Clinical Importance of Recipient Site Characteristics for Vertical Ridge Augmentation: A Systematic Review of Literature and Proposal of a Classification

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This review evaluated the characteristics of vertical alveolar defects that were augmented via onlay bone grafting or guided bone regeneration. Information regarding the anatomic site, type of edentulism, and defects' dimensions were extracted. The experiments differed vastly in the description of the defects' features. Aiming to mitigate the confounding effect of recipient site's morphology in future experiments, a classification of vertically deficient recipient sites is proposed.

Key Words: alveolar bone defect, vertical ridge augmentation, onlay bone graft, guided bone regeneration

INTRODUCTION

Presence of sufficient alveolar bone volume is one of the principal prerequisites for implant treatment.[1] A considerable part of recent research has been directed toward distinguishing the most favorable augmentation procedure for restoring deficient alveolar ridges.[1–3] Restoration of alveolar vertical defects has remained a challenge in reconstructive surgery.[4,5] A variety of augmentation techniques, namely onlay bone grafting (OBG), inlay bone grafting, guided bone regeneration (GBR), and distraction osteogenesis have been used for augmentation of vertical defects, using different types of bone grafts and stimulating factors.[3] The applicability of augmentation procedures, to a large extent, depends on the recipient site morphology.[6] On one hand, it influences choosing the optimal treatment modality, given that the selection criteria for different augmentation techniques are partly established based on the characteristics of the recipient site.[7–9] In addition, the suitability of bone graft options with different regenerative properties should be determined in view of the regenerative demands of the defect.[10] On the other hand, the regenerative potential of the recipient site is a major factor for effective bone formation within the augmented area.[11] A bony region with compromised vascularization and cellularity shows suppressed healing ability.[12] It has also been suggested that the morphology of alveolar ridge significantly affects bone regeneration.[8]

The focus of studies has been mainly on improving the techniques and introducing novel augmentation materials to provide more promising outcomes. However, the variation among studies does not allow for a generalized conclusion on the effectiveness of the suggested protocols.[1] This inconsistency may be partly due to imprecise consideration of the properties of recipient sites within the study designs. To verify the validity of this assumption, a systematic review was conducted on experiments evaluating vertical alveolar ridge augmentation as a pre-implant reconstructive surgery. The aim was to assess the characteristics

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of recipient sites subjected to vertical ridge augmentation and to evaluate the consistency of the defects' features within and between the studies. Furthermore, the present article proposes a morphologic classification of vertical bone defects in edentulous alveolar ridges.

Materials and Methods

Study selection

The study design was not a criterion of inclusion for this attentive review. Full or partially edentulous patients who required vertical augmentation with or without horizontal augmentation of alveolar ridge(s) for subsequent implant-based jaw rehabilitation were included. Augmentation techniques involving (1) onlay bone grafting or (2) guided bone regeneration procedures were evaluated regardless of the follow-up duration. Inlay bone augmentation in which an outlined osteotomy site serves as the recipient site[7] as well as distraction osteogenesis were not incorporated for evaluation. Reconstruction procedures on defects with specific morphologies such as socket preservation, sinus lifting, or treatment of dehiscence/fenestration type peri-implant defects were excluded. Immediate implant placement into extraction socket was another exclusion criterion. Simultaneous implant placement with bone grafting was included only if no peri-implant defect was created or if implants were intentionally placed in a defined supra-alveolar position. Studies merely incorporating histologic evaluation or assessment of implant success/survival rate were not included. Table 1 summarizes the exclusion criteria of the present review of literature.

All studies considered for inclusion in this review were evaluated with regard to the description of initial bone defects. For this purpose, the involved jaw(s) and the anatomic site(s) of the defects included in each study (maxillary/mandibular and anterior/posterior) were recorded. The type of edentulism was also documented for the defects. Quantitative information regarding the dimensions of bone defects (height and width) was documented. If measurements were not reported, descriptive details of the defect's height and width were recorded. Besides the above-mentioned defect-related factors, the augmentation procedure, the augmentation material, and the time of implant insertion were specified for each article. Results achieved regarding the amount of bone augmentation, amount of graft resorption, graft failure, and the amount of marginal bone loss around implants were also extracted, if available.

Table 1

The criteria of study exclusion

Defect	Horizontal defect in edentulous alveolar ridge
	Dehiscence/fenestration type peri-implant defect
Intervention	Distraction osteogenesis
	Inlay bone augmentation
	Socket preservation
	Sinus lifting
	Immediate implant placement into extraction socket
Outcome	Histologic evaluation
	Implant success/survival rate

Study search tools

An electronic search was conducted in PubMed and the Cochrane library from January 1990 to September 2011. English-language published studies on humans were found using the following keywords alone or in combination: alveolar bone defect, vertical alveolar bone defects, alveolar ridge augmentation, alveolar bone augmentation, vertical ridge augmentation, vertical bone augmentation, onlay bone grafting, and guided bone regeneration.

Initial study selection was conducted through examining titles and abstracts of all identified articles. The full texts of potentially eligible papers were obtained for final assessment based on the defined exclusion and inclusion criteria. Multiple reports of a same experiment, describing different numbers of patients and different outcomes were identified. The report providing the most relevant information with respect to the measurements of this review study was included.

