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REVIEW

VERTICAL BONE AUGMENTATION WITH GUIDED BONE REGENERATION. A SCOPING REVIEW.

Aumento óseo vertical con regeneración ósea guiada. Scoping review.

Jaime Segovia-Chamorro.[1,2]
Natalia Faúndez-Moreno.[1]
Matías Valenzuela-Lezana.[1]
Hector Oñate.[3]

AFFILIATIONS:
[1]Departamento de Odontología Conservadora, Facultad de Odontología, Universidad Andrés Bello, Viña del Mar, Chile.
[2]Cátedra de Periodoncia, Facultad de Odontología, Universidad de Valparaíso, Valparaíso, Chile.
[3]Escuela de Ciencias de la Salud, Universidad de Viña del Mar, Viña del Mar, Chile.

CORRESPONDING AUTHOR:
Héctor Oñate. Escuela de Ciencias de la Salud, Universidad Viña del Mar, Agua Santa 7055, Sector Rodelillo, Viña del Mar, Chile. Phone: (56-9) 62144449. E-mail: hector.onate.n@gmail.com

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ABSTRACT:

Introduction: There are multiple techniques for vertical bone augmentation. Guided bone regeneration is one of them; however, the literature is diverse and includes different study designs, which makes it difficult to synthesize results.

Objective: To analyze the general technical characteristics, clinical results, and complications of vertical bone augmentation performed with guided bone regeneration in humans.

Material and Methods: This scoping review was based on the PRISMA-ScR guidelines. A search was performed in the Pubmed, Scielo, and Worldcat databases. Papers published from 1990 to April 2020 were included in the study. Research articles not conducted in humans or published in languages other than English and Spanish were excluded. Title and abstract were screened by two reviewers, then full studies were extracted, and data tabulated.

Results: 89 studies were included. The highest percentage reported having obtained a vertical bone increase of less than 5 mm and having used non-resorbable membranes. The most frequent type of graft is autogenous and combinations of grafts, the most common being autogenous with xenograft. All studies that reported bone stability of implants in regenerated bone were favorable, as was implant survival, reporting values between 83.8% and 100%. Membrane exposure is the most frequently reported complication, followed by infection or abscesses, and tissue dehiscence.

Conclusion: Vertical bone regeneration is a reliable technique, with high predictability and low incidence of complications compared to other vertical bone augmentation techniques.

KEYWORDS:

Bone regeneration; alveolar ridge augmentation; dental implantation; alveolar process; alveolar bone loss; review.

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RESUMEN:

Introducción: Existen múltiples técnicas para el aumento óseo vertical siendo una opción la regeneración ósea guiada, sin embargo, la literatura es diversa y con distintos diseños que dificultan la síntesis de resultados.

Objetivo: Analizar las características generales técnicas, resultados clínicos y complicaciones del aumento óseo vertical realizado con regeneración ósea guiada en humanos

Material y Métodos: Esta revisión de alcance se basó en la guía PRISMA-ScR. Se realizó una búsqueda en las bases de datos *Pubmed, Scielo* y *Worldcat*. Fueron incluidos aquellos publicados desde el año 1990 hasta abril de 2020. Se excluyeron los estudios no realizados en humanos o publicados en idiomas distintos al inglés y español. Dos revisores examinaron título y resumen, luego los estudios completos se extrajeron y se ordenaron los datos en tablas.

Resultados: 89 estudios fueron incluidos. El mayor porcentaje reportó haber obtenido un aumento óseo vertical menor a 5 mm y haber utilizado membranas no reabsorbibles. El tipo de injerto que más frecuente es el autógeno y las combinaciones de injertos, siendo el más común autógeno con xenoinjerto. Todos los estudios que reportaron estabilidad ósea de implantes en hueso regenerado fueron favorables, al igual que la supervivencia de implantes, reportando valores entre 83,8% y 100%. La exposición de membrana es la complicación que más se repite en los estudios, seguido por infección o abscesos y dehiscencia de tejidos.

Conclusión: La regeneración ósea vertical es una técnica confiable, con alta predictibilidad y baja inci-dencia de complicaciones en comparación a otras técnicas de aumento óseo vertical.

PALABRAS CLAVE:

Regeneración ósea; aumento de la cresta alveolar; implantación dental; proceso alveolar; pérdida de hueso alveolar; revisión.

INTRODUCTION.

As part of the post tooth-extraction phenomena, a decrease in the height and width of the alveolar bone may occur, which is aggravated if the extraction is performed for periodontal, endodontic, or traumatic causes, frequently requiring a bone augmentation to correct gingival contour, esthetics, and feasibility of implant insertion.[1]

In complex cases, it is not only necessary to perform horizontal bone augmentations, which have been more clinically and laboratory tested, but it is also necessary to perform vertical bone augmentation (VBA). VBA is any technique aimed at raising the recipient bone in a vertical dimension to receive dental implants of adequate length.[2] The quality of this increase is also relevant, since the implant installed in the site using VBA methods must prove successful in the long term.[3]

Over the past ten years, short- and long-term studies have shown guided bone regeneration (GBR) to be a successful and reliable technique for VBA and horizontal BA.[4] This technique involves filling the bone with autogenous bone and/or bone substitutes and lining the graft site with a resorbable or non-resorbable membrane to provide room and protection for regenerating tissues.[5]

One study concluded that vertical defects could be successfully treated with guided bone regeneration or block bone grafting and osteogenic distraction, but with a high rate of complications.[6] On the other hand, it has been shown that guided bone regeneration is the most reliable technique in terms of bone stability, as it causes less resorption, has o low rate of complications and morbidity.

Besides, in the mandibular area, regardless of the technique applied, the survival of the implant and the success rates are high in short-term eva-

luations, although studies on long-term results are still needed.[7]

Although almost thirty years have passed since the first articles on vertical regeneration, there is still little high-level evidence, due to the technical, methodological, and ethical difficulties to study vertical regeneration. Although there is a modest body of evidence, the methodological variety described in the papers and the lack of standardization make it necessary to conduct a comprehensive review of everything that has been documented on vertical bone regeneration in humans. This review, due to its characteristics, addresses the issue and improves the current knowledge in this area.

This scoping review seeks to analyze the general technical characteristics, clinical results, and complications of VBA performed with guided bone regeneration in humans available in the literature.

MATERIALS AND METHODS.

The present review was conceived as a scoping review or exploratory systematic review, using the reporting elements of systematic reviews and meta-analyses, and extension for scoping reviews (PRISMA-ScR).[8]

This scoping review was guided by the following research question "What are the general technical characteristics, clinical outcomes, and complications of vertical bone augmentation performed with guided bone regeneration in humans documented in the literature?"

Inclusion criteria

Studies were eligible for inclusion if they described vertical bone augmentation techniques with guided bone regeneration.

Those that only pointed out the concept, superficially described the subject or when the concept was just one more variable within the experiment were excluded, such as horizontal bone regeneration experiments that measured vertical and horizontal changes, but were not the result of vertical bone regeneration techniques.

All studies without time limitation were included, since the interest of this review is to show the behavior and progress of this technique over the years. Studies that were not conducted in humans and all those published in languages other than English and Spanish were excluded from the analysis.

Sources of Information and Search

The search was carried out in April 2020, in the following databases: *PubMed* and *SciELO*, and in gray literature. No limits were established with respect to the date of the articles or papers. The following concepts were used for the search terms: ((guided bone regeneration) AND vertical AND ridge augmentation). All citations were imported into Mendeley's web-based reference management software. Duplicate citations were removed. The results obtained from the search were recorded in the search flowchart according to the PRISMA-ScR guideline.

Selection of sources of evidence

For the first level of data collection, only the title and abstract were reviewed to avoid wasting resources on articles that did not meet the inclusion criteria. A title and abstract relevance screening form was created. The form was tested by 2 reviewers (NFM and MVL), in case of not reaching an agreement between them, a third reviewer (JSC) intervened.

Data tabulation process

All the articles and papers that were considered relevant after the selection underwent a complete review by the same two reviewers. In case of disagreement on data extraction, the third reviewer intervened to reach a consensus. The two reviewers had to discuss the results and update the data form constantly.

Data items

Data on the characteristics of each study were extracted, such as year of publication, study design, regenerated bone height, type of membranes used, type of grafts, bone stability, implant survival, number of implants placed, number of participating patients, follow-up period, number of surgeries, and complications.

