Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

HORIZONTAL REGENERATION TECHNIQUES: SURGICAL PROCEDURES, INDICATIONS AND SUCCESS.

Madrid, academic year 2022/2023

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SUMMARY AND KEYWORDS

Introduction: The removal of a tooth would result in major changes of the alveolar bone affecting its shape and volume since the first 2-3 months. The development of dental implant these past years offers an excellent fixed option for restoring missing teeth with an excellent long-term prognosis. To be successful the osseointegration needs to be complete requiring an adequate volume of bone that can be provided by horizontal regeneration. Numerous procedures which use bone graft or bone-graft substitutes exist to fulfil this objective; **Objectives**: Aims of this study were to determine the optimal surgical technique for achieving horizontal bone width gain and investigate the long-term stability of these the graft; **Methodology**: A systematic review was made based on an automatized electronic literature search in the Medline and Pubmed databases. The studies ranged from 2017 to 2023 and were researched in English. Inclusion and exclusion criteria were established; **Results**: After duplicate articles removal, 718 publications were identified, and 678 articles were excluded by evaluating the titles and abstracts. Finally, 12 articles meeting the criteria were included in this study, constituting a sample of 384 patients. Demographic data and characteristics were organized and presented in tables as the results; **Conclusion**: No significant differences in horizontal width gain and stability of the graft were found comparing the different techniques studied in this review. All the procedures studied demonstrated great efficacy to achieve horizontal regeneration, thus it was not possible to determine which would be the best. The choice may be dependent on other factors that must be studied in further investigations.

Keywords: dentistry; horizontal regeneration; guided bone regeneration; block graft; split crest.

RESUMEN Y PALABRAS CLAVE

Introducción: La extracción de un diente resulta en cambios importantes en el hueso alveolar que afectan su forma y volumen desde los primeros 2-3 meses. El desarrollo del implante dental en estos últimos años ofrece una excelente opción fija para restaurar los dientes ausentes con un excelente pronóstico a largo plazo. La osteointegración es un requisito al éxito del procedimiento y requiere un volumen adecuado de hueso que puede ser proporcionado por la regeneración horizontal. Existen numerosos procedimientos que utilizan injertos óseos o sustitutos de injertos óseos para cumplir este objetivo; **Objetivos:** Los objetivos de este estudio fueron determinar la técnica quirúrgica óptima para lograr una ganancia de ancho óseo horizontal e investigar la estabilidad a largo plazo de estos injertos; **Metodología:** Se realizó una revisión sistemática basada en una búsqueda automatizada de literatura electrónica en las bases de datos Medline y Pubmed. Los estudios comprendieron el período de 2017 a 2023 y se investigaron en inglés. Se establecieron criterios de inclusión y exclusión; **Resultados:** Después de eliminar los artículos duplicados, se identificaron 718 publicaciones y se excluyeron 678 artículos evaluando los títulos y resúmenes. Finalmente, se incluyeron en este estudio 12 artículos que cumplían los criterios, constituyendo una muestra de 384 pacientes. Los datos demográficos y las características se organizaron y presentaron en tablas como los resultados; **Conclusión:** No se encontraron diferencias significativas en la ganancia de ancho horizontal y la estabilidad del injerto al comparar las diferentes técnicas estudiadas en esta revisión. Todos los procedimientos estudiados demostraron una gran eficacia para lograr la regeneración horizontal, por lo tanto, no fue posible determinar cuál sería el mejor. La elección puede depender de otros factores que deben ser estudiados en investigaciones futuras.

Palabras claves: odontología, regeneración horizontal, regeneración ósea guiada, injertos en bloque, split crest.

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1. INTRODUCTION

1.1 Background

The loss of a tooth has a major impact on the periodontium surrounding and supporting it. Among the structures composing the periodontium, the alveolar process would see its shape and volume affected by the presence or not of the tooth, as well as the gingival tissues. The removal of a tooth would result in bone resorption in both horizontal and vertical dimensions, especially marked the first 2-3 months (1,2).

Studies suggest that the buccal plate was more affected than the palatal and lingual plates. But when some studies report that this resorption is responsible for a displacement of the center of the edentulous ridge toward lingual, others report that the resorption pattern would depend on the position of the osseous base with the tooth position (1,3). Hence, the maxillary bone would suffer centripetal resorption, when in the mandible we would expect centrifugal resorption (4).

This would result in a shorter and narrower maxilla and a shorter and wider mandible, making a discrepancy between the jaws and more difficult prosthetic rehabilitation (3).

This problem is particularly true when treating with dental implants. The development of this means to set dental prostheses these past years has made it an excellent fixed option for restoring missing teeth with an excellent long-term prognosis. The osseointegration of the implant is one of the main keys to evaluate the predictability and success of its placement and would depend among others on the amount of bone. Therefore, when the case requires it, bone regeneration is pertinent into the prosthetic treatment plan, to get an optimal recipient site for the implant (5).

The literature state that the horizontal dimension would be more affected by the alveolar ridge resorption in the years following the extraction thus horizontal regeneration (or augmentation) is a common surgical intervention before or during the implant placement (6).

1.2 Defects classification

Several classifications are available in the literature to describe alveolar ridges defects. In 2018, Chiapasco and Casentini classified the horizontal defects into 4 classes, according to a prosthetically driven diagnostic protocol:

Class 1 is described in situations in which an adequate volume of bone is present (>1,5-2mm around) for the implant to be placed in an ideal position. No discrepancy exists; thus, no bone augmentation is indicated, however, a connective tissue graft is often performed in the esthetic area (Figure 1). In class 2, we find a moderate horizontal deficit (fenestration or de-hiscence), commonly created during the preparation of the implant site at the buccal plate, or when the residual buccal wall thickness is not sufficient (<1mm) to guarantee a favorable long-term prognosis (Figure 2). In this class of defect, simultaneous bone regeneration is necessary although the implant can be placed in the correct prosthetically driven position. It is not the case in defects class III, where the residual amount of bone does not allow the correct place-ment of the implant (Figure 3). The stability being compromised, the horizontal regeneration with a healing period between 4 and 9 months is necessary to achieve its stability. Class 4 is the most complicated situation to treat with the presence of a combined horizontal and ver-tical defect (Figure 4). These defects require more demanding techniques thus higher inci-dences of complications of the defect are reported (7).

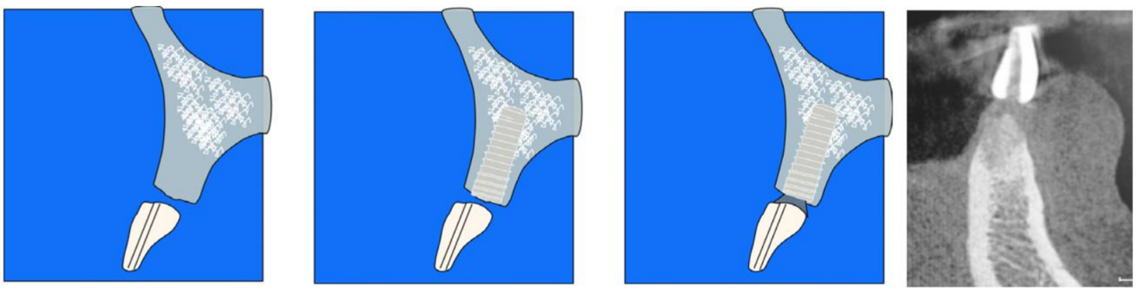

Figure 1. Class 1 horizontal alveolar defect: the bone volume is adequate for implant place-ment without bone regeneration (7).