Results

Following the initial screening of titles and abstracts and the final screening of full texts, 40 articles completely fulfilled the inclusion criteria of this study (Figure 1). In experiments with nonhomogenous case selection, certain cases showing the exclusion criteria as defined in this study were excluded, and if possible, the qualifying data were extracted from the remaining cases.[13–18] Since different types of study

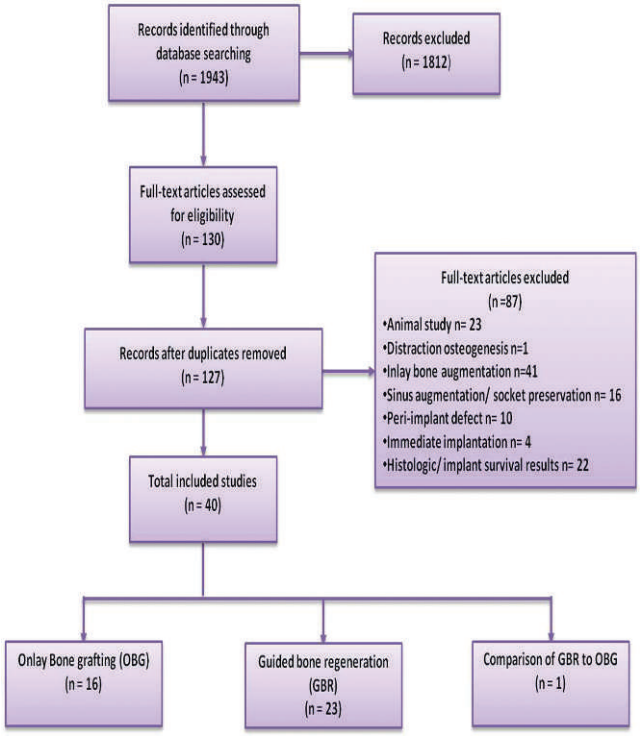


Figure 1. The process of study selection; 40 studies were included.

designs with a wide variation regarding the number of cases were included in this review, the results were reported based on both the number of cases and articles. The total number of vertical cases evaluated in these studies was 528.

The features of the vertical alveolar defects presented in the studies were first assessed regardless of the augmentation procedure. In 20 studies,[15,17,19–36] incorporating 29.4% of all cases (155/528 cases), edentulism type was determined and matched between the cases of each study, while in 13 studies (284/528 cases, 53.8%),[13,37–47] cases were not matched for this criteria; in 7 experiments (89/528 cases, 16.9%)[14,16,48–52] no information was presented. Four studies[18,23,49,50] did not specify the jaw in which the augmentation was performed (60/528 cases, 11.4%), while in the remaining studies, cases were either matched for the involved jaw (20 studies, 175/528 cases, 33.1%)* or were not matched (16 studies, 293/528 cases, 55.5%).† On the other hand, the defect's anatomic site was not evaluable in 15 experiments (295/528 cases, 55.9%)‡; however, augmentation procedure was performed in either the anterior or the posterior parts of the jaw in 15 studies (74/528 cases, 14.0%).§ Ten experiments (159/528 cases, 30.1%) included both cases of anterior and posterior jaw augmentation.[30,38,40–44,46,47,51] The vertical and horizontal dimensions of defects, if available, were either reported quantitatively as the amount of the deficiency or as the amount of the residual bone or descriptively, using terms such as "severely atrophied," and "sufficient/not sufficient for implant placement." In some studies, classifications for the edentulous jaw such as that of Cawood and Howell[53] (7 studies, 122/528 cases, 23.1%)[27,29,30,33,35,42,52] or Fonesca's classification (1 study,[40] 14/528 cases, 2.6%) were used to describe the severity of ridge atrophy. In 2 studies[16,28] (11/528 cases, 2.1%), no information was available on the height of the alveolar defects; conversely, with regard to the defect's width, this was the case in 16 studies (245/528 cases, 46.4%).‖ Measurements of the defects' height were presented in 22 studies (243/528 cases, 46.0%),¶ while in 16 articles only descriptive information could be extracted (274/528 cases, 51.9%).# The initial defect's width was evaluated descriptively in 18 articles (222/528 cases, 42.0%).** In only 6 experiments, quantitative data were reported (61/528 cases, 11.6%).[31,32,34,38,41,42]

For further evaluation, the 40 included studies were categorized based on the augmentation procedure: OBG technique was evaluated in 16 studies, while 23 articles appraised GBR. One controlled clinical trial included both cases of OBG and GBR for comparison.[30] This study was included in both categories.