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Summary of results

To synthesize the range of selected evidence, tables were designed and drawn up by the reviewers. These included the same categories mentioned in the data list, to organize the data and respond to the stated objectives.

RESULTS.

Literature search

A search was carried out in the *PUBMED* and *SciELO* databases; 223 studies were obtained. In addition, two studies were selected from the gray literature (Worldcat).

Of the 155 studies obtained, two were duplicates, 124 were excluded after analyzing the title and abstract, and ten when reviewing the full text for not meeting the inclusion criteria. Consequently, 89 studies were included in this review (Figure 1).

Characteristics of the studies

Of the total selected studies, the oldest was from 1994 and the most current from 2020. In relation to their design, 15 studies were case reports, 29 studies were case series, 13 systematic reviews and meta-analyses, ten narrative reviews, 15 clinical trials, six retrospective or prospective cohort studies, and one cross-sectional study (Table 1).

Regenerated bone height

Fifty-eight studies (65%) reported regenerated bone height values; 46.5% of the studies that reported VBA were case reports or case series reports; 17.2% of the studies were controlled clinical trials, 12% were narrative reviews, and 10.3% were cohort studies.

13.7% of the studies that reported regenerated bone height were systematic reviews. Among these, 50% reported an increase lower than 5mm, 37.5% reported an increase of up to 8mm, and 12.5% reported an increase greater than 10mm. Of the studies that reported a VBA greater than 10mm, two were case reports and one was a systematic review.

Most of the studies (74.1%) reported having obtained a VBA lower than 5mm, while 51.7% of the studies reported a VBA greater than or equal to 5mm and up to 10mm.

Few studies (5.1%) reported having obtained a VBA greater than 10mm.

Membrane type

Eighty-six studies reported the type of membrane used (96.6%); 62.8% of the studies used non-resorbable membranes, 15.1% of the studies used resorbable membranes, while 22.1% of the studies used both types of membrane.

Reported regenerated bone height values that were clinically measured in studies using resorbable membranes ranged between 1.8mm and 7.5mm, while in studies using non-resorbable membranes, they were between 2mm and 15mm. Ten percent of the studies used high-density polytetrafluoroethylene (d-PTFE) membranes with a regenerated height ranging between 2mm and 6mm. On the other hand, 40% of the studies used expanded polytetrafluoroethylene (e-PTFE) with a regenerated height ranging between 1.7mm and 14.3mm.

Bone graft type

Eighty-five studies reported the type of bone graft used (95.5%); 66.2% of the studies used autogenous graft, 48.3% used xenograft, 33.7% used allograft, and 5.6% used alloplastic graft.

Most of the studies used combinations of grafts; autogenous bone with xenograft was the most commonly used, with anorganic bovine bone being the most used xenograft.

Bone stability in grafted bone

Thirty-eight studies (42.6%) reported information on bone stability, all were favorable. Only twelve studies (13.4%) mentioned that they had good bone stability or indicated bone resorption in mm, while 26 studies (29.2%) reported bone stability per unit of time (Table 2).

The marginal bone loss reported in the first year always turned out to be higher in contrast to that of the following years, which was considerably lower. The study that reported the greatest stability had a marginal bone loss of 0.3 mm in the first year. The study that reported good bone stability over a longer period had a follow-up of 14 years.

Table 1. Study designs and main results.

TYPE	AUTHOR/ YEAR	TITLE	REGENERATED BONE HEIGHT (MM)	MEMBRANE TYPE	TYPE OF GRAFTS	NUMBER OF IMPLANTS	FOLLOW-UP	NUMBER OF PATIENTS
Case reports	La Monaca et al.[9] 2019	Vertical Guided Bone Regeneration with Mineralized Cancellous Bone Allograft in a Severe Anterior Maxillary Defect: A Clinical Report with 14-Year Follow-Up.	Does not report	e-PTFE	Cancellous bone allograft	2	14 years	Does not report
	Al-Askar et al.[11] 2018	Feasibility of using allograft bone with resorbable collagen membrane for alveolar ridge vertical defect augmentation for dental implant placement in Patient with Aggressive Periodontitis: A case report.	Does not report	Resorbable collagen	Allograft	1	Over 12 months	Does not report
	Baltacioğlu et al.[10] 2017	Peri-implant plastic surgery techniques to hard and soft tissue augmentation in implant rehabilitation.	3 mm (maxillary sinus floor augmentation)	d- PTFE	Freeze-dried bone allograft	6	12 months	Does not report
	Alagl et al.[12] 2018	Localized ridge augmentation in the anterior maxilla using titanium mesh, an alloplast, a nano-bone graft: a case report.	10 mm	Titanium	Alloplastic mixed with graft (silica gel with hydroxyapatite crystals)	1	up to 12 years	Does not report
	Ghensi et al.[13] 2017	Management of the exposure of a dense PTFE (d-PTFE) membrane in guided bone regeneration (GBR): a case report.	Does not report	High-density PTFE (d-PT FE)	Autologous bone combined with deproteinized bovine bone	2	2 years	Does not report
	Suzuki et al.[14] 2017	Narrow-Diameter Implants: Dual Function as a Tent Pole for Vertical Ridge Augmentation and a Guide for Definitive Implant Position.	10.9 mm	non-absorbable reinforced with titanium	Anorganic bovine bone mineral	1	Up to 5 years	Does not report
	Simion et al.[15] 2015	The Association of Guided Bone Regeneration and Enamel Matrix Derivative for Suprabony Reconstruction in the Esthetic Area: A Case Report.	Does not report	e-PTFE reinforced with titanium	Autogenous bone and deproteinized bovine bone mineral	2	12 months	Does not report
	Cucchi et al.[23] 2014	Vertical Guided Bone Regeneration using Titanium-reinforced d-PTFE Membrane and Prehydrated Corticocancellous Bone Graft.	Does not report	d-PTFE reinforced with titanium	Pig bone	1	Up to 24 months	Does not report
	Speroni et al.[16] 2011	Hard and soft tissue augmentation in implant surgery: a case report.	Does not report	e-PTFE	Autologous and xenograft	6	12 months	Does not report
	Brugnami et al.[18] 2011	A Case report of bilateral mandibular Vertical guided bone regeneration with and activated platelet rich plasma.	Does not report	Non-absorbable expanded polytetrafluoroethylene (e-PTFE) reinforced with titanium	Autogenous bone + autologous PRP + activated (Ca chloride and bovine thrombin)	Does not report	6 months	Does not report
	Naruse et al.[17] 2010	Advanced alveolar bone resorption treated with implants, guided bone regeneration, and synthetic grafting: a case report.	15 mm	Titanium micromesh	non-resorbable and absorbable hydroxyapatite and demineralized lyophilized bone graft	3	4 years	Does not report
	Hur et al.[19] 2010	Double flap incision design for guided bone regeneration: a novel technique and clinical considerations.	4 to 5 mm	Non-expanded polytetrafluoroethylene (e-PTFE) reinforced with titanium	Freeze-dried bone allograft	4	1.5 years approx	Does not report

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	Urban et al. [xxx] 2009	Simultaneous vertical guided bone regeneration and guided tissue regeneration in the posterior maxilla using recombinant human platelet-derived growth factor: a case report (20)	Does not report	e-PTFE reinforced with titanium	Autogenous bone, anorganic bovine bone and rhPDGF-BB	3	12 months	Does not report
	Tinti et al. [xxx] 2001	Treatment of peri-implant defects with the vertical ridge augmentation procedure: a patient report (21)	Does not report	e-PTFE reinforced with titanium	Autogenous bone	3	12 months	Does not report
	Cornelin et al. [xxx] 2000	Simultaneous implant placement and vertical ridge augmentation with a titanium-reinforced membrane: a case report (22)	Bone augmentation without graft up to 3 mm	Expanded polytetrafluoroethylene (e-PTFE) reinforced with titanium	x	2	Over 32 months	Does not report