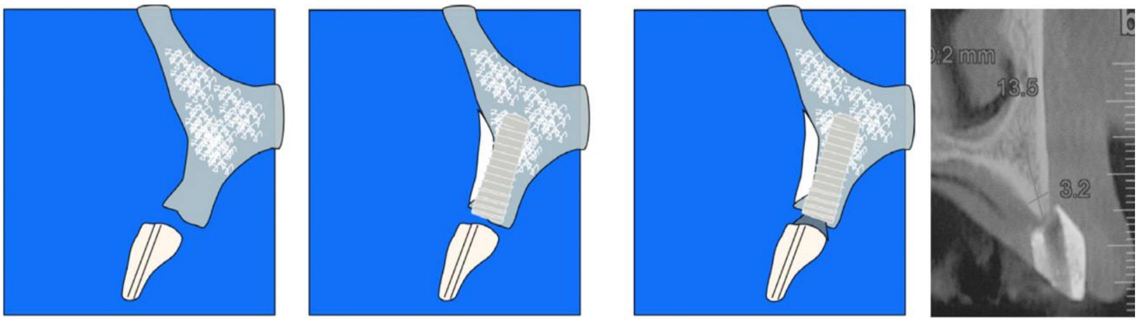

Figure 2. Class 2 horizontal alveolar defect: the bone volume allows the implant placement, but bone regeneration is indicated (7).

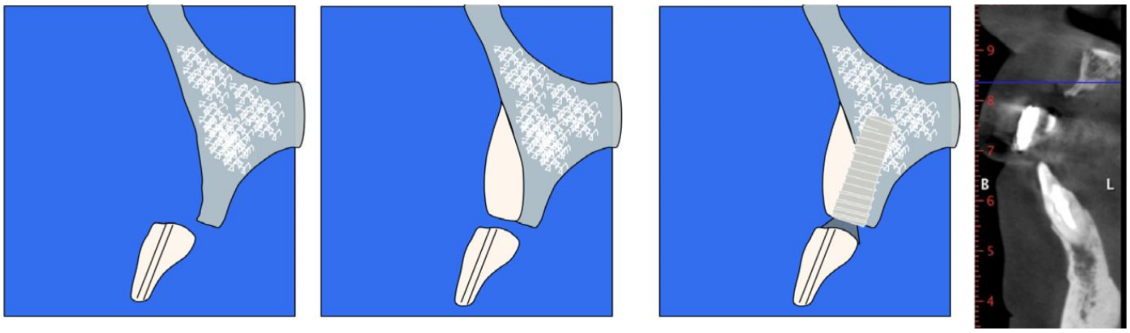

Figure 3. Class 3 horizontal alveolar defect: the bone volume does not allow the implant; bone regeneration is needed to achieve the primary stability of the implant (7).

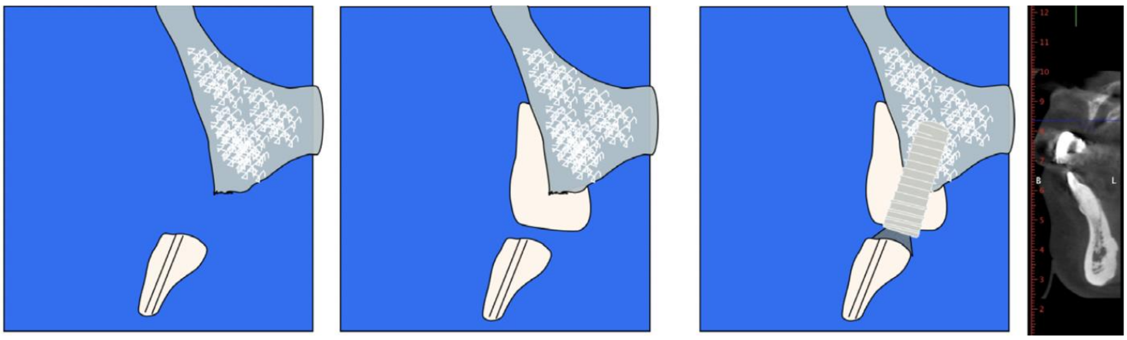

Figure 4. Class 4 horizontal alveolar defect: combined horizontal and vertical defect increasing the complexity and risk of the surgery (7).

Another classification named “The Cologne Classification of Alveolar Ridge Defects” or CCARD was established in 2013 by the European Association of Dental Implantologists (BDIZ EDI). This classification has for objective to provide an easy classification that uses three-part codes to describe the defect of the alveolar ridge in order then to propose the existing therapeutic option corresponding to each case. It considers the volume deficiencies of the alveolar process and the extent of the augmentation needed (8).

Part 1 of the code is related to the orientation of the defect:

- H: horizontal
- V: vertical
- C: combined
- S (or +S): sinus area.

Part 2 is associated with the reconstruction needs associated with the defect:

- 1: low: < 4 mm
- 2: medium: 4-8 mm
- 3: high: > 8 mm.

Part 3 of the code is about the relationship between augmentation and defect region:

- i: internal, inside the contour
- e: external, outside the ridge contours (8).

1.3 Bone grafts and substitutes

Horizontal regeneration involves the use of bone graft or bone-graft substitute, which can be classified according to their origin and properties (Table 1).

1.3.1. Autograft

Thereby autograft, whose origin is the individual itself, is harvested from nonessential bones such as the iliac crest, mandibular symphysis, or coronoid process. This type of graft was considered the ideal material to achieve bone augmentation thanks to its osteogenic, osteoinductive, osteoconductive, and osseointegration properties, however, the complications and morbidity related to the donor site make its use questionable (5,9).

1.3.2 Allograft

Allograft is the term used to describe grafts taken from humans but from different individuals. The material is obtained from cadavers and processed to make it sterile and deactivate proteins. We distinguish fresh-frozen bone, fresh dried bone (FDBA), and demineralized fresh dried bone (DFDBA) as kinds of bone allograft. It can induce osteoconduction, osteoinduction, and osseointegration due to the growth factors, proteins, and bioactive elements it contains (5,9,10).

1.3.3 Xenografts

Xenografts come from species other than humans that could be bovine and porcine. Pathogen transmission, immunogenic rejection, prolonged graft integration period, and fracture remain extremely significant complications. Although these disadvantages, xenografts are still occasionally used to treat osseous defects, mostly due to their abundance and acceptable osteoconductive properties (9,10).