OBG technique

Data collected from the studies in the OBG category are shown in Table 2. Among the 17 included studies, a prospective and a retrospective design was used in nine†† and three[18,19,33] studies, respectively. Four were case reports/series[15,17,20,28] and 1 study was a

* *References 13–15, 17, 19–22, 24–29, 31, 32, 34–36, 40.*
† *References 16, 30, 33, 37–39, 41–48, 51, 52.*
‡ *References 13, 14, 16, 18, 19, 23, 27, 29, 35, 39, 45, 48–50, 52.*
§ *References 15, 17, 20–22, 24–26, 28, 31–34, 36, 37.*
‖ *References 13–16, 19, 22–24, 26, 28, 36, 39, 43, 45, 50, 51.*
¶ *References 19–22, 24–26, 30–32, 34–38, 41, 42, 44, 45, 49, 50, 52.*
\# *References 13–15, 17, 18, 23, 27, 29, 33, 39, 40, 43, 46–48, 51.*
** *References 17, 18, 20, 21, 25, 27, 29, 30, 33, 35, 37, 40, 44, 46–49, 52.*
†† *References 13, 14, 16, 23, 29, 35, 46, 48, 51.*

controlled clinical trial.[30] A total of 232 cases of vertical augmentation were assessed in these studies. Overall, in 5 studies,[16,46,48,51,54] including 32.7% of all cases within this category, none of the morphologic features were clearly determined and matched. As depicted in Figure 2, the feature that was unavailable in most of the cases was the anatomic site of the defect (9 studies, 177/232 cases, 76.3%).‡‡ Most of the information regarding the defects' height was descriptive (11 studies, 181/232 cases, 78.0%).§§ The defects' width was not demonstrated quantitatively in any of the experiments.

A full-jaw vertical augmentation was performed in 6 studies (76/232 cases, 32.7%).[15,19,28,29,33,35] In 4 of these studies,[15,28,29,33] information regarding both vertical and horizontal dimensions of the edentulous ridges were either not evaluable or merely descriptive (49/76 cases, 64.5%). Vertical defects in the interdental edentulous areas were reconstructed in 4 studies (25/232 cases, 10.8%).[17,23,30,46] In only 2 case reports in this subgroup, the defect's height was measured and reported.[30,46]

GBR technique

Table 3 shows the data collected from the 24 studies that were included in the GBR category. The total number of vertical cases was 296, which were evaluated in 1 controlled clinical trial,[30] 13 prospective studies,‖‖ 3 retrospective studies,[39,45,49] and 7 case reports.[21,25–27,31,32,34]As shown in Figure 3, these articles mainly lacked data regarding the defects' width (8 studies,[22,24,26,36,39,43,45,50] 142/296 cases, 48.0%) as well as the anatomic site of the defects (6 studies,[27,39,45,49,50,52] 118/296 cases, 39.9%). In 3 articles,[39,43,47] including 26.3% of all GBR cases, none of the features were explicitly defined and matched.

Among 15 cases of full maxillary augmentation,[24,27] the anatomic sites (anterior or posterior) as well as quantitative measurements of the defects' height were available in 14 cases.[24] Nine experiments[21,22,25,26,30–32,34,36] incorporated reconstruction of partially edentulous areas, the type of which was similar among the cases within each study (40/296 cases, 13.5%). Free-end edentulous ridges (25/40 cases, 62.5%)[21,22,26,32,34,36] and interdental areas (15/40 cases, 37.5%)[25,30,31] were augmented. Measurements of defects' height were included in all, while defects' width was reported quantitatively in only 3 case reports.[31,32,34]

Classification

Characterizing the morphology of vertical alveolar defects subjected to reconstruction via different augmentation techniques eliminates the potential confounding effects of this factor on the efficacy and practicability of the examined technique.[6] The present article proposes a classification for edentulous sites in need of vertical bone augmentation. Two major components of a vertical bony defect are considered in this classification:

The number of surrounding bony walls

Presence of bone around the teeth adjacent to the partially edentulous area should be considered while assessing the number of bony walls surrounding a defect:

- A: Two-wall defects (Figure 4a).
- B: One-wall defects (Figures 4b and 5a).
- C: A defect with no surrounding walls (Figures 4c, 5b, and 6).

Width of the defect base

Considering the least amount of the defect base width, taken by computerized tomography or intrasurgical measurement, the bony defect can be categorized as follows (Figures 4 through 6):

- I: A bony defect with a base width of 5 mm or more.
- II: A bony defect with a base width of 3 mm or more, but less than 5 mm.
- III: A bony defect with a base width less than 3 mm.

Discussion

This review intended to assess the homogeneity of study designs with regard to the characteristics of vertical alveolar defects subjected to augmentation. The evaluated experiments with diverse augmentation techniques and materials differed in the extent of description of vertical defects' features. In order to elucidate the role of the recipient bed characteristics in the success of an augmentation proce-

‡‡ *References 13, 14, 16, 18, 19, 23, 29, 35, 48.*
§§ *References 13–15, 17, 18, 23, 29, 33, 46, 48, 51.*
‖‖ *References 22, 24, 36–38, 40–44, 47, 50, 52.*