Type	Author/ Year	Title	Regenerated bone height (mm)	Membrane type	Type of grafts	Number of implants	Follow-up	Number of patients
Case Series	Malik et al.[24] 2019	Evaluation of Alveolar Ridge Height Gained by Vertical Ridge Augmentation Using Titanium Mesh and Novabone Putty in Posterior Mandible.	Mean 4.825 ± 1.1387 mm	Titanium mesh	NovaBone® dental putty	x	6 months	20
	Tolstunov et al.[25] 2019	Bone Augmentation Techniques for Horizontal and Vertical Alveolar Ridge Deficiency in Oral Implantology.	Does not report	Non-resorbable with or without titanium	Autogenous, xenogenic or allograft in defects less than 5 mm	5	Does not report	2
	Zhang et al.[26] 2019	The application of a newly designed L-shaped titanium mesh for GBR with simultaneous implant placement in the esthetic zone: A retrospective case series study.	3.61 ± 1.50 mm	Titanium mesh - collagen membrane	Deproteinized bovine bone	16	41 months	12
	Ciocca et al.[27] 2018	Prosthetically CAD-CAM-Guided Bone Augmentation of Atrophic Jaws Using Customized Titanium Mesh: Preliminary Results of an Open Prospective Study.	Mandibular: 1.72 to 4.1 mm (mean 3.83 mm). Maxillary: 2.14 to 6.88 mm (mean: 3.95 mm)	Customized titanium mesh by CAD/CAM	Particulate bone graft of autogenous bone and inorganic bovine bone in a 1:1 ratio	26	2 years	9
	Cho et al.[28] 2018	Guided bone regeneration using K-incision technique.	Does not report	D-PTFE reinforced with titanium or collagen membrane	Inorganic bovine bone minerals	4	Up to 5 years	3
	Hur et al.[29] 2017	Bone Resorption During Submerged Healing After Guided Bone Regeneration: A Prospective Case Series.	Does not report	Expanded polytetrafluoroethylene (e-PTFE) reinforced with titanium	Freeze-dried mineralized bone allograft	Does not report	6 months	16
	Urban et al.[30] 2016	Long-term Evaluation of Peri-implant Bone Level after Reconstruction of Severely Atrophic Edentulous Maxilla via Vertical and Horizontal Guided Bone Regeneration in Combination with Sinus Augmentation: A Case Series with 1 to 15 Years of Loading.	5.1 mm ± 1.8	d-PTFE or e-PTFE	Mixture of autogenous bone and anorganic bovine bone	122	12 to 180 months	16
	De Angelis et al.[31] 2015	Surgical combined approach for alveolar ridge augmentation with titanium mesh and rhPDGF-BB: a 3-year clinical case series.	Does not report	Titanium	Bovine derived xenograft + rhPDGF-BB	Does not report	3 years	2

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Merli et al.[32] 2015	Fence technique for localized three-dimensional bone augmentation: a technical description and case reports.	6.75 mm	Titanium osteosynthesis plate and collagen membrane	Combination of deproteinized bovine bone and autologous bone	13	12 months	6
Toffler et al.[33] 2015	Guided bone regeneration (GBR) using cortical bone pins in combination with leukocyte and platelet-rich fibrin (L-PRF).	Does not report	Pericardium membranes	Allograft and xenograft	4	Does not report	2
Urban et al.[34] 2014	Vertical ridge augmentation with titanium -reinforced, dense-PTFE membranes and a combination of particulated autogenous bone and anorganic bovine bone-derived mineral: a prospective case series in 19 patients.	Average gain 5.45 mm	d-PTFE reinforced with titanium	Combination of particulate autogenous bone and anorganic bovine bone mineral derivative	Does not report	12 months	19
Funato et al.[35] 2013	A novel combined surgical approach to vertical alveolar ridge augmentation with titanium mesh, resorbable membrane, and rhPDGF-BB: a retrospective consecutive case series.	8.6 ± 4.0 mm and in unexposed patients 8.8 ± 4.2 mm	Titanium mesh covered with resorbable cross-linked collagen membrane	Mixture of autogenous bone from the mandibular ramus with inorganic bovine bone, soaked in rhPDGF- BB for 0 min.	Does not report	1.5 years approx	19
Annibali et al.[36] 2012	Horizontal and vertical ridge augmentation in localized alveolar deficient sites: a retrospective case series.	Media 3.84 ± 1.09 mm (rango 1.5 a 6 mm)	Expanded polytetrafluoroethylene (e-PTFE) reinforced with titanium or resorbable membrane	Autogenous bone and frozen demineralized bone allograft	56	12 months	5
Langer et al.[37] 2010	Vertical ridge augmentation procedure using guided bone regeneration, demineralized freeze-dried bone allograft, and miniscrews: 4- to 13-year observations on loaded implants.	2 a 8 mm	Expanded polytetrafluoroethylene (e-PTFE) reinforced with titanium and resorbable	Demineralized freeze-dried bone allograft	15	4 to 13 years	8
Canullo et al.[38] 2008	Vertical Ridge Augmentation Around Implants by e-PTFE Titanium-Reinforced Membrane and Bovine Bone Matrix: A 24 , to 54-Month Study of 10 Consecutive Cases.	3 to 9 mm (mean 5.3 mm)	Titanium reinforced expanded polytetrafluoroethylene (e-PTFE)	Deproteinized bovine bone	24	36 months	10
Trombelli et al.[39] 2008	GBR and autogenous cortical bone particulate by bone scraper for alveolar ridge augmentation: a 2-case report.	3 a 4 mm	Titanium reinforced e-PTFE	Autogenous bone	1 per pacient	9 months	2
Windisch et al.[40] 2008	Reconstructive periodontal therapy with simultaneous ridge augmentation. A clinical and histological Case Series Report.	1.8 ± 1.8 mm	Collagen membrane	Natural bone mineral	x	2 years	8
Llambés et al.[41] 2007	Vertical guided bone regeneration with bioabsorbable barriers.	Ganancia ósea promedio 3 mm	Collagen membrane	Autogenous bone; when not enough, it is mixed with bovine bone	32	> 1 year	11
Kfir et al.[42] 2007	Minimally invasive guided bone regeneration.	2.4 a 5.1 mm	Biodegradable membrane (GTR)	Synthetic bone graft material with autologous fibrin.	12	Up to 12 months	11
Simion et al.[43] 2007	Vertical ridge augmentation by expanded-polytetrafluoroethylene membrane and a combination of intraoral autogenous bone graft and deproteinized anorganic bovine bone (Bio Oss.	3.15 mm (autogenous + bovine), 3.85 mm (autogenous)	e-PTFE	Combination of autogenous bone and deproteinized anorganic bovine bone	27	1 year approx	7

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Proussaefs et al.[44] 2003	The use of titanium mesh in conjunction with autogenous bone graft and inorganic bovine bone mineral (bio-oss) for localized alveolar ridge augmentation: a human study.	2.86 mm	Titanium mesh	Autogenous bone and inorganic bovine bone mineral	23	1 year approx	7
Shanaman et al.[45] 2001	Localized ridge augmentation using GBR and platelet-rich plasma: case reports.	Mean gain of 3 and 4 mm	e-PTFE reinforced with titanium	Mixture of frozen dry demineralized bone allograft and autogenous bone	3	12 months approx	3
Simion et al.[46] 1994	Vertical ridge augmentation using a membrane technique associated with osseointegrated implants.	3 to 4 mm	e-PTFE	Does not report	15	1 year approx	5
Rocchieta et al. [47] 2015	Vertical Bone Augmentation with an Autogenous Block or Particles in Combination with Guided Bone Regeneration: A Clinical and Histological Preliminary Study in Humans.	5.03 mm mean height gain	e-PTFE reinforced with titanium	Particulate autogenous bone	12 sites	Over 12 months	10
Kaner et al.[48] 2011	Soft tissue expansion with self-filling osmotic tissue expanders before vertical ridge augmentation: a proof of principle study.	Mean gain 7.5 ± 2.4 mm (range 3 to 12 mm)	Collagen	Ramus graft from patient's mandible, covered with granular bone substitute	53	2 years	12
Canullo et al.[49] 2010	Early implant loading after vertical ridge augmentation (VRA) using e-PTFE titanium-reinforced membrane and nano-structured hydroxyapatite: 2-year prospective study.	Mean gain of 5.6 mm	Expanded polytetrafluoroethylene (e-PTFE) reinforced with titanium	Mg-enriched nanostructured hydroxyapatite (Mg-eHAP)	42	2 years	20
Tinti et al.[50] 1998	Vertical ridge augmentation: surgical protocol and retrospective evaluation of 48 consecutively inserted implants (50)	5 and 7 mm	e-PTFE reinforced with titanium	Autogenous bone chips and particles	48	12 months	18
Piattelli et al.[51] 1996	Histological evaluation of freeze-dried dura mater (FDDMA) used in guided bone regeneration (GBR): a time course study in man.	Does not report	Lyophilized dura mater membranes	Autologous bone	x	12 months	26
Tinti et al.[52] 1996	Vertical ridge augmentation: what is the limit?	Mean 4.95 mm	e-PTFE reinforced with Ti	Autogenous bone	14	1 year	6