1.3.4 Alloplastic grafts

Alloplastic grafts are synthetic products, that often originated from hydroxyapatite for its osteoconductive potency. They are mainly used for their hardness and compatibility with bone. Hydroxyapatite can be found associated with tricalcium phosphate which allows osteoconduction first and then resorbability. They can also be of calcium phosphate cement, calcium sulfate, or bioactive glass (5,9,10).

1.3.5 Growth factors

Grafts with growth factors are made using recombinant DNA technology. They either contain morphogens or human growth factors (BMPs in conjunction with a carrier medium, such as collagen). Growth factors bind to cell surface receptors and activate the intracellular environment (9).

Table 1. Grafting materials: origin and properties (5,9,10).

Graft material	Origin	Properties	Examples
Autograft	Patient himself	Osteoconduction Osteoinduction	Intra or extra-orally harvested bone

		Osteogenesis	
Allograft	Individuals from the same species	Osteoconduction Osteoinduction	-Fresh-frozen bone -Fresh dried bone (FDBA) -Demineralized fresh dried bone (DFDBA)
Xenograft	Individuals from another species	Osteoconduction	-Bovine origin -Porcine origin -Equine origin
Alloplastic graft	Synthetic	Osteoconduction	-Tricalcium phosphate -Hydroxyapatite Hydroxyapatite/Trical-cium phosphate compo-site -Calcium phosphate ce-ment -Calcium sulfate -Bioactive glass -Polymers

1.4 Grafting techniques

As a result of its fragility and thinness, the anterior maxilla frequently suffers post-extraction bone resorption. By adopting a less traumatic extraction approach as well as socket preservation, it could be reduced. When extracting the tooth, particulate bone graft materials are applied, either with or without membrane barriers. This treatment could help to lessen dimensional alterations in the alveolar bone (11,12).

However, bone augmentation may be necessary for an alveolar defect with significant horizontal and vertical dimension loss. Numerous procedures, such as guided bone regeneration (GBR), distraction osteogenesis, particulate grafting materials, onlay block graft, and crest split techniques, can be used to achieve horizontal regeneration (11).

1.4.1 Guided bone regeneration

Bone regeneration is possible through the action of several types of cells. Among them, the osteogenic cells present in the inner osteogenic layer of the periosteum are responsible for the production of cells potent for differentiation into osteoblast. The essence of GBR is the application of barrier membranes to maintain space above a defect, encourage the formation of osteogenic cells, and stop undesirable cells from migrating into the wound from the soft tissues above by protecting the blood clot in the defect and excluding gingival connective tissue (Figure 5). This technique has become a predictable surgical method over time, especially to promote peri-implant bone formation and alveolar ridge augmentation, however, it requires excellent surgical skills (5,7,11,13,14).

Guided bone regeneration involves the use of a variety of non-resorbable and bioabsorbable barrier membranes (Table 2) that should have specific characteristic as biocompatibility, stability necessary for space maintenance, cell exclusiveness, promotion of soft tissue healing, sufficient long-term healing, and good handling (11,14).

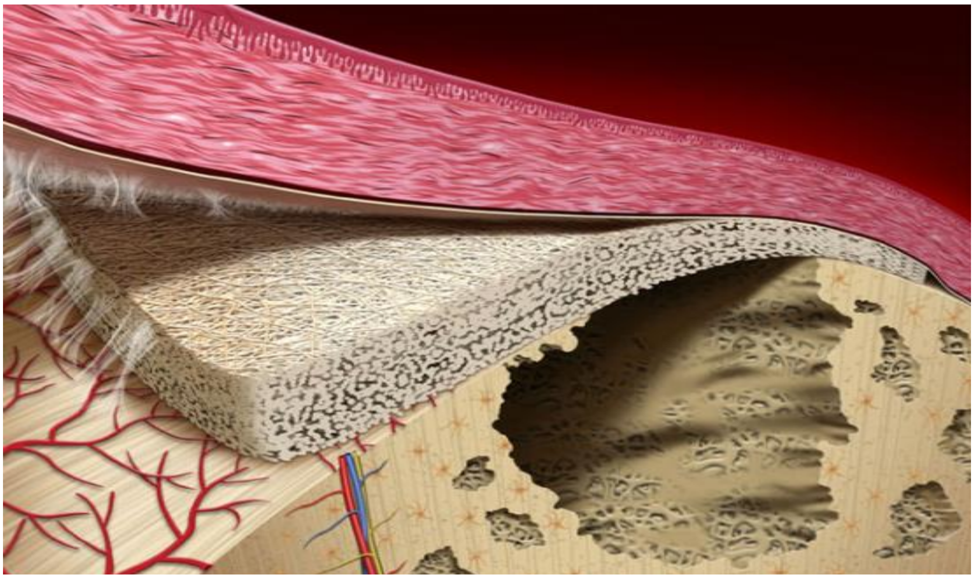

Figure 5. Illustration of the guided bone regeneration’s principle (13).

1.4.1.1 Guided bone regeneration with non-resorbable membranes

Several non-resorbable membranes are available nowadays, among them, are mainly used polytetrafluoroethylene (PTFE), expanded polytetrafluoroethylene (e-PTFE), dense polytetrafluoroethylene (d-PTFE), titanium-reinforced PTFE (Ti-PTFE) and titanium mesh (5).

The e-PTFE membrane is a synthetic polymer with a porous structure. It has a central cell occlusive region and an outer cell adherent region. e-PTFE is the most studied membrane in animals and humans and is standard for bone augmentation. It has the advantage of being resistant to enzymatic degradation and does not induce an immune response. However, premature exposition of the membrane in the oral cavity would be responsible for soft tissue complications due to rapid bacterial colonization on its porous surface compromising the regeneration process. This inflammation provoked by the membrane exposition is reduced when using d-PTFE as they are not stabilized by bonding to the tissue (5,11,13,14).

These membranes can integrate titanium reinforcement (Figure 6) to improve their space maintenance properties, especially in larger defects where the membrane cannot be supported by the adjacent walls. Titanium ribs improve their mechanical stability and allow the membranes to be individually shaped. Titanium mesh can also be used to contain the graft and maintains the space when the conventional membranes collapse. It provides a solid scaffold for bone proliferation and is very malleable. Its microporosity also allows the maintenance of the blood supply necessary for tissue integration. The bone healing capacity is influenced by the size of the defect, in large defects the combined use of bone grafts or substitutes with these membranes is necessary. Non-resorbable membranes characteristics make them very used despite the necessity of their removal by another surgery that increases tissue damage and patient morbidity (5,13,14).