TABLE 2

Description of vertical bone defects in onlay bone grafting studies

Author	Study Type*	No. of Vertical Cases*	Type of Edentulism†	Jaw‡	Site‡
Güven[15]	CR	1	Full	Mand	Ant
Moses et al[28]	CR	1	Full	Mand	Ant
Verhoeven et al[35]	PS	13	Full	Mand	NE
Bell et al[19]	RS	14	Full	Mand	NE
Nystrom et al[29]	PS	30	Full	Max	NE
Van der Meij et al[33]	RS	17	Full	Both	Ant
Cardaropoli[20]	CR	1	ID	Mand	Ant
Roccuzzo et al[30]	CCT	12 Cases of GBR; 12 cases of OBG.	ID	Both	Both
Moghadam[17]	CR	2	ID	Max Mand	Ant Ant
Fukuda et al[23]	PS	9	ID	NE	NE
Barone and Covani[13]	PS	37	Full NE for partial cases	Max	NE
Cordaro et al[46]	PS	9	FE ID	Both	Both
Schwartz-Arad and Levin[54]	RS	33	Full FE ID	NE	NE
Barone et al[14]	PS	19	NE	Max	NE
Amrani et al[48]	PS	12	NE	Both	NE
Proussaefs and Lozada[51]	PS	12	NE	Both	Both
Hising et al[16]	PS	10	NE	Both	NE

*Study type and no. of vertical cases: CCT indicates controlled clinical trial; CR, case report/case series; PS, prospective study; RS, retrospective study; GBR, guided bone regeneration; OBG, onlay bone grafting.

†Type of edentulism: FE indicates free end partial edentulism; ID, interdental edentulism; NE, not evaluable.

‡Jaw and site: Max indicates maxilla; Mand, mandible; Ant, anterior; Post, posterior.

§Defect height and width: D indicates descriptive; M, measurement; RB, residual bone.

‖Augmentation material and implant insertion: Allog indicates allogeneic; Autog, autogenous; EO, extraoral; IO, intraoral; Partic, particulate; PDGF, platelet-derived growth factor; Simul, simultaneous; Xenog, xenogenic.

¶Results: BH indicates bone height; BHG, bone height gain; BW, bone width; BWG, bone width gain; GF, graft failure; GR, graft resorption; Impl, implant; MBL, marginal bone loss around implants.

#All of the results for which time of assessment is not specified in the table were reported at the time of the second surgery for implant placement/membrane removal.

Table 2
Extended

Defect Height§	Defect Width§	Augmentation Material‖	Implant Insertion‖	Results¶#
D	NE	EO block (iliac)	Staged (6 mo)	Satisfactory results were achieved.
NE	NE	EO block (iliac)	Simul	No considerable GR was seen during the 17-y follow-up.
M RB 8.9 mm	D	EO block (iliac)	Simul	GR occurred mainly during the first years; 51% of the grafted BH remained after 10–11 y.
M >7 mm	NE	EO block (iliac)	Staged (4–6 mo)	Postoperative BHG was 12 mm, GR was 33% until impl placement and 7% after 2 y.
D	D	EO block (iliac)	Simul	MBL in the first 3 y was 4.6 mm.
D	D	EO block (iliac)	Simul	GR was 15% of the initial graft height. GF occurred in 1 case.
M 9 mm	D	Xenog block/ PDGF	Simul	At 6 mo, complete graft integration was seen in radiography.
M >4 mm	D	GBR (IO block-ramus/ Ti mesh) vs OBG (IO block-ramus)	Staged (4–6 mo)	BHG was 5.7 mm for the GBR vs 5.5 mm for OBG. GR was 13.5% for GBR vs 34.5% for OBG. GF in 1 patient in the OBG group.
D	D	IO block (ramus)	Staged (4–5 mo)	The ideal ridge volume was achieved.
D	D			
D	NE	IO block (chin)	Simul	GF occurred in 1 case. Excellent clinical and radiographic outcomes in 1.5- to 4.7-y follow–up.
D	NE	EO block (iliac)	Staged (4–5 mo)	GF in 3 patients.
D	D	IO block (ramus/ symphysis)	Simul	Mean BWG was 5 mm. Mean BHG was 2.2 mm. Percentage of GR before impl insertion was 23.5% of BW and 42% of BH. Greater amounts of GR in mand vs max.
D	D	IO block (ramus/ retromolar/ symphysis/ tuberosity)	Staged (5.2 mo)	GF in 1 case. Mean BHG was 5.6 mm. Mean BWG was 3.8 mm.
D	NE	Allog block	Staged (5 mo)	GF in 2 patients.
D	D	IO block (coronoid/ ramus)	Staged (5–6 mo)	Grafts were successful and implants were stable.
D	NE	IO block (ramus/chin)	Staged (4–8 mo)	GF occurred in 3 cases. BHG, 4–6 mo after surgery was 4.75 mm. GR rate was 17.4%.
NE	NE	Partic xenog with or without partic autog + thrombin solution	Simul staged (11.9 mo)	MBL 1 y after loading was <1 mm for 90% of impls, advanced resorption was seen around 2 impls. MBL after 3 years was <1 mm for 82% of impls.

dure based on evidence, this review also evaluated the accomplished results of the included studies with different augmentation techniques; whenever possible, an interstudy comparison was also performed. Bone graft survival was evaluated as one of the major criteria of success (Tables 2 and 3). Among the included studies in this review, a total of 12 cases of bone graft failure were reported with the OBG technique[13,14,18,23,30,33,51]; however, due to lack of data in 9 cases,[13,14,18,51] it could not be determined if the failure was related to the augmentation of a full jaw or a single-tooth missing area. Similarly, 2 cases of bone graft failure were associated with GBR, both of which belonged to studies with unclear information regarding the type of edentulism.[39,47] The amount of graft resorption was another criterion reported in the assessed experiments, from which 2 studies with similar techniques could be compared. These studies, each including 12 cases of OBG with intraoral autogenous bone grafts followed by staged implant insertion, reported different amounts of graft resorption at the time of implant placement (Table 2).[30,51] Augmentation of interdental bone defects with an initial vertical deficiency of more than 4 mm had led to 34.5% graft resorption.[30] In the other

