UNIVERSIDADE FERNANDO PESSOA

EFFICACY OF I. URBAN AND F. KHOURY TECHNIQUES IN GUIDED BONE REGENERATION: A SYSTEMATIC REVIEW

Dissertação de Mestrado

[Mestrado Integrado em Medicina Dentária]

Erica Pasqualini

Orientadores:

Filipe Miguel Correia de Castro

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DEDICATION

Agradeço ao meu orientador Filipe Miguel Correia de Castro por me acompanhar até esta última meta, ajudando-me e apoiando-me e por ter confiado em mim ao atribuir-me um tema tão interessante e avançado, não só despertando o meu interesse pelo mundo da cirurgia óssea guiada, mas também mostrando-me um caminho que gostaria de seguir num futuro próximo.

Dedico esta conquista aos meus pais, a quem devo tudo. Agradeço por todas as oportunidades que me deram na vida, por todos os sacrifícios que fizeram por mim e que ainda hoje fazem. Agradeço por serem sempre os meus primeiros fãs, por me apoiarem, me ajudarem e, acima de tudo, por me suportarem. Se hoje cheguei até aqui, é graças a vocês, aos vossos carinhos, aos vossos ensinamentos e lições. À minha mãe, que é a pessoa mais forte que conheço, espero me tornar pelo menos metade da mulher que tu és. Ao meu pai, sempre sorridente e brincalhão, sempre ao meu lado e pronto para torcer por mim. Ver nos seus olhos as paixões que carrega consigo é uma das maiores inspirações. Agradeço-vos por me terem dado este sorriso, pelo qual, em dias como este, não posso deixar de olhar com orgulho e ver um pouco de vocês em mim. Amo-vos.

Aos meus irmãos. As partes mais bonitas de mim, um dos presentes mais bonitos que a vida me deu e do qual não poderia prescindir.

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Agradeço aos meus colegas de casa: Veronica, Lorenzo, Ludovico, Karim e Chiara. Por me terem acompanhado nesta aventura de cinco anos. Deram-me recordações preciosas que levarei no meu coração para toda a vida. Vocês foram a noite e o dia desta jornada e as âncoras de salvação que me mantiveram à tona, mesmo tão longe de casa. Tornando-se para mim uma segunda família.

Por fim, agradeço a Carmela, Sonn, Damiani, Moreno, Sofia e Giovanna. Todas pessoas profundamente diferentes que entraram na minha vida num dia qualquer e a transformaram. Se hoje sou a pessoa que sou, é também graças a vocês.

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I dedicate this achievement to my parents, to whom I owe everything. I am grateful for all the opportunities they have given me in life, for all the sacrifices they have made for me and continue to make today. I am grateful for always being my biggest fans, for supporting me, helping me and, above all, for putting up with me. If I have made it this far today, it is thanks to you, your affection, your teachings and lessons. To my mother, who is the strongest person I know, I hope to become at least half the woman you are. To my father, always smiling and playful, always by my side and ready to cheer me on. Seeing the passions you carry with you in your eyes is one of my greatest inspirations. I thank you for giving me this smile, which, on days like this, I cannot help but look at with pride and see a little bit of you in me. I love you.

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I thank my brother Ermanno, my lifelong accomplice. I thank him for always being by my side with patience, kindness and joy.

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I thank my housemates: Veronica, Lorenzo, Ludovico, Karim and Chiara. For accompanying me on this five-year adventure. You have given me precious memories that I will carry in my heart for the rest of my life. You were the night and day of this journey and the anchors of salvation that kept me afloat, even so far from home. You became a second family to me.

Finally, I would like to thank Carmela, Sonn, Damiani, Moreno, Sofia and Giovanna. All profoundly different people who came into my life one day and transformed it. If I am the person I am today, it is also thanks to you.