1.4.1.2 Guided bone regeneration with resorbable membranes

Resorbable membranes have been developed despite the success of e-PTFE membranes to simplify surgical protocols. Indeed, these membranes do not need a second surgery for their removal and avoid complications of soft tissue and infections related to regenerated bone exposure during the surgery or premature membrane exposure. Nevertheless, their resorption process may be responsible for complications in bone formation and wound healing. Also, space maintenance functions would be compromised due to their lack of stability and duration. Bioabsorbable membranes can be classified according to their origin, natural or synthetic. Natural membranes are made of collagen which has the advantage of good tissue integration and biodegradation and fast vascularization with a low complication rate. Collagen barriers act to promote osteoblast proliferation and alkaline phosphate activity. One of the main advantages of native collagen is its ability to epithelize when exposed, resulting in the spontaneous healing of secondary wounds. Thus, even when facing soft tissue complications, the membrane can be left in place. Though, these membranes present poor mechanical properties and a tendency to collapse. Their rapid mechanism of degradation by enzymatic activity can also be a limiting characteristic, however, degradation time may be dependent on the source and structure of the membrane. Synthetic resorbable membranes are made of aliphatic polyesters such as polylactic acid, polyglycolic acid, trimethyl carbonate, and their copolymers. Besides their origin, they differ from the natural membrane by their mode of resorption, unlike collagen barriers which undergo enzymatic degradation, synthetic membranes are degraded by hydrolysis. This parameter is important to consider as their degradation could be responsible for soft tissue inflammation that could lead to regenerated bone resorption (5,6,13,14).

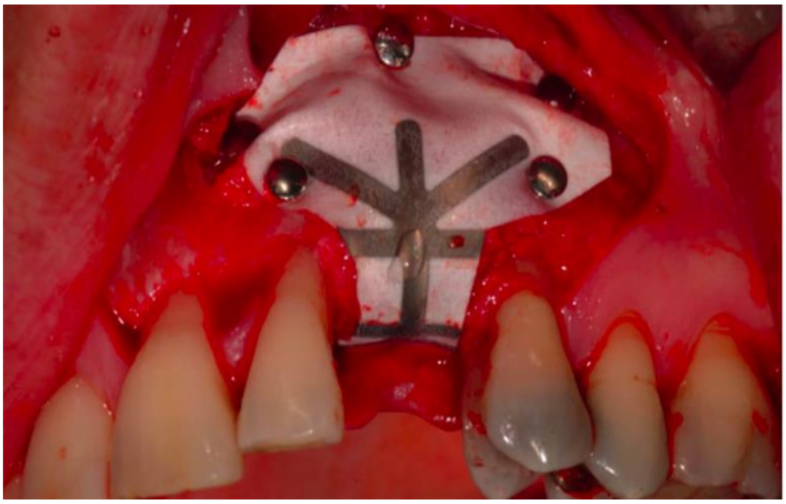

Figure 6. Non-resorbable membrane reinforced with titanium and fixed by titanium screws (7) .

Table 2. Classification of the membranes used for GBR (11,14).

Type of membrane	Membranes	Advantages	Disadvantages
Non-resorbable	-Polytetrafluoroethylene membranes (PTFE, e-PTFE, d-PTFE, Ti-PTFE) -Titanium mesh	-Inert -Stable	-Soft tissue complications -Higher morbidity due to their removal
Resorbable	*Natural:* -Collagen and extracellular matrices *Synthetic:* -Aliphatic polyester (PGA, PLA, PTMC)	-Bioresorbable -Low immunogenicity -Good tissue integration -Lesser morbidity	-Low stability -Low rigidity -Tendency to collapse

PTFE: poly(tetrafluoroethylene); e-PTFE: expanded poly(tetrafluoroethylene); d-PTFE: dense poly(tetrafluoroethylene); Ti-PTFE: titanium-reinforced PTFE; PGA: poly(glycolic acid); PLA: poly(lactic acid); PTMC: poly(trimethylene carbonate).

1.4.2 Particulate bone grafting technique

Particulate bone grafting is used to restore dental arches that have reduced volume or contour based on the osteogenic, osteoinductive, osteoconductive potential, or combination of all the actions. This grafting technique employs different types of bone graft material, thus particulate bone graft could be an autograft, allograft, xenograft, or alloplastic graft. Regarding which particulate materials should be employed for typical clinical applications, the justification for their use, as well as combining one or more materials, and the percentages of each material used in combination, there are many different suggestions made by specialists. Particulate bone grafting is used in a variety of applications, including sinus augmentation, ridge augmentation, and extraction socket applications (11,15).

1.4.3 Autogenous bone block grafts

Autogenous block grafting is a predictable technique that allows significant horizontal augmentation. Biologically, the autogenous block graft will heal and integrate combining osteoclastic destruction of necrotic bone and osteoblastic substitution by viable bone. Its healing process is described as "creeping substitution". As for the other techniques, their success mainly rests in the stabilization, and its contact with the recipient bed using fixation screws (Figure 7). Angiogenesis and revascularization are also important variables, that can be positively influenced by decortication, intramarrow penetration (perforations within the bone), and inlay shaping of the recipient bed. These preparations also enhance the osteoprogenitor cell's availability. Autogenous bone block graft is mainly harvested from the ramus, symphysis, or the external oblique ridge of the mandible. However, when the bone defect requires a large sample, extraoral locations, such as the iliac crest, cranium, or tibia, are chosen. The harvesting techniques require high operator skills and are associated with donor site morbidity (7,11).

Figure 7. A bone block is harvested and fixed using fixation screws (7).

1.4.4 Combination Approaches

The aforementioned bone grafting technique can be combined to maximize guided bone regeneration. The use of barrier membranes in concert with particulate grafts enables its correct support, maintains the space, and reduces alveolar bone resorption while promoting bone regeneration. Combining GBR with an autologous bone block graft is frequently performed as non-resorbable membranes insulate the graft and prevent it from resorbing. When implant placement and grafting procedures are done simultaneously, combination techniques are also relevant for lowering patient morbidity. Indeed, by reducing the number of surgeries and inducing a shorter recovery time, it would promote and improve bone regeneration (11,15).

1.4.5 Crest splitting

Crest splitting is a surgical technique that requires a high level of skill and experience from the surgeon and consists in splitting the alveolar bone longitudinally (Figure 8) to increase the horizontal ridge width. This technique can be associated with implant placement and is a good alternative to guided bone regeneration. The employ of crest splitting is limited to moderate horizontal bone loss and cannot be performed in presence of buccal crest inclination. In the mandible, its application is rare as the presence of cancellous bone between the cortical crest is compulsory (7,11).