Type	Author/ Year	Title	Regenerated bone height (mm)	Membrane type	Type of grafts	Number of implants	Follow-up	Number of patients
Studies systematic reviews and meta-analyses	Urban et al.[6] 2019	Effectiveness of vertical ridge augmentation interventions: A systematic review and meta-analysis.	Average gain 3.5 mm absorbable and 4.42 mm	Non-absorbable Resorbable and nonresorbranes	Autogenous, xenogeneic, allogeneic bone	Does not report	Does not report	Does not report
	Saletta et al.[53] 2018	Quality assessment of systematic reviews on vertical bone regeneration.	2 to 8 mm	Does not report	Does not report	Does not report	Does not report	Does not report
	Wessing et al.[54] 2018	Guided bone regeneration with collagen membranes and particulate graft materials: a systematic review and meta-analysis.	4.25 mm with fixation membrane and 2.94 mm without fixation	Non-absorbable	Allogeneic, xenogeneic and alloplastic	Does not report	Does not report	Does not report

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	Elnayef et al.[7] 2017	Vertical Ridge Augmentation in the Atrophic Mandible: A Systematic Review and Meta -Analysis.	3.83mm mean gain	e-PTFE, titanium mesh, resorbable collagen mesh, growth factors-rich plasma	Allograft, autogenous bone, inorganic bovine bone mineral, deproteinized bovine bone mineral	Does not report	Does not report	Does not report
	Keestra et al.[3] 2016	Long-term effects of vertical bone augmentation: a systematic review.	Does not report	non-resorbable and resorbable mesh	Autogenous bone and allografts and combinations: autogenous + allograft and autogenous + xenograft	Does not report	Does not report	Does not report
	Al-Nawas et al.[55] 2014	Augmentation procedures using bone substitute materials or autogenous bone - a systematic review and meta-analysis.	Does not report	Does not report	Autologous bone and bone substitutes	Does not report	Does not report	Does not report
	Khojasteh et al.[56] 2013	Clinical importance of recipient site characteristics for vertical ridge augmentation: a systematic review of literature and proposal of a classification.	Up to 14.3 mm (highest value from various studies)	Titanium mesh and e-PTFE	Autogenous, xenogenic and allograft	Does not report	Does not report	Does not report
	Ricci et al.[57] 2013	Rehabilitation of deficient alveolar ridges using titanium grids before and simultaneously with implant placement: a systematic review.	Up to 8.8 mm	Titanium mesh	Autogenous bone and bone substitutes (separately and mixed)	Does not report	Does not report	Does not report
	Clementini et al.[58] 2012	Success rate of dental implants inserted in horizontal and vertical guided bone regenerated areas: a systematic review.	Does not report	Does not report	Does not report	Does not report	Does not report	Does not report
	Esposito et al.[59] 2009	The efficacy of horizontal and vertical bone augmentation procedures for dental implants - a Cochrane systematic review.	2.48 mm non-resorbable and 2.1 mm in resorbable	e-PTFE	Autogenous *versus* allogeneic	Does not report	Does not report	Does not report
	Esposito et al.[60] 2009	Interventions for replacing missing teeth: horizontal and vertical bone augmentation techniques for dental implant treatment.	Does not report	e-PTFE	Autologous bone, allograft	Does not report	Does not report	Does not report
	Rocchietta et al.[61] 2008	Clinical outcomes of vertical bone augmentation to enable dental implant placement: a systematic review.	Between 2 and 8 mm	Resorbable collagen mesh, e-PTFE reinforced with titanium	Autogenous, allograft, deproteinized bovine bone	Does not report	Does not report	Does not report
	Esposito et al.[2] 2007	The efficacy of various bone augmentation procedures for dental implants: a Cochrane systematic review of randomized controlled clinical trials.	Does not report	Resorbable and non-resorbable Ti-reinforced barriers	Particulate autogenous bone compared with intraoral grafts	Does not report	Does not report	Does not report
Narrative review studies	Miller et al.[62] 2020	Indications for Simultaneous Implantation and Bone Augmentation Using the Allograft Bone Ring Technique.	Resorbable collagen membrane	Does not report	Autogenous bone mixed with allograft	Does not report	Does not report	Does not report
	Cuchi et al.[63] 2019	Statements and Recommendations for Guided Bone Regeneration: Consensus Report of the Guided Bone Regeneration Symposium Held in Bologna, October 15 to 16, 2016.	2 to 5.6 mm	Resorbable and non-resorbable	Autogenous bone is the gold standard. Allograft, xenograft and mixtures	Does not report	Does not report	Does not report

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	Plonka et al.[64] 2018	Decision Tree for Vertical Ridge Augmentation.	According to defect: small 3mm, medium 5.45mm, long and long	Absorbable and non-absorbable for small, non-absorbable for medium vine bone	Combination of autogenous bone and deproteinized bo-	Does not report	Does not report	Does not report
	Rocchietta et al.[65] 2018	Vertical ridge augmentation in the esthetic zone.	4 mm approximately	Titanium reinforced expanded polytetrafluoroethylene (e-PTFE) mesh	Mix of autologous bone chips and deproteinized bovine bone	Does not report	Does not report	Does not report
	Urban et al.[66] 2017	Principles for Vertical Ridge Augmentation in the Atrophic Posterior Mandible: A Technical Review.	Does not report	Ti-reinforced PTFE	Autogenous bone	Does not report	Does not report	Does not report
	Soldatos et al.[67] 2017	Limitations and options using resorbable *versus* nonresorbable membranes for successful guided bone regeneration.	Mean bone gain case 1: 5 to 6 mm (resorbable) and case 2: 3 mm (Ti)	Resorbable and non-resorbable membranes	Mixture of inorganic bovine bone matrix and autogenous bone	Does not report	Does not report	Does not report
	Urban et al.68 2016	Surgical Management of Significant Maxillary Anterior Vertical Ridge Defects.	Does not report	Ti-reinforced membrane	Mixture of autogenous bone and anorganic bovine bone particles	Does not report	Does not report	Does not report
	Jensen et al.[69] 2010	Bone augmentation procedures in localized defects in the alveolar ridge: clinical results with different bone grafts and bone-substitute materials.	4.8 mm	Resorbable (2.8mm) and non-resorbable (2.1mm) membrane	Autograft, xenograft, alloplast and mixtures	Does not report	Does not report	Does not report
	Bernstein et al.[70] 2006	Vertical bone augmentation: where are we now?	Up to 5.8 mm	Resorbable membrane supported by Ti micro mesh.	Autogenous bone and bovine bone	Does not report	Does not report	Does not report
	Nappe et al.[71] 2013	Regeneración ósea guiada para el aumento vertical del reborde alveolar.	2 to 8 mm	Resorbable and non-resorbable membranes	Autogenous bone, deproteinized bovine bone	Does not report	Does not report	Does not report

Type	Author/ Year	Title	Regenerated bone height (mm)	Membrane type	Type of grafts	Number of implants	Follow-up	Number of patients
Clinical trial studies	Byun et al.[72] 2020	Soft tissue expander for vertically atrophied alveolar ridges: Prospective, multicenter, randomized controlled trial.	5.12 to 4.22 mm	PTFE	Xenogeneic	Does not report	Up to 19 months	23 from each of two groups
	Cuchi et al.[73] 2019	Histological and histomorphometric analysis of bone tissue after guided bone regeneration with non-resorbable membranes *versus* resorbable membranes and titanium mesh.	Does not report	Group A: Ti-PTFE and group B: collagen + Ti mesh	Autogenous bone + allograft	1 or more for each patient	at least 1 year	20 from each group (2 groups)
	Jiang et al.[74] 2017	Hard tissue volume stability of guided bone regeneration during the healing stage in the anterior maxilla: A clinical and radiographic study.	Does not report	collagen membrane	Particulate bovine bone graft	Does not report	6 months	14 for each group (2 groups)
	Rokn et al.[75] 2018	Comparing 4-mm dental implants to - longer implants placed in augmented bones in the atrophic posterior mandibles: One-year results of a randomized controlled trial.	2.2 mm	membrane. resorbable (CenoMembrane)	Particulate allograft mixed with autogenous bone	From 2 to 4 implants	1 year	11