TABLE 3

Description of vertical bone defects in guided bone regeneration studies

Author	Study Type*	No. of Vertical Cases*	Type of Edentulism†	Jaw‡	Site‡	Defect Height§	Defect Width§
Heberer et al[24]	PS	14	Full	Max	Ant	M RB < 5 mm	NE
Lozada and Proussaefs[27]	CR	1	Full	Max	NE	D	D
Trombelli et al[32]	CR	1	FE	Mand	Post	M RB 7 mm	M 5 mm
Fontana et al[22]	PS	10	FE	Mand	Post	M > 3 mm	NE
Simion et al[36]	PS	10	FE	Mand	Post	M 2–7 mm SA impl	NE
Longoni et al[26]	CR	2	FE	Mand	Post	M RB 6 mm	NE
Vassos[34]	CR	1	FE	Mand	Post	M 5 mm	M 12 mm
Cornelini et al[21]	CR	1	FE	Mand	Post	M 4–7 mm SA impl	D
Stiegmann[31]	CR	1	ID	Max	Ant	M 13 mm	M 2 mm
Roccuzzo et al[30]	CCT	12 Cases of GBR; 12 cases of OBG	ID	Both	Both	M >4 mm	D
Kaufman and Wang[25]	CR	2	ID	Max	Ant	M 6–7 mm	D
Maiorana et al[40]	PS	14	Full NE in partial cases	Max	Both	D	D
Urban et al[45]	RS	36	Full NE in partial cases	Both	NE	M 2–12 mm	NE
Louis et al[39]	RS	45	Full NE in partial cases	Both	NE	D	NE
von Arx and Kurt[47]	PS	16	Full NE in partial cases	Both	Both	D	D
Le et al[38]	PS	15	FE ID	Both	Both	M >7 mm	M <4 mm
Peleg et al[41]	PS	25	FE ID	Both	Both	M <3 mm	M <5 mm
Pieri et al[42]	PS	19	FE ID	Both	Both	M RB <9 mm	M RB <5 mm
Proussaefs and Lozada[43]	PS	17	FE ID	Both	Both	D	NE
Artzi et al[37]	PS	10	FE ID	Both	Post	M 5–8 mm	D
Ueda et al[44]	PS	8	Full FE ID	Both	Both	M 5 mm SA impl	D
Langer et al[50]	PS	8	NE	NE	NE	M 3–9 mm	NE
Canullo et al[49]	RS	10	NE	NE	NE	M 3–9 mm SA impl	D
Roccuzzo et al[52]	PS	18	NE	Both	NE	M >4 mm	D

*Study type and no. of vertical cases: CCT indicates controlled clinical trial; CR, case report/case series; PS, prospective study; RS, retrospective study; GBR, guided bone regeneration; OBG, onlay bone grafting.

†Type of edentulism: FE indicates free end partial edentulism; ID, interdental edentulism; NE, not evaluable.

‡Jaw and site: Max indicates maxilla; Mand, mandible; Ant, anterior; Post, posterior.

§Defect height and width: D indicates descriptive; Impl, implant; M, measurement; RB, residual bone; SA, supra-alveolar.

‖Augmentation material and implant insertion: Allog indicates allogeneic; Autog, autogenous; EO, extraoral; ePTFE, expanded poly tetrafluoroethylene; IO, intraoral; Partic, particulate; RM, resorbable membrane; Simul, simultaneous; Ti, titanium; Xenog, xenogenic.

¶Results: BHG indicates bone height gain; BWG, bone width gain; GF, graft failure; GR, graft resorption; MBL, marginal bone loss around implants.

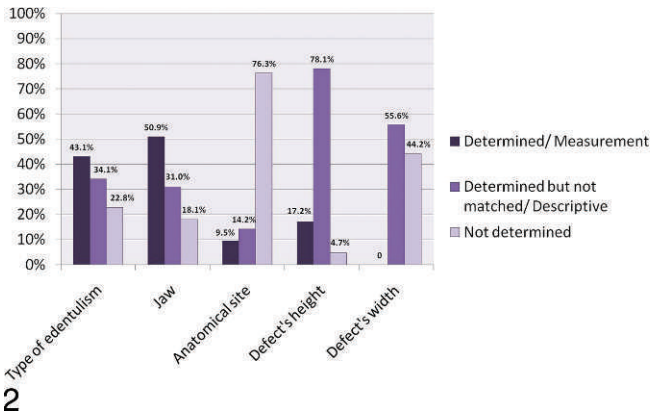
#All of the results for which time of assessment is not specified in the table were reported at the time of the second surgery for implant placement/membrane removal.