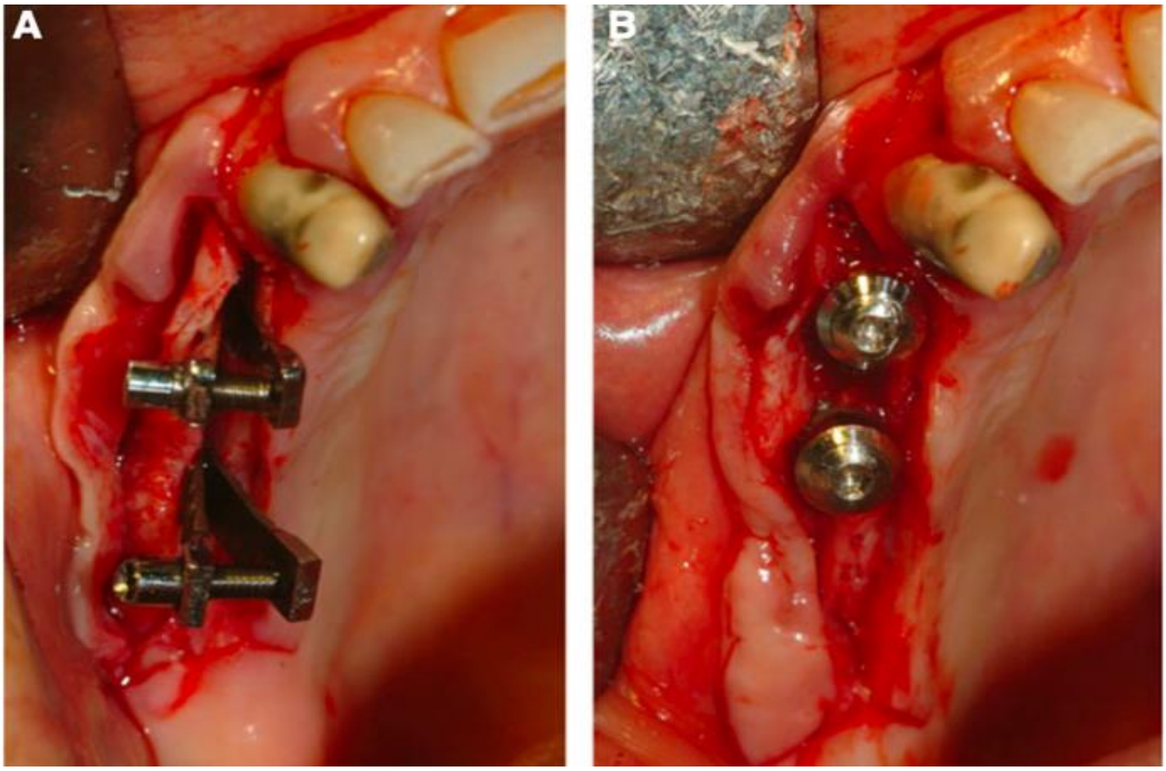

Figure 8. A. Mid-crestal and, mesial and distal releasing bone cuts are performed. Then the sagittal split is realized using chisels, expansion screws or special expansion devices. B. Implants are placed, usually of conical shape due to the shape of the cavity (7).

1.4.6 Distraction Osteogenesis

Distraction osteogenesis is based on the separation of the bone into two pieces, creating a space that is going to be filled by new bone. First, corticotomy is performed to separate the segments, and then a distraction device is placed. Distractors can be intra or extraosseous and the separation made needs to be carried out slowly and under pressure. Three phases take place during distraction osteogenesis: latency, distraction, and consolidation phase. During the latency period of 7 days, soft tissues are regenerating, and the wound is healing. This period allows the formation of the callus and does not have to be too long to prevent its calcification. At the distraction phase, the two segments of bone undergo gradual incremental separation by the activation of the distraction device. The distraction rate depends on the protocol associated with the case, a rate of 1 mm with 2 to 4 activations per day is often performed. Finally, comes the consolidation phase that lasts around 4 to 12 weeks and during which the immobilization of the callus allows its maturation into new mature bone (11,15,16).

1.5 Treatment planning

Meticulous analysis of the patient is essential to identify the objective of the therapy and its associated risk. Also, before planning any surgery, an evaluation of the patient's health, soft tissue, and bone morphology should be conducted (5).

A clinical and radiographic examination is performed to establish the dental and periodontal health status of the patient. Bone defect morphology, ridge contour, and mesiodistal size of the edentulous area are assessed, and panoramic and periapical radiographs allow a good preliminary overview of these. After the exclusion of the relative and absolute local and general contraindications for oral surgery, the esthetic and functional needs of the patient are assessed. Soft tissues should be evaluated, the quality and quantity of soft tissue are important factors for bone regeneration success. As the matter of fact, in case of deficit and/or an area with high esthetic demand, soft tissue augmentation may be indicated before performing bone augmentation. Nowadays, prosthetically driven implant dentistry is the gold standard for implant-supported prostheses thus evaluation of the prosthetic feasibility is a requisite. Ideal ridge profile and dental anatomy can be simulated by a diagnostic wax-up on a mounted cast. The wax-up permit to assess intermaxillary discrepancies or asymmetries between the two sides of the dental arch in addition to simulate the bone augmentation and measure the quantity of bone needed. Intra and extra-oral photographs are important in the diagnostic protocol to be used as a communication tool with the technician and the patient. A mock-up could also be done to collect the patient's point of view about his future restoration, increasing his motivation by involving him more in the treatment. Esthetic expectations of the patient must be considered, and it is important to explain to the patient the limitations of the surgery (5,7).

The next step is the assessment of the surgical feasibility which is carried out by evaluating the volume of bone available and planned or not its augmentation. The wax-up is used to manufacture a diagnostic template placed in the mouth when doing the computerized tomography. The information collected by the scan is analyzed and virtual placement of the implants is done using implant/dental software. The decision of bone augmentation is then made, and if necessary, the most appropriate procedure is chosen. The diagnostic template could be converted into a surgical template to ease the implant placement by the surgeon (7).

1.6 Justification

Adequate bone volume is essential to rehabilitate prosthetically the patient by the mean of implants, thus horizontal regeneration represents a high stake. Nowadays, dental surgeons have at their disposal a great variety of techniques and materials to restore the horizontal dimension of dental arches. It is therefore of interest to determine by this review, which surgical technique would be optimal to achieve horizontal bone width gain. The stability of the graft over time will also be reviewed, as it is also a factor that must be taken into consideration when deciding on the materials to be used and the intervention to be carried out.

These variables must be studied to answer to the following research question: Which of the surgical technique available nowadays is the best to achieve horizontal regeneration?

2. OBJECTIVES

2.1. Objectives

The objectives of this review are:

1. To determine the optimal surgical technique for achieving horizontal bone width gain.
2. To investigate the long-term stability of horizontal bone width gain achieved through different regeneration techniques.

2.2. Hypothesis

The use of guided bone regeneration techniques in conjunction with horizontal regeneration procedures can improve the predictability and success of the procedure.

3. MATERIALS AND METHODS

Automatized electronic searches were conducted in two major electronic databases: MEDLINE and PUBMED. This review included publications in English ranging from 2017 to 2023.

The search strategy was performed using the MeSH terms following the research equation: (((alveolar ridge augmentation) OR (mandibular) OR (maxillary) OR (horizontal regeneration) AND (guided bone regeneration) OR (block graft) OR (particulate graft) OR (distraction osteogenesis) OR (crest splinting) OR (autologous block graft)) NOT (vertical ridge augmentation))).

Filters were applied on MEDLINE (Full text 2017-2023; English; Subject: Major heading: alveolar ridge augmentation; All database) and PUBMED (Free full text 2017-2023; English; Randomized clinical trial; Clinical trial; Human).

The articles were selected following specific inclusion and exclusion criteria described in table 3. Randomized controlled trials, prospective cohort studies, and systematic reviews were included. Were excluded from this review: case reports, letters to the editor, expert reports, reviews, or studies on vertical augmentation.

Table 3. Inclusion and exclusion criteria.