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Cucchi et al.[4] 2017	Evaluation of complication rates and vertical bone gain after guided bone regeneration with non-resorbable membranes versus titanium meshes and resorbable membranes. A randomized clinical trial (4)	Group A: 2.7 mm - 5.8 mm; group Group B: 2.6 mm - 6.3 mm	A: dense non-resorbable membranes reinforced with Ti (d-PTFE). B: Ti meshes covered by cross-linked collagen membrane	50% autogenous bone and 50% bone allograft were mixed	108	1 year	20 from each group (2 groups)
Roccuzzo et al.[76] 2016	Long-term outcomes of implants placed after vertical alveolar ridge augmentation in partially edentulous patients: a 10-year prospective clinical study (76)	Minimum 4 mm	Titanium micromesh	Particulate autogenous bone	82	10 years	41
Simion et al.[77] 2016	Turned Implants in Vertical Augmented Bone: A Retrospective Study with 13 to 21 Years Follow-Up (77)	Does not report	e-PTFE reinforced with titanium	Autogenous bone or mixture of autogenous bone with deproteinized bovine bone mineral	91	13 to 21 years	33
Poli et al.[78] 2014	Alveolar ridge augmentation with titanium mesh. A retrospective clinical study.	Does not report	Titanium mesh	mixture of autologous bone graft and deproteinized anorganic bovine bone	20	12 to 128 months (mean 88 months)	13
Merli et al.[79] 2014	Bone level variation after vertical ridge augmentation: resorbable barriers *versus* titanium-reinforced barriers. A 6-year double-blind randomized clinical trial.	1.7 to 4.2 mm	Collagen membrane supported by an osteosynthesis plate and e-PTFE membrane reinforced with titanium	Particulate autogenous bone	42 (test), 55 (control)	6 years	11 per group (2 groups)
Jung et al.[8'0] 2013	Cone beam computed tomography evaluation of regenerated buccal bone 5 years after simultaneous implant placement and guided bone regeneration procedures-a randomized, controlled clinical trial.	4.3 ± 1.5mm and 4.8 ± 2.6mm	Polyethylene glycol membrane and membrane. porcine collagen	Xenogenic bone mineral	Does not report	5 years	37
Ronda et al.[81] 2014	Expanded *versus* dense polytetrafluoroethylene membranes in vertical ridge augmentation around dental implants: a prospective randomized controlled clinical trial.	Mean 5.49 mm (test: d-PTFE) 4.91 mm (control: e-PTFE)	e-PTFE and d-PTFE	Composite bone graft:(50% autologous bone and 50% mineralized bone allograft)	78	15 a 37 months	23
Fontana et al.[82] 2008	Clinical and histologic evaluation of allogeneic bone matrix *versus* autogenous bone chips associated with titanium-reinforced e-PTFE membrane for vertical ridge augmentation: a prospective pilot study.	Mean test group: 4.7 mm. Control group: 4.1mm	Titanium reinforced expanded polytetrafluoroethylene (e-PTFE) membrane	Allogeneic bone matrix (test) and auto genous bone chips (control)	25	1 to 3 years	5
Jung et al.[83] 2009	A randomized, controlled clinical trial to evaluate a new membrane for guided bone regeneration around dental implants.	4.21 mm (control group) and 5.63 mm (test group)	Synthetic bioresorbable polyethylene glycol (PEG) hydrogel membrane (test) and collagen membrane (control)	Bovine bone	Does not report	6 months	37
Merli et al.[84] 2007	Vertical ridge augmentation with autogenous bone grafts: resorbable barriers supported by ostheosynthesis plates *versus* titanium-reinforced barriers. A preliminary report of a blinded, randomized controlled clinical trial.	2.2 mm absorbable membrane, 2.5 mm non-absorbable membrane	Collagen supported by osteosynthesis plates or by e-PTFE reinforced with titanium	Particulate autogenous bone graft	77 (34 absorbable and 43 non-absorbable)	20 months	22
Brown et al.[85] 2016	Development and Characterization of a Magnesium/Polymer Composite for Guided Bone Regeneration.	.5; 2.4; 2.6 mm	Mg screws, allograft	Mg screws, allograft	Does not report	Does not report	Does not report

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Type	Author/ Year	Title	Regenerated bone height (mm)	Membrane type	Type of grafts	Number of implants	Follow-up	Number of patients
Cohort studies	Park et al.[86] 2017	Dimensional alterations following vertical ridge augmentation using collagen membrane and three types of bone grafting materials: A retrospective observational study.	3.9mm (particulate bone substitute) 4.5mm (allogenous) and 5.1 mm (autogenous)	Collagen membrane, and Ti mesh for particulate bone. Autogenous bone, allogenic bone, and particulate bone substitute	15 autogenous, 26 halogenous and 18 particulate substitute	Does not report	3 years	32
	Gultekin et al.[5] 2017	Clinical and 3-Dimensional Radiographic Evaluation of Autogenous Iliac Block Bone Grafting and Guided Bone Regeneration in Patients With Atrophic Maxilla.	5.07 ± 0.97 mm	PTFE	Autogenous and deproteinized bovine bone	174	Over 12 months	39
	Todisco et al.[87] 2010	Early loading of implants in vertically augmented bone with non-resorbable membranes and deproteinised anorganic bovine bone. An uncontrolled prospective cohort study.	5.2mm mean gain	Deproteinized anorganic bovine bone	Non-resorbable e-PTFE reinforced with titanium	64	1 year	20
	Merli et al.[88] 2006	Vertical bone augmentation with dental implant placement: efficacy and complications associated with 2 different techniques. A retrospective cohort study.	Does not report	Expanded polytetrafluoroethylene (e-PTFE) reinforced with titanium and collagen membrane	Autogenous particulate bone graft	29 (18 non-resorbable, 11 resorbable)	1 year	19
	Chiapasco et al.[89] 2004	Alveolar distraction osteogenesis versus vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: a 1-3-year prospective study on humans.	Does not report	e-PTFE	Autogenous bone	59 (25 group 1; 34 group 2)	1 a 3 years	21
	Parma-Benfenati et al.[90] 1999	Histologic evaluation of guided vertical ridge augmentation around implants in humans.	Does not report	Expanded polytetrafluoroethylene (e-PTFE) reinforced with titanium	Autogenous bone chips and/or powder	30	Over 1 year	6

Table 2. Studies that reported bone stability.

AUTHORS	YEAR	TITLE	BONE STABILITY	FOLLOW-UP
Miller et al.[62]	2020	Indications for Simultaneous Implantation and Bone augmentation using the allograft bone ring technique.	Good primary stability	x
Zhang et al.[26]	2019	The Application of a newly designed L-shaped titanium mesh for GBR with simultaneous implant placement in the esthetic zone: a retrospective Case Series Study.	Vestibular bone resorption was −0.81 ± 1.00 mm	41 months
Ghensi et al.[13]	2017	Management of the exposure of a dense PTFE (d-PTFE) membrane in guided bone regeneration (GBR): a case report.	Stable reconstruction	2 years
Elnayef et al.[7]	2017	Vertical Ridge Augmentation in the atrophic mandible: a systematic review and (minor resorption) meta-analysis.	GBR is the most reliable and stable technique	Does not report
Roccuzzo et al.[7]	2016	Long-term outcomes of implast placed after vertical alveolar augmentation in a partially edentulous patients: a 10-year prospective clinical study (76) meta-analysis.	Mean interproximal bone loss 0.57 mm to 0.58 mm	10 years
Urban et al.[30]	2016	Long-term Evaluation of peri-implant bone level after reconstruction of severely atrophic edentulous maxilla via vertical and horizontal guided bone regeneration in combination with sinus augmentation: a case series with 1 to 15 years of loading.	Pérdida ósea periimplantaria media 1.4 ± 1 mm	12 to 180 months
Poli et al.[78]	2014	Alveolar ridge augmentation with titanium mesh. A retrospective clinical study.	Mean peri-implant bone loss mesial 1.7 mm and distal 1.9 mm (mean 88 months)	12 to 128 months
Annibali et al.[36]	2012	Horizontal and vertical ridge augmentation in localized alveolar deficient sites: a retrospective case series.	Marginal bone resorption after definitive prosthetic loading: 0.86 to 1.32 mm (M) and 0.83 to 1.40 mm (D)	12 months
Hur et al.[19]	2010	Double flap incision design for guided bone regeneration: a novel technique and clinical considerations.	Good primary stability	1.5 years aprox.
Fontana et al.[82]	2008	Clinical and histologic evaluation of allogeneic bone matrix *versus* autogenous bone chips associated with titanium-reinforced e-PTFE membrane for vertical ridge augmentation: a prospective pilot study.	Clinically stable: marginal bone loss around implants: GP:1.26mm, CG: 0.84mm	1 to 3 years
Jung et al.[83]	2009	A randomized, controlled clinical trial to evaluate a new membrane for guided bone re-regeneration around dental implants.	Greater stability in PEG than in m. collagen	6 months
Chiapasco et al.[89]	2004	Alveolar distraction osteogenesis *versus* vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: a 1-3-year prospective study on humans.	Total bone resorption at the end of the resorption period: 2.96 mm	1 to 3 years
La Monaca et al.[9]	2019	Vertical Guided Bone Regeneration with mineralized cancellous bone allograft in a severe anterior maxillary defect: a clinical report with 14-year follow up.	Stable at 14 years of follow-up	14 years