RESUMO

Introduçao: A regeneração óssea guiada (GBR) é um dos meios mais importantes de reabilitação com implantes em casos de atrofia óssea maciça. Entre os procedimentos mais testados e comprovados, a técnica da concha de Khoury e a técnica da salsicha de Urban diferem na sua metodologia em relação à estabilidade do coágulo e ao material de enxerto. **Objectivo:** Esta revisão sistemática tem como objetivo contrastar a eficácia clínica e a previsibilidade dos dois tratamentos no tratamento de defeitos horizontais e verticais, com base nas evidências científicas mais recentes. **Materiais e métodos:** Foram pesquisadas cinco bases de dados eletrónicas (PubMed, Cochrane Library, Ebsco, B-On, ScienceDirect) e complementadas com pesquisa manual. Foram incluídos estudos clínicos dos últimos cinco anos, em língua inglesa, realizados em seres humanos, com acompanhamento mínimo de seis meses e com menção específica à utilização da técnica de Khoury ou Urban. A qualidade do método nos estudos foi avaliada utilizando a Ferramenta de Avaliação Crítica JBI. Doze estudos foram incluídos na síntese qualitativa. **Resultados:** Foram encontrados 13 artigos que compõem este trabalho. De acordo com os resultados, ambos os métodos permitem um ganho ósseo médio clinicamente significativo, com uma tendência para melhores resultados nos métodos de modo puro em comparação com as variantes. A técnica Shell também se revelou muito eficaz para defeitos tridimensionais complexos com maior estabilidade a longo prazo, enquanto a técnica Sausage se revelou universalmente eficaz em defeitos horizontais devido à facilidade da cirurgia e à utilização de membranas reabsorvíveis. **Conclusao:** Ambas as técnicas são métodos seguros em GBR com indicações específicas, dependendo da anatomia do defeito e do manuseamento dos tecidos moles. Devem ser realizados ensaios clínicos aleatórios com séries de casos mais elevadas, a fim de estabelecer protocolos padronizados e previsíveis.

Palavra-chave: procedimentos de enxerto ósseo; aumento do rebordo; enxerto autógeno; bloco ósseo; resultados clínicos; complicações.

ABSTRACT

Background: Guided bone regeneration (GBR) is one of the most important means of implant rehabilitation in cases of massive bone atrophy. Among the most tried and tested procedures, Khoury's Shell Technique and Urban's Sausage Technique differ in their methodology towards clot stability and grafting material. **Objective:** This systematic review aims to contrast the clinical efficacy and predictability of the two treatments in horizontal and vertical defect treatment, based on the most current scientific evidence. **Methodology:** The electronic databases searched were five in total (PubMed, Cochrane Library, Embase, B-On, ScienceDirect) and complemented with manual search. Clinical studies from the last five years, English language, conducted on human subjects, follow-up of a minimum of six months and with specific mention of utilization of Khoury or Urban technique included. The method quality in the studies was assessed using the JBI Critical Appraisal Tool. Twelve studies were included in the qualitative synthesis. **Results:** 13 articles were found that constitute this work. According to the findings, both methods allow clinically significant average bone gain, with a trend towards improved results in the pure mode methods compared with the variants. The Shell Technique was also found to be very effective for complex three-dimensional defects with greater long-term stability, while the Sausage Technique was found to be universally effective in horizontal defects due to ease of surgery and the use of resorbable membranes. **Conclusion:** Both the techniques are safe methods in GBR with specific indications depending on defect anatomy and handling of soft tissues. Higher case series randomized clinical trials should be conducted in order to set standardized and predictable protocols.

Keyword: bone grafting procedures; ridge augmentation; autogenous graft; bone block; clinical results; complications

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LIST OF ABBRFEVIATIONS AND ACRONYMS

3D mesh 3D-printed titanium mesh

ABBM anorganic bovine bone mineral

BMPs Bone Morphogenic Proteins

CAD/CAM Computer-aided design/Computer-aided manufacturing

CBCT Cone Beam Computed Tomography

DBBM deproteinized bovine Bone Mineral

DFDBA Demineralized and freeze-dried allogeneic bone graft

e-PTFE expanded polytetrafluoroethylene

GBR   Guided Bone Regeneration

GTR Guided Tissue Regeneration

HBW   horizontal bone width

RCT randomized controlled trial

SPTT Subperiosteal Tunnel Technique

SBB Split bone Block technique

Ti-mesh Titanium mesh

I. INTRODUCTION

I.1 Evolution, Biological Principles and Clinical Applications of GBR

GBR is an advanced surgical technique and one of the most well-documented bone defect reconstruction therapies for alveolar atrophy, vertical and horizontal, in patients. GBR is a cellular biological process by which selection of cells is done with physical barriers, and it was developed based on the concept of GTR. Nyman et al. (1982) and Gottlow et al. (1984) were the first to demonstrate that regeneration of a specific tissue is feasible only when unwanted cells are excluded from entering the location. Practising these principles in bone, GBR depends upon the exclusion of soft tissue cells and channelling of osteoblasts and bone progenitor cells through the application of a selective barrier membrane (Retzepi and Donos, 2010), The biological principle is based on four fundamentals:

- selective isolation from soft tissues;

- provision of a three-dimensional support for cell growth.