Inclusion criteria	**Exclusion criteria**
In vivo	In vitro
Clinical human studies	Animal studies
≥10 patients	Articles dated before 2017
Patients with atrophic alveolar ridges	Articles about vertical regeneration
Minimum of 4 months follow-up	Uncontrolled systemic condition
English articles	History of radiation to the head and neck
ASA score of I or II	Metabolic bone disorders
≥18 years of age	Autoimmune diseases or immunocompromised status

	Bad oral hygiene
	Pregnant women

Manual removal of the duplicates of the articles obtained through the database research and selection by title and abstract and according to inclusion and exclusion criteria was made before to evaluate the articles' eligibility. Final eligibility consisted in screening the surgical interventions performed, and variables studied in each article. The surgical interventions and variables searched are described in table 4.

Table 4. Surgical interventions and variables screened.

Surgical interventions	**Variables studied**
Horizontal regeneration	Preoperative horizontal width
Guided bone regeneration	Postoperative horizontal width
Block graft	Follow-up horizontal width
Particulate graft	Horizontal width gain
Distraction osteogenesis	Graft resorption
Crest splinting	

4. RESULTS

This review complies with the PRISMA statement (Preferred Reporting Items for Systematic reviews and Meta-Analyses). 12 articles were selected following the previous criteria constituting a sample of 384 patients (Figure 5). Tables containing the characteristics (Table 5) and demographic data (Table 6) of the selected articles were established.

With the aim of summarizing and comparing studies and consequently to the difference of nature or methodology of measurement, the data of the variables, preoperative horizontal width (W^1), post-operative horizontal width (W^2), and horizontal width after follow-up (W^3) were extracted directly from the articles' results or averaged from several measurements. Horizontal width gain was calculated by subtracting W^1 from W^3 and bone resorption was obtained by subtracting W^3 from W^2. Values associated with these variables are described in table 7. The interventions were classified according to the surgical technique used and weighted arithmetic mean of horizontal width gain and graft resorption were calculated to be compared (Table 8 and Figure 10).

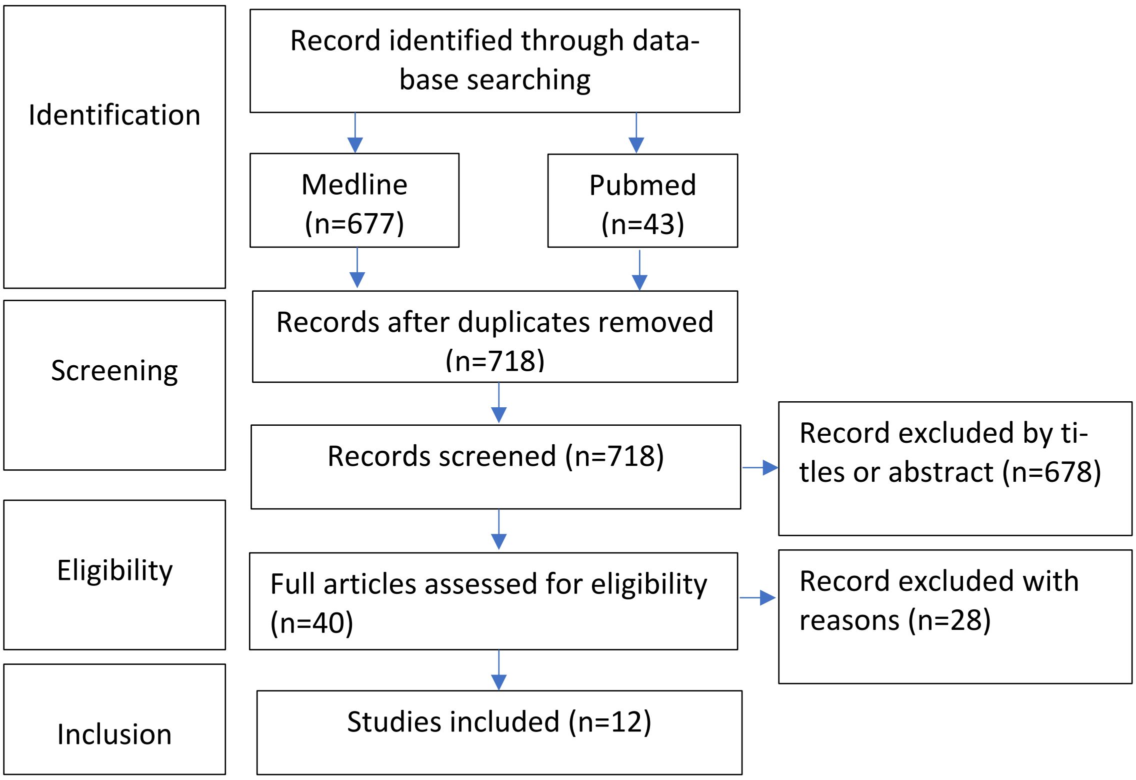

Figure 9. PRISMA flowchart of the included studies.

Table 5. Characteristics of the studied articles

Authors	Year	Study design	Assessment method	N° Patients	Follow up time
Aboelela SAA et al. (17)	2021	RCT	CBCT: Measures at 2, 5, and 10 mm from the alveolar crest then averaged.	28	6 months
Ahmadi RS et al.(18)	2017	Prospective clinical trial	Clinical measurement with a bone caliper at 2mm and 5mm from the crest.	10	6 months
Atef M et al.(6)	2019	RCT	CBCT: Measures 2.0 mm below the tip of the crest at every single deficient site then averaged.	20	6 months
Bartols A et al.(19)	2017	RCT	CBCT: Measures at 2mm below the highest point of the alveolar crest for pre- and post-operative width. Measures 2 mm below the implant shoulder for follow-up width.	30	1 year
Crespi R et al.(20)	2021	Cohort	CBCT: Measures of the alveolar crest width, distance between the most prominent points on the palatal and buccal aspect, and the buccal bone wall thickness at 1 mm apical to the most coronal point.	38	5 years
Elraee L et al.(21)	2021	RCT	Clinical measurement with a bone caliper at the bone crest and CBCT at 3 mm and 6mm from the bone crest then averaged.	42	6 months

Işık G et al.(22)	2021	RCT	CBCT: Measured using reference points at 2mm, 4mm, and 6mm from the implant shoulder.	44	6 months
Meloni SM et al.(23)	2019	Cohort	CBCT: Measures at 2mm below the bone crest.	18	7 months
Mendoza-Azpur G et al.(24)	2018	RCT	CBCT: Measures at 5, 7, and 11mm from the crest.	42	18 months
Romito GA et al.(25)	2021	RCT	Clinical measurement with a bone caliper at 2mm from the alveolar crest.	64	7 months
Wang M et al.(26)	2021	RCT	CBCT: Measures at 1,2,3,4 and 5 mm apical to the alveolar ridge crest.	24	6 months
Thoma DS et al.(27)	2017	RCT	Clinical measurement with bone caliper bone.	24	4 months

RCT: Randomized Controlled Trials; CBCT: Cone Beam Computed Tomography.