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Plonka et al.[64]	2018	Decision Tree for Vertical Ridge Augmentation.	Stability for 4 to 5 years has been maintained	Does not report
Rokn et al.[75]	2018	Comparing 4-mm dental implants to longer implants placed in augmented bones in the trophic posterior mandibles: one-year a results of a randomized controlled trial.	After 1 year loss of 0.30 mm for short implants and 0.47 mm for long implants	1 year
Rocchietta et al.[65]	2018	Vertical ridge augmentation in the esthetic zone.	Bone stability up to 7 years, remodeling of 1.01 mmat 12 months	Does not report
Park et al.[86]	2017	Dimensional alterations following vertical ridge augmentation using collagen membrane and three types of bone grafting materials: a retrospective observational study.	Autogenous resorption but stable from the 1st year. The other reabs up to 1.5 years later	3 years
Suzuki et al.[14]	2017	Narrow-Diameter Implants: Dual function as a tent pole for vertical ridge augmentation and a guide for definitive implant posittionz.	Stable bone levels for 3 years	Up to 5 years
Simion et al.[77]	2016	Turned Implants in vertical augmented bone: a retrospective study with 13 to 21 years follow-up.	Mean bone loss of 1.02 mm one year after loading	13 to 21 years
Keestra et al. et al.[3]	2016	Long-term effects of vertical bone augmentation: a systematic review	Marginal loss during the 1st year 1.01 - 1.86 mm, and in 5 years 0.22 mm	12 months
Simion et al.[15]	2015	The Association of guided bone regeneration and enamel matrix derivative for suprabony reconstruction in the esthetic area: a case report.	Good bone stability after 1 year of follow-up	12 months
Merli et al.[32]	2015	Fence technique for localized three-dimensional bone augmentation: a technical description and case reports.	6 months after implant placement: 0.36 mm marginal bone loss	12 months

Table 3. Studies reporting implant survival (%).

AUTHORS	YEAR	TITLE	IMPLANT SURVIVAL
Cuch et al.[63]	2019	Statements and Recommendations for guided bone regeneration: consensus report of the guided bone regeneration symposium held in Bologna, October 15 to 16, 2016.	According to stages approach: immediate 98.9 % and delayed 100%
Zhang et al. et al.[26]	2019	The Application of a newly designed L-shaped titanium mesh for GBR with simultaneous implant placement in the esthetic zone: a retrospective case series study.	100% (41 months of follow-up)
Plonkaet al. et al.[64]	2018	Decision Tree for Vertical Ridge Augmentation (64)	Survival 93.75% to 100%
Urban et al.[6]	2019	Effectiveness of vertical ridge augmentation interventions: a systematic review and meta-analysis.	Mean 98.95% (90.5% to 100%)
Saletta et al	2018	Quality assessment of systematic reviews on vertical bone regeneration (53)	83.8% to 100%
Soldatos et al.[67]	2017	Limitations and options using resorbable *versus* nonresorbable membranes for successful guided bone regeneration.	93.3% to 98% after 5 years post definitive restoration
Roccuzzo et al.[76]	2016	Long-term outcomes of implant placed after vertical alveolar ridge augmentation in partially edentulous patients: a 10-year prospective clinical study.	94.1% (10 years of follow-up)
Urban et al.[30]	2016	Long-term Evaluation of of peri-implant bone level after reconstruction of severely atrophic edentulous maxilla via vertical and horizontal guided bone regeneration in combination with si nus augmentation: a case series with 1 to 15 years of loading.	100%, and satisfactory survival 97.5%
Simion et al. et al.[77]	2016	Turned Implants in vertical augmented bone: a retrospective study with 13 to 21 years follow-up.	97% (follow-up 13 to 21 years)
Keestra et al.[3]	2016	Long-term effects of vertical bone augmentation: a systematic review.	99.3% (range 94.1 % to 100%)
Al-Nawas et al.[55]	2014	Augmentation procedures using bone substitute materials or autogenous bone – a systematic review and meta-analysis.	97.4% to 100% (follow-up of 4 to 120 months)
Jung et al.[80]	2013	Cone beam computed tomography evaluation of regenerated buccal bone 5 years after simultaneous implant placement and guided bone regeneration procedures- a randomized controlled clinical trial.	100 % (5 years of follow-up)
Ricci et al.[57]	2013	Rehabilitation of deficient alveolar ridges using titanium grids before and simultaneously with implant placement: a systematic review.	100%
Clementini et al.[58]	2012	Success rate of dental implants inserted in horizontal and vertical guided bone regenerated areas: a systematic review.	93.75 % to 100 %
Annibali et al. et al.[36]	2012	Horizontal and vertical ridge augmentation in localized alveolar deficient sites: a retrospective case series.	100%
Todisco et al.[87]	2010	Early loading of implants in vertically augmented bone with non-resorbable membranes and deproteinised anorganic bovine bone. An uncontrolled prospective cohort study.	100%
Jensen et al.[69]	2010	Bone augmentation procedures in localized defects in the alveolar ridge: clinical results with different bone grafts and bone-substitute materials.	93% to 100%
Urban et al.[20]	2009	Simultaneous vertical guided bone regeneration and guided tissue regeneration in the posterior maxilla using recombinant human platelet-derived growth factor: a case report.	100% for 12 months
Canullo et al.[38]	2008	Vertical ridge augmentation around implants by e-PTFE titanium-reinforced membranes and bovine bone matrix: a 24-to 54-month studyof 10 consecutive cases.	100%

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Rocchietta et al.[61]	2008	Clinical outcomes of vertical bone augmentation to enable dental implant placement: a systematic review.	92.1 to 100% (follow-up of up to 7 years)
Windisch et al.[40]	2008	Reconstructive periodontal therapy with simultaneous ridge augmentation. A clinical and histological case series report.	Survival of 100% for 2 years
Bernstein et al.[70]	2006	Vertical bone augmentation: where are we now?	95.80%
Chiapasco et al.[89]	2004	Alveolar distraction osteogenesis vs vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: a 1-3-year prospective study on humans	100% (1-3 years of follow-up)
Nappe et al.[71]	2013	Regeneración ósea guiada para el aumento vertical del reborde alveolar	High survival 92.1% to 100% (up to 13 years of follow-up)
Cucchi et al.[23]	2014	Vertical Guided Bone Regeneration using Titanium-Reinforced d-PTFE membrane and prehydrated corticocancellous bone graft	100% up to 24 months

Table 4. Studies reporting complications.