- good vascularisation to provide the supply of nutrients and osteogenic cells.

- mechanical stability of the clot and barrier as physical and, in accordance with recent literature, also bioactive barrier (Buser et al., 1995; Retzepi and Donos ,2010)

The main goal of GBR is to create adequate bone volume for the correct positioning and long-term osseointegration of dental implants, especially in the most functionally and aesthetically challenging areas. It is among the most developed and validated protocols of pre-implant surgery due to its very high predictable success in complicated clinical cases (Buser et al., 2023).

On this matter, the authors suggested two main techniques for GBR: the simultaneous one, wherein implant placement and bone regeneration take place at the same time, and the staged one, wherein operating time is utilized for regeneration, followed later by implant placement.

The first clinical application of GBR in implantology dates back to 1988 when Dahlin et al. (1988) were able to form new bone around tibial implants of rats through e-PTFE membranes, forming the foundation of the use of barriers in implant regenerative surgery.

GBR has since then become one of the fundamental cornerstones of pre-implant and maxillofacial surgery. (Dahlin et al. 1988; Murray et al.,1957)

The theoretical basis for this is the creation of a mechanically stable, closed and well-perfused space in which the membrane plays not only the role of a physical barrier but also that of a bioactive matrix for cell migration and tissue stimulation. Three phases are distinguishable in the course of historical development of GBR, according to Buser et al.(2022) - pioneering phase (1988-1995), where non-resorbable membranes and autologous grafts in staged mode were used; - consolidation phase (1995-2010), which was distinguished by the appearance of resorbable collagen membranes and the principle of mixed grafting (autologous + ABBM) (autologous + DBBM) - current phase (2010 and subsequent), distinguished by a biotechnological breakthrough with the use of CAD/CAM, 3D scaffolds, bioactive membranes and immuno-modulator principles to induce regeneration specifically (Buser et al., 2023; Buser , 2022; Di Spirito et al., 2024; Urban et al., 2023).

The advent of 3D printing and digital planning has further broadened the clinical application of GBR. Di Spirito et al. (2024) confirm that the use of customized titanium mesh, 3D-printed membranes and bioresorbable scaffolds now makes the patient's anatomy-specific tailor-made concept possible, with advantages of stability, operating time and reduction of postoperative complications.

Clinically, GBR is used in a broad range of cases such as localized or generalized bone defects due to atrophy, extractions, trauma or infection. Bone resorption is a natural and physiological process that can be intensified by old age, tooth loss, extended use of dentures or systemic illness. The absence of periodontal ligament fibre stimulation after tooth extraction can accelerate bone loss, requiring the regenerative treatments to provide adequate bone volume for implant restorative procedures. Bone grafting is one of the most important components of GBR. Grafts may be autologous, allogeneic, xenogeneic or alloplastic, and their success depends on four basic characteristics: Osteoconduction: the ability of the material to act as a 'scaffold' for bone growth (Albrektsson et al.,2001)- Osteoinduction: ability to induce cellular differentiation (Urist et al., 1965; Reddi et al., 1981); through mediators such as BMPs; Osteopromotion: activation of osteoinduction (e.g. DFDBA) even without intrinsic properties (Laurencin et al., 2006); Osteogenesis:

the intrinsic property of the material, with living cells (autologous graft), to produce new bone (Giannaudis et al., 2005; Laurencin et al., 2006).

Keeping this in view, GBR must be conceived as a 'stable regenerative environment' where mechanical immobility, periosteal planes preservation and vascular stimulation are absolute necessities. The study also implies a paradigm shift: GBR must no longer be centered on 'elite materials', but on minimally invasive procedures that respect the biology of the recipient site, such as SPTT or INTRALIFT, performed with piezo surgical techniques that preserve the integrity of the periosteum. (Troedhan et al., 2015)

Through the classification system applied by Cawood and Howell (1988), it is possible to make a precise measurement of the degree of atrophy of an edentulous maxilla and determine the optimal GBR method based on that. Selecting among membrane (e-PTFE, collagen, Ti-mesh), material (autologous grafting or substitute grafts), and, as an optional treatment method, customized technology (3D mesh, scaffold), modern dentistry provides ever-improving matching surgical adaptation to the most divergent morphologies of bones with increasingly improved outcomes (Urban et al., 2023; Troedhan et al., 2015).