Table 6. Demographic data of the studied articles.		
Authors	**Mean age (interval)**	**Gender**
Aboelela SAA et al.(17)	40,21	16 ♂ 12♀
Ahmadi RS et al.(18)	45	7 ♂ 3♀
Atef M et al.(6)	(20-60)	N/A
Bartols A et al.(19)	47,3 (18-72)	16 ♂ 14♀
Crespi R et al.(20)	N/A	15 ♂ 23♀
Elraee L et al.(21)	Dentin block group: 30,1/ Autogenous bone block group: 28,7	Dentin block group: 9 ♂ 12♀/ Autogenous bone block group: 8 ♂ 13♀
Işık G et al.(22)	N/A	N/A
Meloni SM et al.(23)	56,8 (24-78)	7 ♂ 11♀
Mendoza-Azpur G et al.(24)	ABG group: 49,62 / GBR group: 55,06	ABG group: 3♂ 18♀/ GBR group: 6 ♂ 12♀
Romito GA et al.(25)	ABB group: 43,6 / CXBB group: 45,3	ABB: 12♂ 20♀/ CXBB: 10♂ 22♀
Wang M et al.(26)	CAAB group: 38,67 / ABB group: 29,83	CAAB group: 6♂ 6♀/ ABB group: 4♂ 8♀
Thoma DS et al.(27)	Xenogeneic block group: 56,17 / Autogenous block: 47,5	N/A

ABG: Autogenous Block Graft; GBR: Guided Bone regeneration; ABB: Autogenous Bone Block; CXBB: Collagenated Xenogeneic Bone Blocks; CAAB: Customized Allogeneic Bone Block.

Table 7. Data extracted from the articles, horizontal width, and graft resorption.

Authors	Techniques / *Graft + membrane*	N^3	W^1	W^2	W^3	Horizontal width gain	Graft resorption
Aboelela SAA et al.(17)	GBR with resorbable membrane / *1:1 Particulate AB + ABBM + collagen membrane*	14	6,77	9,70	9,00	2,23	0,7
	GBR with resorbable membrane / *1:1 Particulate AB + ABBM + AFG + CGF*	14	6,09	9,37	7,90	1,81	1,47
Ahmadi RS et al.(18)	Block graft / *Corticocancellous freeze-dried allograft bone block*	10	3,09	8,69	6,9	3,81	1,79
Atef M et al.(6)	GBR with resorbable membrane / *1:1 Particulate AB + ABBM + collagen membrane*	10	3,30	7,90	7,30	4,00	0,6
	GBR with non-resorbable membrane / *1:1 Particulate AB + ABBM + titanium mesh*	10	3,60	8,00	7,00	3,40	1
Bartols A et al.(19)	Block grafts	14	2,67	8,93	6,60	3,93	2,33
	GBR with resorbable membrane / *SonicWeld Rx shell technique (Poly-D-L-Lactide foil + autogenous and deproteinized bovine bone particles (SWST))*	8	2,20	9,00	7,18	4,98	1,82

Crespi R et al.(20)	Split crest	38	3,70	N/A	7,65	3,95	N/A
Elraee L et al.(21)	Block graft / *Dentin block*	21	4,35	8,43	7,91	3,56	0,52
	Block graft / *AB block*	21	4,17	8,32	6,99	2,82	1,33
Işık G et al.(22)	GBR with resorbable membrane / *Bovine xenograft + liquid PRF*	22	N/A	3,12	2,44	N/A	0,68
	GBR with resorbable membrane/ *Bovine xenograft*	22	N/A	3,09	2,27	N/A	0,82
Meloni SM et al.(23)	GBR with resorbable membranes / *1:1 Particulate xenograft + AB + collagen membrane*	18	3,07	N/A	8,09	5,02	N/A
Mendoza-Azpur G et al.(24)	Combination GBR with block / *Particulate xenograft + collagen membrane + AB block*	21	2,80	N/A	7,60	4,80	N/A
	GBR with resorbable membrane / *Particulate xenograft + collagen membrane*	18	3,00	N/A	8,60	5,60	N/A
Romito GA et al.(25)	Block graft / AB block	30	2,95	N/A	6,47	3,52	N/A
	Block graft */ Collagenated xenogenic bone block*	30	2,65	N/A	6,34	3,69	N/A

Wang M et al.(26)	Block graft / *Customized allogenic bone block*	12	4,53	10,65	8,63	4,10	2,02
	Block graft / *AB block*	12	4,03	9,26	6,52	2,49	2,74
Thoma DS et al.(27)	Block graft / *Xenogeneic bone block with rhBMP-2*	11	3,18	7,55	6,91	3,73	0,64
	Block graft / *AB block*	11	2,18	7,18	6,73	4,55	0,45

W1: Preoperative horizontal width (mm); W2: Postoperative horizontal width (mm); W3: Follow-up horizontal width (mm); GBR: Guided bone regeneration; AB: autogenous bone, ABBM: Anorganic bovine bone mineral; AFG: Autologous fibrin glue; CGF: Concentrated growth factors; DDBM: Deproteinized bovine-derived bone mineral; PRF: Platelet rich fibrin.

Table 8. Mean horizontal width gain and graft resorption according to the surgical technique used.

Techniques	n	Mean horizontal width gain (mm)	n	Mean graft resorption (mm)
GBR with resorbable membranes	82	3,99	90	0,93
GBR with non-resorbable membranes	10	3,40	10	1,00
Block graft	172	3,57	112	1,42
Split crest	38	3,95	N/A	N/A
Combination GBR with block	21	4,80	N/A	N/A

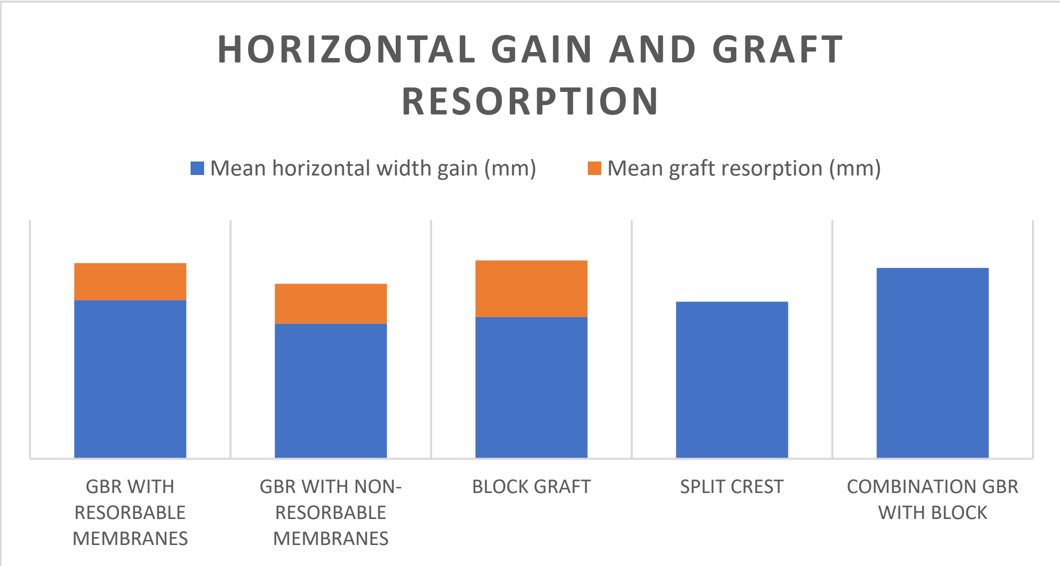

Figure 10. Comparison of the horizontal gain and graft resorption of the different techniques studied.

