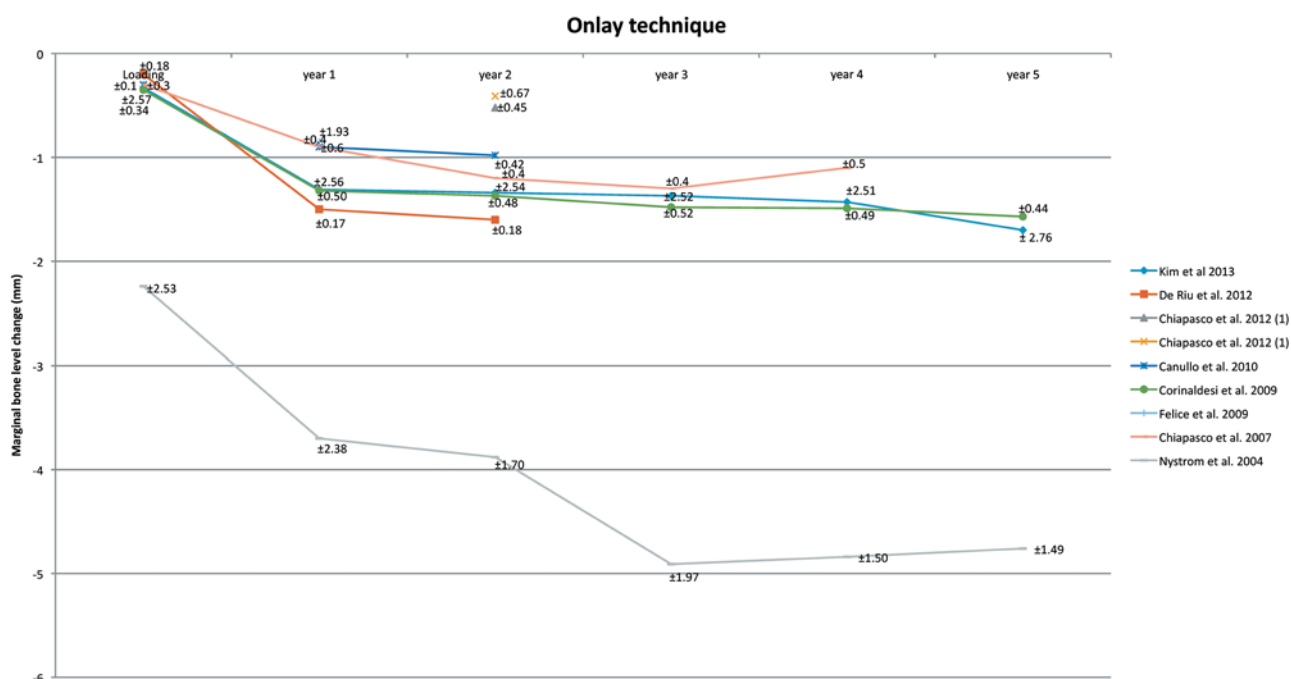


Figure 5- Onlay technique. Mean and Standard Deviation are indicated

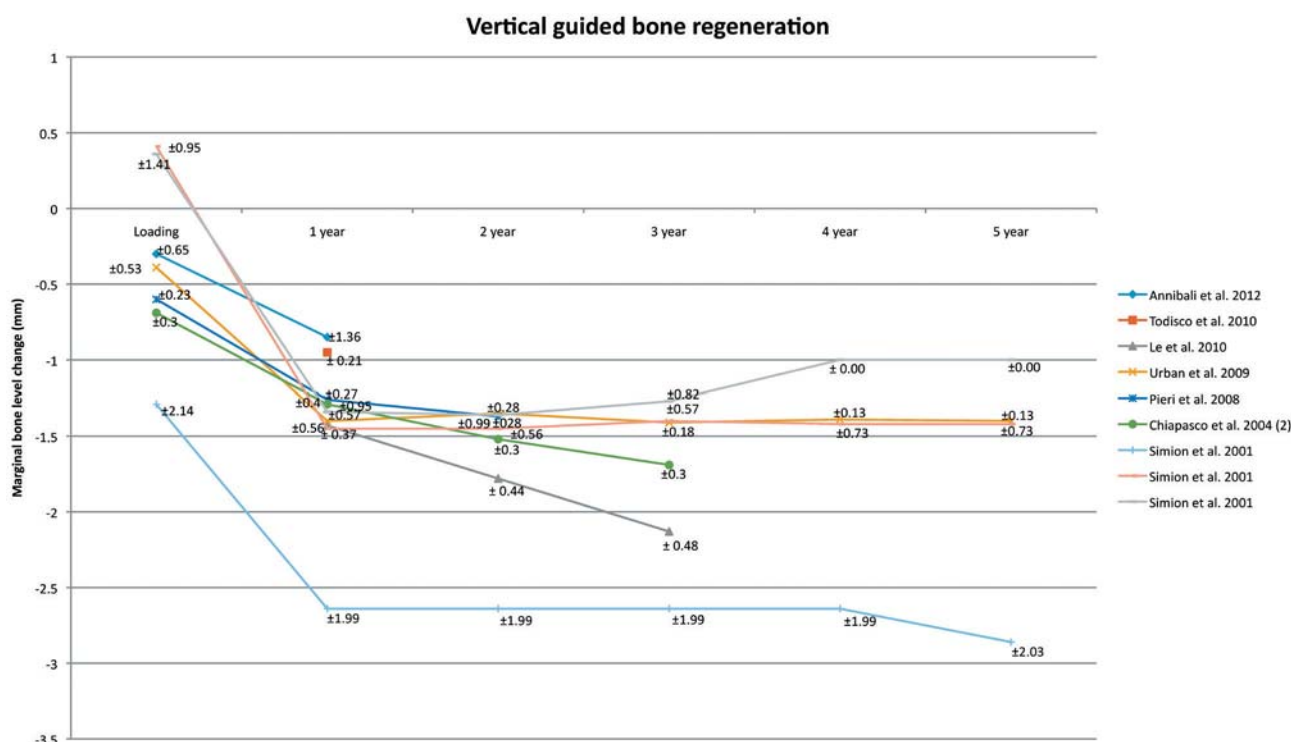


Figure 6- Vertical guided bone regeneration. Mean and Standard Deviation are indicated

loading -0.41 – -3.88 mm, 3rd year of loading -1.30 – -4.91 mm, 4th year of loading -1.10 – -4.84 mm, and 5th year of loading -1.57 – -4.76 mm.

Vertical guided bone regeneration (Table 1, Figure 6)

The 51 articles included provided seven studies^{6,22,61,80,96,100,105} 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 (ramus^{22,96,105} and chin^{96,105}) and allografts^{61,100}. 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^{6,22,61,80,96,100,105} 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 study⁹⁶ 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^{4,5,17,101} 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 bone⁴. 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^{21,57,81}. 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^{5,17}. 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 pneumatization 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 graft⁴⁷. 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 bone⁴. The

line graph (Figure 3) shows an overview of the marginal bone level change for the first 5 years. Only one study³⁸ 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^{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 allows a marginal bone loss of 1-1.5 mm, and of 0.1 mm for the 2nd, 3rd, 4th, and 5th year^{5,17}. However, one study⁷⁴ showed more marginal bone loss in comparison with others^{25,29,57}.

The onlay technique is done mostly with an autogenous bone graft. Before the year 2000, most implants were immediately placed together with the bone grafts. The implants were used to secure the graft. The capacity and volume of the bone grafts are variable between the studies. These differences could be explained by different follow-up periods, timing of implants placement, different sites, and different bone grafting material. Overall, the resorption rate is higher in the first year, but stabilizes after it. The autogenous bone graft is still the most frequently used graft for the onlay technique. It is a recommendation to use corticocancellous bone instead of particulated bone grafts. Ideally, oversized grafts should be harvested to maintain enough volume after the

initial resorption phase. The major difficulty for the onlay technique is the management of the soft tissues to maintain a full wound closure. For the long-term, it seems that the marginal bone level change is comparable with dental implants in non-augmented bone.

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^{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^{5,17}. However, one study⁹⁶ 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 difficult⁷⁶. 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^{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 satisfaction¹⁰¹. The first criteria for marginal bone loss exist since 1986⁵. 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 years¹⁷. 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)¹⁰¹.

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 Conference¹¹.

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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