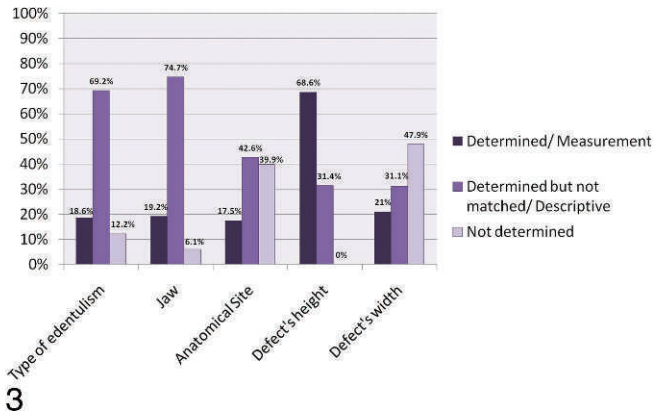
Table 3
Extended

Augmentation Material‖	Implant Insertion‖	Results¶#
EO blocks (iliac) + membrane vs periosteum	Staged (3 mo)	GR rate was 1.2 mm. There was no significant difference between the 2 groups.
Partic autog + Ti mesh	Staged (12 mo) mesh removal (7 mo)	BHG was 10 mm.
Partic autog + ePTFE	Staged (9 mo)	Bone contour remained stable during the 3-y follow-up.
Partic autog vsPartic allog + ePTFE	Staged (6 mo)	Allog: BHG was 4.7 mm. MBL was 1.26 mm at second surgery. Autog: BHG was 4.1 mm. MBL was 0.84 mm at second surgery.
Partic autog or mixture of partic autog/xenog + ePTFE	Simul staged (6–9 mo)	Mean BHG was 3.15 mm in the mixture group and 3.86 mm in autog group.
Allog block + Ti mesh	Staged (5 mo)	BHG was 4 mm.
IO block (ramus) + membrane on impl	Simul	-
ePTFE on SA impl	Simul	Bone augmentation occurred up to the most coronal thread.
Xenog block + RM	Staged (6 mo)	Bone was augmented to the level of adjacent teeth. MBL after 1 y was < 1 mm.
GBR (IO block-ramus/Ti mesh) vs OBG (IO block-ramus)	Staged (4–6 mo)	BHG was 5.7 mm for the GBR vs 5.5 mm for OBG. GR was 13.5% for GBR vs 34.5% for OBG. GF in 1 patient in the OBG group.
ePTFE + IO block (chin)	Staged (5 mo)	BWG was 6 mm. BHG was 4–5 mm.
Ti mesh + mixture of partic autog/xenog	Staged (6 mo)	Considerable bone augmentation was noted.
Partic autog. + ePTFE	Simul staged (6–9 mo)	BHG in single tooth group was 4.7 mm, in multiple teeth group was 5.1 mm, and in sinus cases 7.4 mm. GR after 1 y was 1.01 mm and not significant between the 3 groups.
Partic autog + Ti mesh	Staged (6–9 mo)	Max BHG in partial edentulous cases was 11.33 mm and in full cases 14.3 mm. Mand BHG in partial edentulous cases was 14 mm and in full cases 13.71 mm. GF occurred in 1 patient.
IO Block (retromolar, chin, osteotomy site) + Ti mesh	NE	GF in 1 patient. GR was <10% in 3 patients in C cases. In 1 patient, half of the graft was lost.
Partic allog + membrane on Ti screw	Staged	Mean BHG was 9.7 mm; 2 patients required second graft procedure.
Allog block + allog membrane	Staged (3–4 mo)	Mean BHG was 2.3 mm. 2.5-mm GR was observed in 1 case.
Mixture of partic autog/xenog + Ti mesh	Staged (8–9 mo)	Mean BHG was 3.71 mm. Mean BWG was 4.16 mm. MBL after 2 y was <1.5 mm in 88.6% impl and >2 mm in 6.9% cases.
Mixture of partic autog/xenog + Ti mesh	Staged (5–15 mo)	Mean BHG was 2.86 mm. Mean BWG was 3.75 mm.
Partic xenog + Ti mesh	Staged (9 mo)	Mean BHG was 5.2 mm.
Injectable bone + membrane	Simul	Mean BHG was 5 mm after 4.8 mo. MBL 6 mo after loading was <1.5 mm.
Partic allog + RM/ePTFE	Simul staged (6–8 mo)	BHG was 2–8 mm. Marginal bone levels were stable during the 4- to 13-year follow-up.
Partic xenog + ePTFE on SA impl or screws	Staged (6–8 mo)	BHG was 5.3 mm.
IO block (symphysis/ramus/ angle) + Ti mesh	Staged (4–6 mo)	Mean BHG was 4.8 mm.

study, the amount of resorption was reported to be 17.4%[51]; however, unclear information on the augmented defects impeded any conclusion on the potential influence of the initial features of the defects on the different amounts of graft resorption observed in these 2 studies.