AUTHORS	YEAR	TITLE	COMPLICATIONS
Malik et al.[24]	2019	Evaluation of Alveolar Ridge Height Gained by Vertical Ridge Augmentation Using Titanium Mesh and Novabone Putty in Posterior Mandible.	Soft tissue dehiscence and membrane exposure (4), graft extrusion(1), presence of some exudate (1)
Cuchi et al.[63]	2019	Statements and Recommendations for Guided Bone Regeneration: Consensus Report of the Guided Bone Regeneration Symposium Held in Bologna, October 15 to 16, 2016.	I. Membrane exposure with fenestration less than 3 mm without purulent exudate II. exposure greater than 3 mm without exudate III exposure with exudate IV abscess without membrane exposure
Cuchi et al.[73]	2019	Histological and histomorphometric analysis of bone tissue after guided bone regeneration with non-resorbable membranes vs resorbable membranes and titanium mesh.	There were complications (unspecified) and 1 dropout
Gallo et al.[91]	2019	Management Of 80 Complications In Vertical And Horizontal Ridge Augmentation With Nonresorbable Membrane (d-PTFE): A Cross-Sectional Study.	Membrane exposure and infection
Tolstunov et al.[25]	2019	Bone Augmentation Techniques for Horizontal and Vertical Alveolar Ridge Deficiency in Oral Implantology.	Post surgery infections
Zhang et al.[26]	2019	The application of a newly designed L-shaped titanium mesh for GBR with simultaneous implant placement in the esthetic zone: A retrospective case series study.	Ti mesh infection and exposure (33% exposure)
Plonka et al.[64]	2018	Decision Tree for Vertical Ridge Augmentation.	Lower complication rate compared to other technique
Ciocca et al.[27]	2018	Prosthetically CAD-CAM-Guided Bone Augmentation of Atrophic Jaws Using Customized Titanium Mesh: Preliminary Results of an Open Prospective Study.	3 cases with premature membrane exposure (2 to 4 weeks), 3 cases with late membrane exposure (10 to 24 weeks) and purulent exudate
Urban et al.[6]	2019	Effectiveness of vertical ridge augmentation interventions: A systematic review and meta-analysis.	GBR with a lower rate of complications (12.1%) compared with osteogenesis by distraction and blocks. 6.9% non-resorbable and 22.7% resorbable
Rokn et al.[75]	2018	Comparing 4-mm dental implants to longer implants placed in augmented bones in the atrophic posterior mandibles: One-year results of a randomized controlled trial.	5 sites with membrane exposure and 3 sites with paresthesia lasting 2 weeks
Saletta et al.[53]	2018	Quality assessment of systematic reviews on vertical bone regeneration	Sensory disturbances, opening of wound, membrane exposure, and prosthetic failure (0 to 60%)
Rocchietta et al.[65]	2018	Vertical ridge augmentation in the esthetic zone.	Soft tissue dehiscence, graft contraction due to lack of blood supply, granulation tissue formation, infection
Ghensi et al.[13]	2017	Management of the exposure of a dense PTFE (d-PTFE) membrane in guided bone regeneration (GBR): a case report	Membrane exposure, infection and collapse
Hur et al.[29]	2017	Bone Resorption During Submerged Healing After Guided Bone Regeneration: A Prospective Case Seriesx.	Continuous discomfort, infection and membrane exposure (42.1%)

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Wessing et al.[54]	2018	Guided bone regeneration with collagen membranes and particulate graft materials: a systematic review and meta-analysis.	Membrane exposure
Urban et al.[66]	2017	Principles for Vertical Ridge Augmentation in the Atrophic Posterior Mandible: A Technical Review.	Complications such as membrane exposure or infection could occur
Cucchi et al.[4]	2017	Evaluation of complication rates and vertical bone gain after guided bone regeneration with non-resorbable membranes *versus* titanium meshes and resorbable membranes. A randomized clinical trial.	A: 3 patients with membrane exposure, abscess, infection (2 failed). B: 4 patients, 10 to 15.8%. Paresthesia A: 5% and B: 15.8%
Park et al.[86]	2017	Dimensional alterations following vertical ridge augmentation using collagen membrane and three types of bone grafting materials: A retrospective observational study.	Wound dehiscence. All healed within 3 weeks with no further complications.
Elnayef et al.[7]	2017	Vertical Ridge Augmentation in the Atrophic Mandible: A Systematic Review and Meta-Analysis.	GBR with fewer complications than the other techniques studied
Gultekin et al.[5]	2017	Clinical and 3-Dimensional Radiographic Evaluation of Autogenous Iliac Block Bone Grafting and Guided Bone Regeneration in Patients With Atrophic Maxilla.	Membrane exposure in 1 patient (equivalent to 9% of patients)
Soldatos et al.[67]	2017	Limitations and options using resorbable *versus* nonresorbable membranes for successful guided bone regeneration.	Membrane exposure, infection, inflammation
Simion et al.[77]	2016	Turned Implants in Vertical Augmented Bone: A Retrospective Study with 13 to 21 Years Follow-Up.	9 of 91 implants with peri-implantitis, membrane exposure in 2 patients
Keestra et al.[3]	2016	Long-term effects of vertical bone augmentation: a systematic review.	Tissue dehiscence
Rocchietta et al. et al[47]	2015	Vertical Bone Augmentation with an Autogenous Block or Particles in Combination with Guided Bone Regeneration: A Clinical and Histological Preliminary Study in Humans.	1 patient with abscess with 2 fistulas without tissue dehiscence
Poli et al.[78]	2014	Alveolar ridge augmentation with titanium mesh. A retrospective clinical study.	Ti mesh exposure in 1 patient, 12 patients without complications.
Merli et al.[79]	2014	Bone level variation after vertical ridge augmentation: resorbable barriers versus titanium-reinforced barriers. A 6-year double-blind randomized clinical trial.	Complications before loading (unspecified). There were no complications after loading.
Khojaste et al.[56]	2013	Clinical importance of recipient site characteristics for vertical ridge augmentation: a systematic review of literature and proposal of a classification.	Implant failure
Funato et al.[35]	2013	A novel combined surgical approach to vertical alveolar ridge augmentation with titanium mesh, resorbable membrane, and rhPDGF-BB: a retrospective consecutive case series.	Membrane exposure without infection, dehiscence with infection
Ronda et al.[81]	2014	Expanded vs. dense polytetrafluoroethylene membranes in vertical ridge augmentation around dental implants: a prospective randomized controlled clinical trial.	Paresthesia, local edema, hematoma.
Ricci et al.[57]	2013	Rehabilitation of deficient alveolar ridges using titanium grids before and simultaneously with implant placement: a systematic review.	Postoperative infections, exposure and loss of grafted material and implant failure.
Annibali et al.[36]	2012	Horizontal and vertical ridge augmentation in localized alveolar deficient sites: a retrospective case series.	1 of 8 patients had membrane exposure and 1 had abscess without membrane exposure
Kaner et al.[48]	2011	Soft tissue expansion with self-filling osmotic tissue expanders before vertical ridge augmentation: a proof of principle study.	1 patient with paresthesia in the mental region (resolved spontaneously at 4 months) and 1 patient with membrane exposure