We can therefore conclude that GBR has become a significant technique in implant rehabilitation, founded on sound biological principles, remarkable technological developments and constant refinement in clinical procedures. It is a convergence of science, surgery and computer technology that is able to offer increasingly predictable regenerative therapy and customized solutions even in the most clinically demanding situations, aimed towards long-term implant success.

In the last fifteen years, there have been two advanced techniques of GBR developed: Istvan Urban's technique, based on collagen membranes and composite grafts; Fouad Khoury's technique, based on the exclusive use of autogenous bone.

They have in common the objective of attaining stable healing but diverge in material and handling of the regenerative site. Urban is concerned with the membrane's role; Khoury with the osteogenic role of viable bone.

I.2 F. Khouy Introduction and his Technique

Bone regeneration is perhaps the most complex clinical case in implant surgery, not so much because of the technical difficulty of three-dimensional reconstruction of the ridge, but above all because of the need to maintain a sequence of elementary biological demand, Fouad Khoury, one of the main promoters of guided regeneration based on autologous bone, he is considered one of the world's foremost experts in the field of bone and soft tissue regenerative surgery. (Khoury,2021). Khoury (2021) has developed a technique that diverges from standard protocols according to the use of biomaterials and artificial membranes (e-PTFE, collagen, synthetic polymers); he proposes the use of autologous cortical bone as natural barrier, capable of undertaking the biological mechanisms that rule the regeneration process, with the advantage of being biologically active and osteogenic. Autologous bone is not a 'filler' alone: it is living tissue, and it can actively participate in new bone formation owing to its osteogenic, osteoinductive and osteoconductive features. (Albrektsson T and Johansson C. 2001; MCAllister BS and Haghighat K., 2007; Sakkas A. et al,2017; Khoury F., 22021) It is the only substance capable of delivering viable cells, growth factors, and scaffold structure, factors no heterologous or synthetic biomaterial can replicate in an equivalent way. (Khoury, 2021)

As Khoury (2021) states, there are three conditions to accomplish successful bone regeneration: 1) Initial stability of the clot, which has to be fixed from micro-movements and thus not damaged in cell differentiation. 2) Maintenance of the regenerative space, and for this a stable but permeable structure has to exist where vascular colonization is possible. 3) Exclusion of soft tissue from the bone space, since cell competition from the connective tissue would compromise bone neogenesis. And what makes the method even more significant is the employment of cortical bone as a firm and natural retaining structure, rather than synthetic membranes; according to Khoury, cortical bone, due to its density and slow ability to remodel, is best suited for structural applications, while spongy bone is best suited for vascular invasion and initial implantation of living bone (Khoury, 2021, pp. 14-17).

Another significant consideration is donor site selection, not to be determined by case convenience but by the histological character of bone excised. The choice of intraoral donor sites (mandibular symphysis and oblique line, chin bone, tuberosity) is thus never casual but weighted according to the nature of the defect to be cured and of the histological type of the desired graft. One of the basic precepts of the Khoury technique is the promptness of harvesting and grafting: any minute lost between harvesting and grafting is an added loss of cell viability.

It is because of this that it can be said that the model proposed by Khoury (2021) is a combination of surgical and biological method, where the surgeon also plays a basic role in the completion of a physiological process where autologous bone is the central. It is on these foundations that his two main techniques, the Shell technique and the SBB proposed by Khoury in 2004, are developed. They are practical expressions of these concepts: techniques to attempt to combine primary mechanical stability and the natural biology of the regeneration process and are the clinical implementation of this vision and an effective treatment technique for horizontally and vertically positioned defects. (Doliveux and Doliveux, 2024; De Angelis et al., 2024)

The shell technique recommended by author Khoury et al (2006) is described as a technique wherein a block of autologous bone is harvested from the line of the external oblique of the mandible and divided into two twin blocks which are stabilised using microscrews as recipient sites, shaped and fixed around the defect. (Khoury F et al, 2007; Khoury F. and Hanser, 2019; Khoury, 2021; Villa et al., 2023).

This technique relies on the positioning of thin plates of cortical bone immobilized at the graft site with screws (instead of the conventional membrane) to form an internal cavity that is then packed with other bone. The particulate bone implanted enhances vascularisation of the graft and bone regeneration, while mechanical stability is provided by the cortical bone (Sbordone L. et al, 2009 ; Khoury F. And Hanser T., 2015; Yu H. et al, 2016; Shaker et al., 2024). The most active donor site in this procedure is the line of the mandible's external oblique and mandibular symphysis; however, other studies suggest the maxillary wall as another option (Rodriguez-Recio O. et al, 2010; Anitua E. et al, 2014; Gluckman H. et al, 2016; Moussa M. et al, 2016).