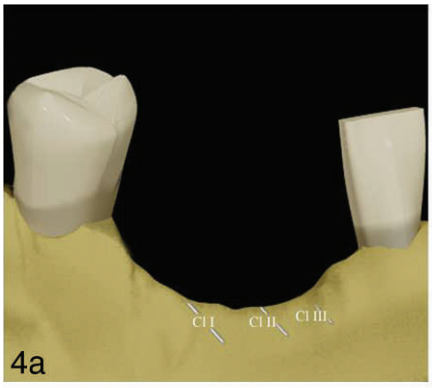
Although the diversity of technical details and other confounding factors did not allow for a comprehensive interstudy comparison in this review, the above-mentioned examples suggest that the conclusions made on the efficacy of different augmentation techniques might have differed if features of the augmented defects were considered in the experiments' designs. The proposed classifi-

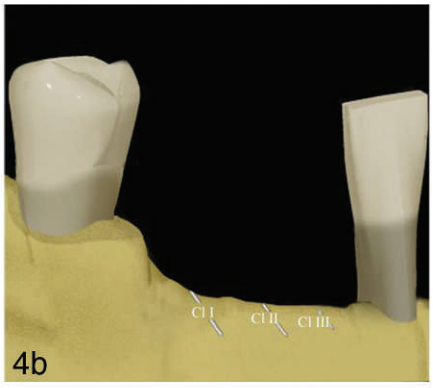


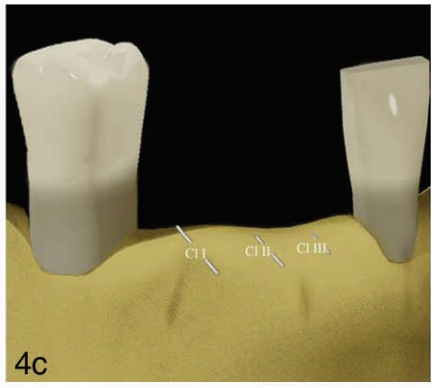


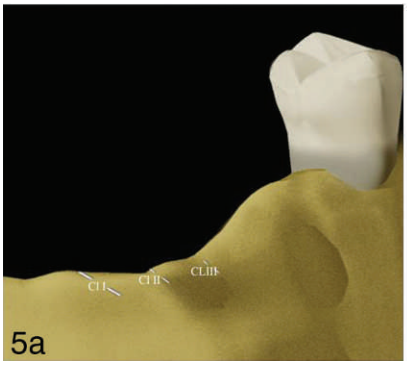
Figures 2 and 3. Figure 2. Characteristics of vertical defects' sites in the onlay bone grafting category. **Figure 3.** Characteristics of vertical defects' sites in the guided bone regeneration category.

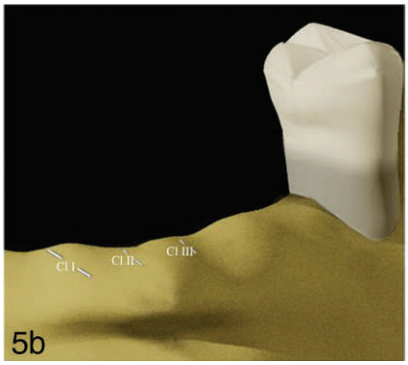
cation of vertical bone defects' morphology tends to homogenize the methods of future studies on vertical ridge augmentation. Morphologic classifications have been previously proposed for reconstruction and augmentation of peri-implant defects,[55] extraction socket defects,[56] and posterior maxillary defects with sinus involvement.[57] Tinti and Parma-Benfenati[6] introduced a classification of bone defects related to immediate or staged insertion of dental implants. Their classification of implant recipient sites with vertical or horizontal defects was based on the amount of deficiency;

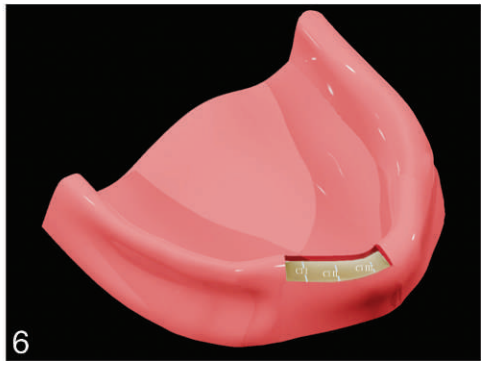












Figures 4–6. Figure 4. Interdental partial edentulism. (a) Class A: two-wall defect. (b) Class B: one-wall defect. (c) Class C: defect with no surrounding bony walls; width of the defect's base, Class I: $\geq$ 5 mm, Class II: $\geq$ 3 mm and $<$ 5 mm; Class III: $<$ 3 mm. **Figure 5.** Free end partial edentulism. (a) Class B: one-wall defect. (b) Class C: defect with no surrounding bony walls; width of the defect's base, Class I: $\geq$ 5 mm, Class II: $\geq$ 3 mm and $<$ 5 mm, Class III: $<$ 3 mm. **Figure 6.** Full edentulism. The defect is surrounded with no bony walls (Class C); width of the alveolar ridge Class I: $\geq$ 5 mm, Class II: $\geq$ 3 mm and $<$ 5 mm, Class III: $<$ 3 mm.

other morphologic features were not considered. Furthermore, complicated defects with combined vertical and horizontal deficiencies could not be evaluated based on this classification. In another classification proposed by Wang and Al-Shammari,[58] the ridge deficiencies were divided into 3 groups: horizontal, vertical, and combined defects. Each category was further categorized based on the amount of the deficiency. Nevertheless, other characteristics of the defects were not considered. To the extent of our knowledge, no classification has been suggested with regard to the morphologic characteristics of vertical defects.