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Esposito et al.[59]	2009	The efficacy of horizontal and vertical bone augmentation procedures for dental implants - a Cochrane systematic review.	20% to 60% (includes all techniques)
Canullo et al.[49]	2010	Early implant loading after vertical ridge augmentation (VRA) using e-PTFE titanium-reinforced membrane and nano-structured hydroxyapatite: 2-year prospective study.	1 of 20 cases late membrane exposure
Todisco et al.[87]	2010	Early loading of implants in vertically augmented bone with non-resorbable membranes and deproteinised anorganic bovine bone. An uncontrolled prospective cohort study.	Membrane exposure at 2 of 25 sites
Langer et al.[37]	2010	Vertical ridge augmentation procedure using guided bone regeneration, demineralized freeze-dried bone allograft, and miniscrews: 4- to 13-year observations on loaded implants.	1 of 6 patients exudate after 10 weeks (diabetes patient)
Jensen et al.[69]	2010	Bone augmentation procedures in localized defects in the alveolar ridge: clinical results with different bone grafts and bone-substitute materials (69)	Membrane exposure and dehiscence
Urban et al.[20]	2009	Simultaneous vertical guided bone regeneration and guided tissue regeneration in the posterior maxilla using recombinant human platelet-derived growth factor: a case report.	Only postoperative swelling
Esposito et al.[60]	2009	Interventions for replacing missing teeth: horizontal and vertical bone augmentation techniques for dental implant treatment.	Membrane exposure, infection, and paresthesia
Fontana et al.[82]	2008	Clinical and histologic evaluation of allogeneic bone matrix versus autogenous bone chips associated with titanium-reinforced e-PTFE membrane for vertical ridge augmentation: a prospective pilot study.	Test group: paresthesia that resolved spontaneously in less than 2 months, dehiscence. Control group: infection without membrane exposure, paresthesia for 4 weeks
Jung et al.[83]	2009	A randomized, controlled clinical trial to evaluate a new membrane for guided bone regeneration around dental implants.	Delayed wound healing and dehiscence. Successful recovery in all cases.
Canullo et al.[38]	2008	Vertical Ridge Augmentation Around Implants by e-PTFE Titanium-Reinforced Membrane and Bovine Bone Matrix: A 24- to 54-Month Study of 10 Consecutive Cases.	1 of 10 patients showed membrane exposure
Rocchietta et al.[61]	2008	Clinical outcomes of vertical bone augmentation to enable dental implant placement: a systematic review.	Wide range of complications, the most common membrane exposure and its sequelae
Trombelli et al.[39]	2008	GBR and autogenous cortical bone particulate by bone scraper for alveolar ridge augmentation: a 2-case report.	Bone dehiscence in case 2. Case 1 without complications
Llambés et al.[41]	2007	Vertical guided bone regeneration with bioabsorbable barriers.	1 patient smoked 40 cigarettes a day, did not stop smoking, had to have the implants removed
Simion et al.[43]	2007	Vertical ridge augmentation by expanded-polytetrafluoroethylene membrane and a combination of intraoral autogenous bone graft and deproteinized anorganic bovine bone (Bio Oss).	Membrane exposure
Merli et al. et al.[84]	2007	Vertical ridge augmentation with autogenous bone grafts: resorbable barriers supported by ostheosynthesis plates versus titanium-reinforced barriers. A preliminary report of a blinded, randomized controlled clinical trial.	Bilateral abscess in 1 patient: membrane was removed and treated with ATB, bone augmentation failed. 1 patient with dehiscence without suppuration, 1 patient with infection treated with ATB.
Esposito et al.[2]	2007	The efficacy of various bone augmentation procedures for dental implants: a Cochrane systematic review of randomized controlled clinical trials.	Abscess, barrier exposure, fistula, swollen node, graft failure

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Merli et al. et al.[88]	2006	Vertical bone augmentation with dental implant placement: efficacy and complications associated with 2 different techniques. A retrospective cohort study.	Dehiscence with and without suppuration
Chiapasco et al. et al.[89]	2004	Alveolar distraction osteogenesis vs. vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: a 1-3-year prospective study on humans.	2 cases with lower lip paresthesia (lasting 1 to 4 weeks) and in front of the mandibular teeth (1 of them persisted even 2 years after surgery). Membrane exposure in 3 cases
Proussaefs et al.[44]	2003	The use of titanium mesh in conjunction with autogenous bone graft and inorganic bovine bone mineral (bio-oss) for localized alveolar ridge augmentation: a human study.	Titanium mesh exposure
Cornelini et al.[22]	2000	Simultaneous implant placement and vertical ridge augmentation with a titanium-reinforced membrane: a case report.	Formation of fibrous connective tissue that was removed with a curette
Tinti et al.[50]	1998	Vertical ridge augmentation: surgical protocol and retrospective evaluation of 48 consecutively inserted implants.	Membrane exposure and suppuration
Piattelli et al.[51]	1996	Histological evaluation of freeze-dried dura mater (FDDMA) used in guided bone regeneration (GBR): a time course study in man.	Small soft tissue dehiscence
Tinti et al[52]	1996	Vertical ridge augmentation: what is the limit?	Exposed membrane in 1 of 6 patients
Simion et al.[46]	1994	Vertical ridge augmentation using a membrane technique associated with osseointegrated implants.	Abscess
Nappe et al.[71]	2013	Regeneración ósea guiada para el aumento vertical del reborde alveolar.	The most common: membrane exposure, graft exposure, mucosal dehiscence, and infection.

Implant survival

Twenty-five studies reported data on the survival of implants in vertically regenerated bone (28.1%). The values range between 83.8% and 100% (Table 3).

Number of surgeries

Seventy-two studies (80.9%) reported having performed two interventions: VBA and implant loading; six studies reported having performed all the procedures in a single intervention (6.7%); five studies (5.6%) reported having performed more than two interventions, in these cases the additional intervention consisted of soft tissue surgery or previous extraction of the teeth to be replaced.

All the studies that used non-resorbable membranes had at least two surgical interventions, due to the characteristics of this material.

Complications

Seventeen studies (19.1%) reported that there were no complications in the procedures, while 58 studies reported complications (65.2%) (Table 4).

Membrane exposure was the most frequently reported complication in the studies.

Over half of the studies with complications reported membrane exposure (55.1%), 41.3% reported infection or abscesses, 20.6% reported tissue dehiscence, 13.8% reported sensory disorders, and 13.8% reported unspecified complications.

Paresthesia was the most common among sensory disorders. Most of the studies reporting membrane exposure used non-resorbable membranes.

DISCUSSION.

Guided bone regeneration is identified in the literature as the most used intervention for VBA[6] and has been in use since the 1990s. Most of the studies used non-resorbable titanium membranes (d-PTFE and e-PTFE), and they have reported the highest values of vertical bone gain.

PTFE-guided bone regeneration can be nearly 100% successful for VBA in all three height groups (small, medium, and large).[64] Regarding grafts, combinations were mainly used, the most common being autogenous bone with xenograft.

Most of the studies using titanium mesh used autogenous bone as the sole material or part of the graft material for VBAs.[24] Other authors suggest that autogenous bone is highly osteogenic and is considered the gold standard for bone regeneration procedures, providing proteins, bone-enhancing substrates, minerals, and vital bone cells to the recipient site, improving the overall grafting process and obtaining high success rates.[63]

On the other hand, many authors mix autogenous bone with various graft materials to transfer the scaffolding properties of a xenograft to the osteogenic and osteoinductive properties of the autogenous graft.[63] In terms of xenografts, the most widely used biomaterial is deproteinized bovine bone mineral graft (DBBM), which is applied as an osteoconductive scaffold that improves bone tissue repair and growth.[63]

Most of the studies reported a VBA of less than 5 mm, which is also reflected in the studies with a higher degree of evidence. Due to the short follow-up times, most of the studies did not report bone stability. However, all the studies that reported bone stability were favorable and the marginal bone loss in the first year was always considerably greater in relation to the following years.

Most of the studies did not report the survival of the implants, while the studies that did report it, showed favorable values greater than 80% in all cases. The main source of information for this review were series and case reports, which makes it clear that more experimental studies with longer follow-up are needed.

Regarding complications, membrane exposure is the most frequently reported in the studies. However, infection or abscesses, tissue dehiscence, sensory disorders, and unspecified complications were also reported in a smaller percentage. Nevertheless, guided bone regeneration is generally preferred over other types of bone augmentation techniques due to its high predictability and low incidence of complications.[64]

For example, distraction osteogenesis reported the highest rate of complications (47.3%), follo-

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wed by block grafts (23.9%) *versus* guided bone regeneration (12.1%).[6] Of the studies that reported sensory disorders, the most common was paresthesia, and among those that reported membrane exposure, the majority used non-resorbable membranes.

However, it is mentioned that resorbable membranes are more prone to complications than non-resorbable membranes (23% *versus* 7%), which is in line with previous systematic reviews.[6] This could be explained by the fact that not only membrane exposure is considered, but also other types of complications.

Within the limitations of this review, it must be considered the short follow-up times of the studies published in the literature. On the other hand, it can be concluded, based on the variables studied, that the technique of vertical guided bone regeneration is effective and reliable.

Although these results are positive, this technique requires a lot of clinical training and expertise, suggesting that certain variables that affect results, such as operator sensitivity, and each regenerated zone and defect has its own characteristics that make comparison difficult.

If these variables could be identified, it would help to clarify and better understand the interpretation of the values and provide an explanation as to why better results are achieved in both bone augmentation and/or the number and severity of complications.

CONCLUSION.

Guided bone regeneration is a safe and reliable technique over other VBA techniques and is one of the most frequently used. It is a reliable method to restore vertical bone tissue defects for subsequent implant placement, ensuring adequate bone volume.

Although this type of technique has some complications, such as membrane exposure, they are not significant when compared to other types of techniques such as osteogenic distraction or block grafts.

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