I.3 Introduction of I. Urban and his Technique

Dr Istvan Urban is one of the best known practitioners of oral regenerative surgery today, and particularly in the field of GBR. Urban has based his clinical and scientific practice on the very straightforward philosophy of combining biologically sound treatments with minimally invasive surgical techniques. His most significant contribution is in the development of consistent methods for ridge augmentation by means of mechanical clot stability and optimal management of soft tissues (Urban, 2017).

Of the most relevant innovations brought about by Urban, so-called Sausage Technique has had the greatest impact on horizontal regeneration's clinical practice. The origin of the term 'sausage' lies in the characteristic form that the membrane covering the grafted material takes, calling to mind the image of a 'sausage'. Urban is based on fixation of resorbable collagen membranes using pins or micro screws, which serve to ensure stability to the rigidly compacted graft material in the bone defect, volume stability and keep the membrane in the head (Pieroni et al., 2024), preferred with clot stabilization and promotion of a good space for bone neogenesis (Urban, 2017). To offer a lower complication rate, Urban's technique also doesn't involve a second procedure for membrane and/or pines removal (Pieroni et al., 2024; Meloni et al., 2019).

The Sausage Technique finds its ideal indication in alveolar ridge horizontal defects, particularly in thin ridge ('knife-edge') and moderate severe horizontal atrophies (Meloni et al., 2019). It is, nevertheless, less indicated for compound three-dimensional defects or isolated vertical defects, where greater three-dimensional stability is required, which may render the utilization of rigid support devices imperative (Urban, 2017).

Two fundamental biological principles underlie the success of the Sausage Technique: first, the stability of the blood clot and graft material that is essential in the early healing phase for ingress and proliferation of osteoprogenitor cells; and second, the maintenance of the regenerative space through membrane tension that prevents collapse of the soft tissue and protects the site from invasion by non-osteogenic epithelial cells (Urban, 2017).

Through this technique, Urban has offered an advanced form of horizontal bone regeneration with an easier surgical protocol and a reduced risk of failure related to soft tissue management, as well as improved clinical and histological results in the medium to long term.

I.4 Objectives

Urban proposes GBR through the use of collagen membranes and composite graft, while Khoury relies on autologous bone architecture. Both can offer predictability and clinical success depending on some indications. The aim of this article is to contrast both their methods and help clinicians choose the method depending on the type of defect, availability of donor bone, and surgeon preference.

II. METHODOLOGY

This Study followed the PRISMA 2020 statement for systematic reviews and the research question was formulated using the PICO (Population, Intervention, Comparison, Outcome) format.

II.1. SEARCH AND SCREENING

II.1.2 Protocol development

In this review paper, the authors report according to PRISMA (Preferred Reporting Items Systematic Review and Meta Analyses) (Page et al., 2021) checklist, only articles with scientific evidence in the treatment of vertical and/ or horizontal defects in maxilla and/ or mandibula treated with I. Urban and F. Khoury in the context GBR were investigated.

II.1.2 Statement of questions

For the development of this work, it was formulated a clinical question, through the P.I.C.O.S. strategy:

- P (Population): Patients with vertical and/or horizontal alveolar ridge defects.
- I (Intervention): GBR in patients with vertical and/or horizontal bone defects.
- C (Comparison): Urban and Khoury techniques
- O (Outcome): Average bone gain.
- S (study type): Clinical human studies with at least 6 month follow up.

II.1.3 Search strategy

According to the protocol described, an electronic research on PubMed, Ebsco, Cochrane Library, B-on, Science direct and a manual research were carried out to identify studies testing:

- GBR (guided bone regeneration)
- Vertical bone regeneration
- Horizontal bone regeneration

Additionally, hand search covering the last 5 years was performed on Journal of Clinical Periodontology, Journal of Periodontology, Clinical Oral Investigations, The International Journal of Periodontics and Restorative Dentistry, Journal of Oral &

Maxillofacial Surgery, International Journal of Oral & Maxillofacial Implants, International Journal of Oral Implantology and Journal of Periodontal Research. The references of included and relevant papers were checked for possible additional studies, and authors were contacted to clarify any doubt about data.