5. DISCUSSION

This review was aimed at evaluating the horizontal bone gain and graft resorption to secondly state whether among the surgical techniques studied one would be more effective to achieve horizontal augmentation.

5.1 Guided bone regeneration

In their review of 2014, Benic and Hammerle demonstrated the high efficiency of horizontal regeneration using guided bone regeneration (5). These last years, new techniques and materials were developed, thus different membranes, resorbable or not, were studied.

Atef and al. compared native collagen membrane and titanium mesh and found that both techniques obtained good results for horizontal gain (6). Nevertheless, the results obtained through this review (Table 8) revealed a higher bone gain with less graft resorption when GBR was performed with resorbable compared to GBR with a non-resorbable membrane. The results obtained with GBR with resorbable membrane coincide with the results obtained by the systematic review conducted by Troeltzsch et al. who obtained a mean horizontal gain of 3.7mm (28). However, they contrast with the results found by Wessing et al. of 2,27mm of mean horizontal bone gain for this type of membrane (29).

Non-resorbable membranes have the disadvantage of requiring a second surgery for their removal and imply more frequent membrane exposure (30). Atef et al. described a higher complication rate (soft tissue dehiscence) in addition to an increased removal difficulty of the barrier due to soft tissue infiltration through the mesh, increasing its removal difficulty, in the group treated by GBR with the non-resorbable membrane (Titanium mesh) (6). GBR with a non-resorbable membrane is described as a highly technique-sensitive procedure that might lead to complications while another review written by Ricci et al. evaluated titanium grid exposure in 22,78% of the patient (6,31). The lack of flexibility of the titanium grid exposure or the suturing technique used would be responsible for the premature exposure, without causing infection or decreased bone gain due to the lack of inflammation following it (32). Aboela et al. described that the use of CGF (Concentrated Growth Factor) membrane did not show a significant difference in treating bone gain when compared to collagen membrane but also highlighted the non-predictability of CGF membrane for GBR (17).

Studies also compared the graft material used for GBR. Isik et al. studied the bovine-derived xenograft in combination with liquid PRF (Platelet Rich Factors) or alone and did not obtain significantly different results (22). However, Wessing et al. described better results when autogenous was mixed with allogeneic or xenogeneic grafts instead of using synthetic materials alone (29).

5.2 Block grafting

Among the techniques studied in this review, horizontal regeneration by means of block graft obtained successful results (Table 8). Unlike the finding of this review, Gultekin et al. obtained better results in patients receiving extraoral autogenous block graft (6,52 mm) than in the patients treated by GBR (5,31 mm) (33). In their study, Ahmadi et al. assessed clinically and histologically corticocancellous allograft block and conclude, despite the short follow-up, that it obtained good results (18). Among the selected studies, two compared xenografts block with autogenous block. Studies conducted by Thoma et al., that used xenograft block combined with rhBMP-2 (27), and Romito et al., that used xenograft alone (25), did not show significant differences in lateral augmentation when compared to augmentation made with autogenous block graft. Wang et al. for their part, obtained more horizontal width gain and less resorption using customized allogenic bone blocks instead of autogenous blocks (26). Elraee et al. also demonstrated less resorption of the dentin block graft compared to autogenous blocks (21).

Autogenous block graft is a surgical intervention that would require harvesting bone from an intra or extra-oral bone donor site. Hence this intervention is highly dependent on the surgeon's skills and can be responsible for the patient’s discomfort due to increased morbidity and operative time (7). The use of other types of material to achieve block graft would present clinical advantages, Wang et al. showed that customized allogenic bone blocks reduce operative time (26) and Elraee et al. presented the dentin block as an alternative to autogenous block (21).

5.3 Combination techniques

In their review, Mc Allister et al. highlight the advantages of the combination of guided bone regeneration with block graft, this combination would provide support and prevent collapsing of the membrane in the space of the grafted site (11). Results described in table 8 showed that a combination of guided bone regeneration with block graft obtained the best results regarding horizontal gain. However, the superiority of this technique for horizontal regeneration could be discussed given the size of the sample studied in this review in addition to the lack of information about graft resorption. Furthermore, Mendoza et al. showed that guided bone regeneration with or without block graft may be an effective technique to restore horizontal dimension to maxillary and mandibular ridges (24).

5.4 Split crest technique

Good results were obtained using the split crest technique horizontal width gain in the Crespi et al. study, especially in posterior areas of the maxilla. However, no data assessing graft resorption were provided (20). If realized by a skilled professional with sufficient grafting material, good tissue protection and stabilization, and providing adequate vascularization this technique would provide results comparable to the other techniques (11).

5.5 Update decision tree of Yu and Wang

Guidelines presented in the form of a decision tree (Annex 1) were established in 2022 by Yu and Wang to choose the appropriate technique to perform horizontal augmentation depending on the amount of bone needed. The article mentioned that for ridges minor ridges defects (requiring less than 3mm) and moderate ridge defects (requiring between 3 and 6mm), guided bone regeneration, bone augmentation with titanium mesh, autogenous or allogenic block grafting, crest splitting would be indicated. For severe ridge defects (requiring more than 6mm), the authors recommended proceeding to guided bone regeneration, bone augmentation with titanium mesh, or block grafting (30).

6. CONCLUSION

The loss of the alveolar bone is a consequence following the loss of one or several teeth that may limit the possibility of prosthetic treatments. Horizontal regeneration is a key phase in the rehabilitation by the mean of implants of a patient with important bone loss. It exists a grand variety of surgical techniques and materials to achieve it.

No significant differences in horizontal width gain were found between the studied techniques. The same conclusion was reached when treating the stability of the graft that was studied by its resorption. Thus, this review did not allow us to point out which surgical intervention would be the best to achieve horizontal regeneration. Indeed, all the techniques studied in this review demonstrated great efficacy to achieve this objective. The techniques chosen may depend on the size of the defect, but also the skills of the surgeon, his experience with the technique, and the potential complications.

Among the limitation of this review, it can be highlighted the relatively small sample of patients in the included studies but also the partial information provided in some of them. Demographic data and results of the variables of interest were missing in some of the selected articles. Indeed, horizontal width gain or graft resorption were missing in some of the included articles and the diversity of measurement methods of these variables among the articles can be a source of bias.

Future research with greater samples, including complications, implant survival, and stability must be conducted with standardized measurement methods to evaluate the most appropriate technique according to the situation.

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8. ANNEXES

Annex 1. Decision tree established by Yu and Wang for horizontal augmentation according to buccal width deficiency (30).