The first feature included in the herein proposed classification is the number of bony walls surrounding a vertical alveolar defect. While the importance of space maintenance for subsequent bone regeneration has been clarified,[9,59,60] in defects associated with fewer numbers of bony walls, the stabilization of the initial blood clot and the maintenance of adequate space for bone regeneration is jeopardized due to the increased possibility of flap/membrane collapse.[59,61] In addition, in such defects, a smaller surface area would be involved in providing vascularization, which is deemed to negatively affect any sort of bone augmentation procedure.[62] Revascularization facilitates osteogenic cell condensation and differentiation, which will directly affect osteogenesis.[63] Successful bone graft integration and osteogenesis largely depends on the revascularization of the area.[62] Accordingly, in the proposed classification, the 2-wall class A defects might be the least demanding with regard to the reconstruction. In a fully edentulous ridge, no bony wall surrounds the defect, and the vascularization is merely provided by the defect's base (a class C defect). However, as depicted in Figures 4 and 5, in partially edentulous areas, a conclusion cannot be made on the number of bony walls of a defect, unless the extent of bone resorption associated with the adjacent teeth is determined. According to the current review of literature, when edentulous ridges were subjected to reconstruction, this criterion seemed to have been neglected in most of the studies. In 87.8% of cases evaluated, only the type of edentulism was reported.

It should be noticed that in cases of immediate implant placement into extraction sockets or replacing failed implants, one of the buccal/labial or palatal/lingual plates might also be present, creating a 3-wall defect. However, these special types of defects have been properly categorized in the literature[55] and, therefore, were not the subject of this classification.

The second feature considered in the current classification is the width of the defect's base. Generally, a recipient site with more than 5 mm width is required for proper implant insertion.[57,61] In vertical defects that also lack sufficient width to accept implants, the augmentation procedure becomes complicated since both dimensions are required to be restored. It has been suggested that wide alveolar ridges have greater potency for bone regeneration compared to narrow sites.[8] Based on the current classification, class III defects with less than 3 mm width represent the so-called "knife-edge" ridges. In these narrow-based defects, decreased mass of the trabecular bone with greater vascularization and cellularity results in limited bone regeneration.[11] On the other hand, it has been proven that the width of the defects' base facilitates space provision and as a result, influences bone regeneration via GBR.[9]

Besides the above-mentioned morphologic features, the anatomic site of the defect might also influence bone regeneration. Anterior and posterior parts of the mandible and maxilla possess dissimilar bone qualities, hence different regenerative abilities.[12] Therefore, it is strongly recommended that the jaw and the anatomic area receiving an augmentation procedure be matched among cases within an experiment.

Another potential factor affecting bone regeneration is the length of the edentulous span that alters the surface area of a defect, hence influencing the degree of vascularization.[62] Various studies have demarcated this factor by using terms such as localized[3,43,64–67] or extensive ridge augmentation,[54,68] though these have not been explicitly defined. Localized defects seem to pertain to missing teeth areas within a range of 1 to 6 teeth,[43] while extensive augmentations often indicate a fully edentulous jaw.[68] The augmentation of extensive defects appears to be more challenging and more technique-demanding. GBR has been suggested as a suitable method for augmentation of localized defects.[69,70] While few experiments have used GBR for extensive reconstructions,[24,27] OBG appears to be more common for this type of defect.[15,19,28,29,33,35] Interestingly, extensive vertical

defects included in this review were mainly augmented using extraoral autogenous blocks from iliac crest.[15,19,24,28,29,33,35,71] This was explicable considering the greater amount of harvestable bone of extraoral sites in comparison to intraoral sites and the more favorable osteogenic potency of autogenous grafts in comparison to other types.[10] Nevertheless, the difference of revascularization between the short- and long-span defects has not been biologically elucidated; therefore, the current classification did not include this factor.

The amount of vertical deficiency indisputably affects the intricacy of reconstructive treatments.[6] This factor has been included in previous classifications, mainly with the aim of proposing more practicable treatment protocols.[6,58] The authors, however, believe that with the current state of literature, proposal of different treatment options based on the amount of vertical deficiency would largely reflect clinical experiences rather than be evidence-based. Therefore, this classification aimed to assist in determining the amount of augmentation that can be achieved with different augmentation methods/materials in a specific recipient bed that might facilitate clinical decision making for clinicians. Accordingly, the classification was not concentrated on suggesting definite treatment modalities for different amounts of vertical deficiencies. Rather, it was designed to refine the focus of future experiments on determining the potency of different methods and materials for vertically augmenting a recipient site with certain morphologic characteristics.

Conclusion

This review of literature demonstrated that information regarding the characteristics of the initial vertical defects is not comprehensively incorporated in most of the studies. The lack of consensus with regard to determining the most efficacious augmentation procedures might partially stem from this uneven methodologic quality of studies. The proposed classification considers 2 critical features of vertical defects—the number of surrounding bony walls and the width of the defects' base. The use of this classification in future experiments on augmentation techniques/materials might mitigate the confounding effect of recipient site's morphology on the accomplished results.

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Abbreviations

GBR: guided bone regeneration

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