The research in the electronic databases was supplemented by crosschecking the bibliographies of the included articles, relevant reviews and by a manual search in the principal journals in the field of periodontology and implantology up to March 2025.

The search covered period from March 2019 to March 2025.

II.1.3.1 Database

Online search was conducted on PubMed, Cochrane Library, B-on, Science Direct and Ebsco. Only Case Reports, Cohort Studies, Case Control Study, Randomized Controlled Trials, Case Series, with a minimum follow-up of six months, and studies utilizing horizontal/vertical ridge augmentation or both with Urban and/or Khoury techniques were included**.**

II.1.3.2 Search query:

The research on PubMed, Ebsco, B-on, Science Direct and Cochrane Library was conducted using the following combination of Search terms such as “bone grafting procedures,” “ridge augmentation,” “autogenous graft,“bone block,” “clinical results,” and “complications,” connected by Boolean operators “AND” and “OR.”

II.2 ELIGIBILITY CRITERIA

II.2.1 Inclusion criteria

Inclusion criteria are: publication within the last five years, studies in English, human studies, study types (Case Reports, Clinical Studies, Clinical Trials, Randomized Controlled Trials, Observational Studies, Comparative Studies, Case Series), a minimum follow-up of six months, and studies utilizing horizontal/vertical ridge augmentation or both with Urban or Khoury techniques.

II.2.2 The exclusion criteria

Secondary studies as bibliographic review, systematic review and meta-analysis, in vitro studies, animal studies, factors negatively influencing GBR (e.g., smoking >10 cigarettes/day, uncontrolled diabetes, severe periodontitis, osteoporosis, poor oral hygiene, graft instability, membrane exposure, and non-standard material choices) as well as studies not employing Urban or Khoury techniques were excluded.

II.2.3 Condition being studied.

The condition being studied is the presence of vertical and/or horizontal alveolar ridge defect in partially or totally edentulous patients, which require bone regeneration prior to implant placement. The review should focused on interventions using GBR through the Urban or Khoury technique to restore bone volume for predictable implant's supported rehabilitation.

II.2.4 Main outcome

In the Main Outcomes we will analyze which of these techniques offers the greatest bone augmentation after a follow-up period.

II.2.5 Additional Outcomes

In order to better understand these data, the correct indications for the use of these techniques will also be explained in this systematic review, so as to provide clinicians with guidance on when to use these techniques in order to achieve the best clinical results.

II.3 DATA EXTRACTION

II.3.1 Study selection

Initially, the studies appearing to meet the inclusion criteria, or those with insufficient data in the title and abstract to make a clear decision, will be selected for the evaluation of the full manuscript.

All studies meeting the inclusion criteria will undergo a validity assessment. The reasons for rejecting studies at this or at subsequent stages will be recorded. Special attention will be paid not to duplicate publications in order to avoid a likely bigger impact of the same data in the overall result.

Reference management was conducted using Mendeley, and article selection was supported by manual cross checking.

The selection process is illustrated in the PRISMA 2020.

II.3.2 Data collection process

Online research was conducted on PubMed, Cochrane Library, B-on, Science Direct and Ebsco, only articles from the last 5 years (2019-2025) were evaluated.

Initial research led to:

- On PubMed: 1080 results between 2019 and 2024 ;
- On Ebsco: 58 articles
- On the Cochrane Library: 451 Trials
- On Science Direct: 32,028
- On B-on: 219.638

All non-relevant articles (ex: based on other arguments, on animals, focused on other technique) were excluded. The most relevant works with the theme of this article were then chosen, namely:

- From Pubmed 2 articles
- From Ebsco 1 articles
- From Cochrane 2 articles
- From B-on 5 articles
- From Science direct 2 articles

3 articles were repeated between Pubmed and Cochrane and B-on; 1 more articles had been added by manual.

Identification of studies via databases and registers

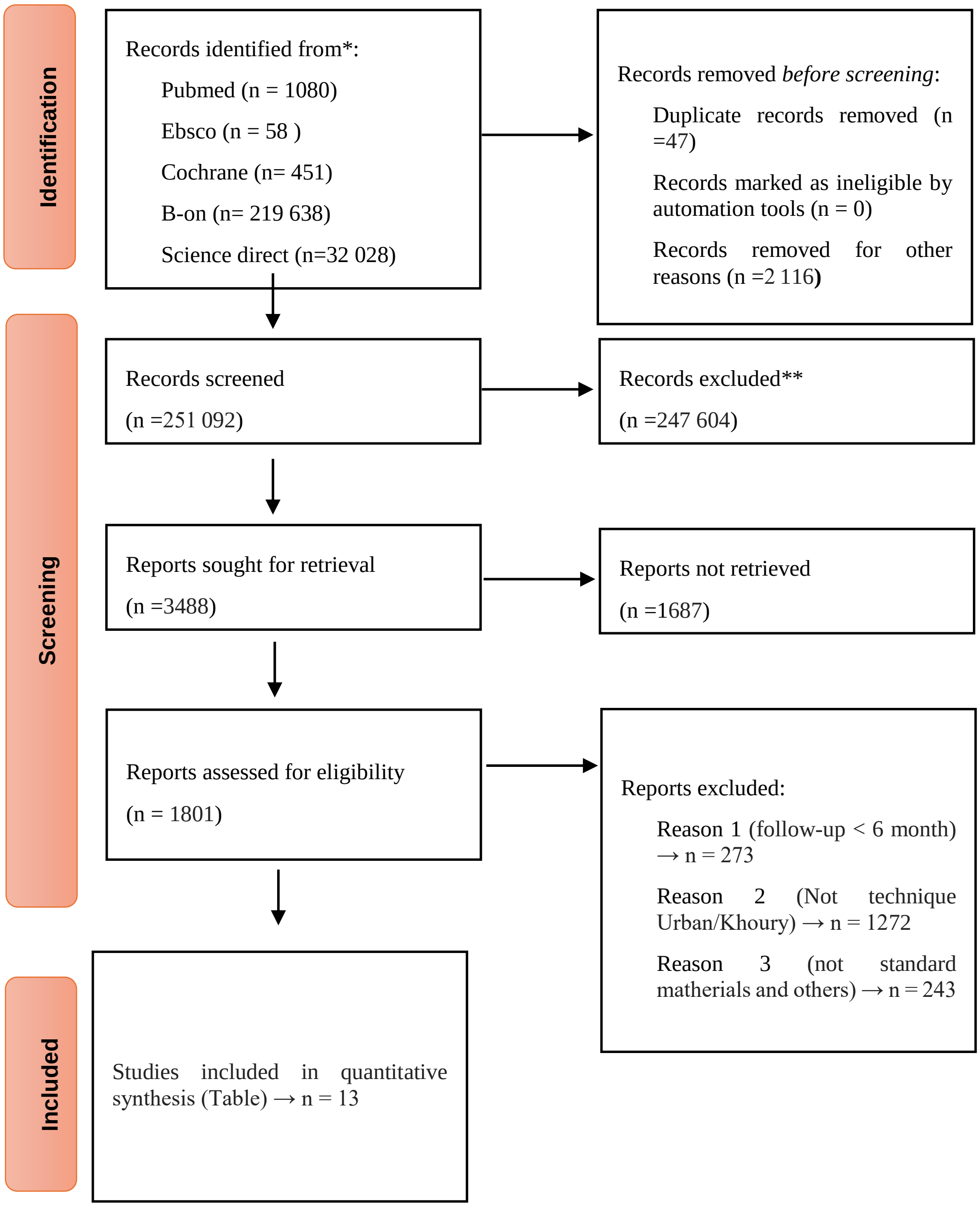

Figure 1. *PRISMA figure for the studies selected*

The final search led to 13 articles that can be included in this work:

1. Khoury, F., & Hanser, T. (2019). Three-dimensional vertical alveolar ridge augmentation in the posterior maxilla: A 10-year clinical study. *International Journal of Oral & Maxillofacial Implants*, *34*(3), 471–480. https://doi.org/10.11607/jomi.6869

2. Meloni, S. M., Jovanovic, S. A., Urban, I., Baldoni, E., Pisano, M., & Tallarico, M. (2019). Horizontal ridge augmentation using GBR with a native collagen membrane and 1:1 ratio of particulate xenograft and autologous bone: A 3-year after final loading prospective clinical study. *Clinical Implant Dentistry and Related Research*, *21*(4), 669–677. https://doi.org/10.1111/cid.12808
3. Tunkel, J., de Stavola, L., & Kloss-Brandstätter, A. (2021). Alveolar ridge augmentation using the shell technique with allogeneic and autogenous bone plates in a split-mouth design—A retrospective case report from five patients. *Clinical Case Reports*, *9*, e04761. https://doi.org/10.1002/ccr3.47
4. Khoury, F., & Hanser, T. (2022). 3D vertical alveolar crest augmentation in the posterior mandible using the tunnel technique: A 10-year clinical study. *International Journal of Oral Implantology*, *15*(2), 111–126.
5. Arnal, H. M., Angioni, C. D., Gaultier, F., Urbinelli, R., & Urban, I. A. (2022). Horizontal guided bone regeneration on knife-edge ridges: A retrospective case–control pilot study comparing two surgical techniques. *Clinical Implant Dentistry and Related Research*, *24*(2), 211–221. https://doi.org/10.1111/cid.13073
6. Kim, K. M., Choi, S. Y., Park, J. H., Kim, H. Y., Kim, S. J., & Kim, J. W. (2023). Six-month stability following extensive alveolar bone augmentation by sausage technique. *Maxillofacial Plastic and Reconstructive Surgery*, *45*, 16. https://doi.org/10.1186/s40902-023-00384-8
7. Pohl, S., & Buljan, M. (2023). Bone shell technique with relocated crestal ridge segment for anterior horizontal mandibular ridge atrophy: A case series. *International Journal of Periodontics & Restorative Dentistry*, *43*(5), 597–605. https://doi.org/10.11607/prd.6095
8. Villa, A., Mangano, F., Karl, M., & Wang, H. L. (2023). Shell technique with a xenogeneic cortical bone lamina and particulate bone graft for horizontal ridge augmentation: A case series. *International Journal of Periodontics & Restorative Dentistry*, *43*(4), 435–441.
9. Happe, A., Blender, S. M., Luthardt, R. G., Rudolph, H., & Kuhn, K. (2023). Digital evaluation of vertical ridge augmentation with the modified shell technique using a xenogeneic bone lamina: A case series. *Journal of Clinical Medicine*, *12*(22), 7013. https://doi.org/10.3390/jcm1
10. De Angelis, P., Cavalcanti, C., Manicone, P. F., Liguori, M. G., Rella, E., De Rosa, G., Palmieri, A., & D'Addona, A. (2024). A comparison of guided bone regeneration vs. the shell technique using xenogeneic bone blocks in horizontal bone defects: A randomized clinical trial. *Dentistry Journal*, *12*, 137. https://doi.org/10.3390/dj12050137
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12. Pieroni, S., Miceli, B., Giboli, L., Romano, L., Azzi, L., & Farronato, D. (2024). Efficacy of the sausage technique in rebuilding the crestal buccal bone thickness: A retrospective analysis. *Dentistry Journal*, *12*, 180.
13. Doliveux, R., & Doliveux, O. (2024). Guided and prosthetically driven bone augmentation using the shell technique and allogeneic cortical plate: A

prospective case series. *International Journal of Oral & Maxillofacial Implants*, *39*(2), 263–271.

II.3.3 Study details

Due to the heterogeneity of study designs, techniques and reported outcomes, a meta-analysis was not conducted. Data are presented in descriptive and comparative tables organized by year .Data were extracted using a standardized form including: Author and year, Type of Study, Sample, Type of Defect, Technique Involve, Materials, Initial bone Level (mm), Final Bone Level (mm), Average of Bone Gain (mm), Type of Measure to Assess Bone Gain and Long Term Follow up.

II.3.4 Risk of bias

The review authors performed the quality assessment of the included studies using Critical Appraisal tools in JBI Systematic Reviews to determine the extent to which a study has addressed the possibility of bias in its design, conduct and analysis.

Risk of bias in the included studies was categorized as below:

A. Low risk of bias (plausible bias unlikely to seriously alter the results) if all criteria were met.

B. Unclear risk of bias (“ plausible bias" data raises some doubt about the results) if one or more criteria were partly met.

C. High risk of bias (plausible bias that seriously weakens confidence in the results) if honor more criteria were not met.

D. Risk evaluation not applicable to this context.

II.2.4. Narrative Summary of Methodological Quality

The methodogical quality of the included studies was assessed using Joanna Briggs Institute Critical Appraisal Tools. Among the 13 included studies, 2 articles, Tunkel et al. 2021 and Villa et al. 2023, met all the criteria presented in the JBI Critical Appraisal Tools, showing a low risk of bias. 12 articles were classified as Unclear risk of bias (“plausible bias" data raises some doubt about the results) if one or more criteria were partly met. Of these, 8 studies present low risk in the articles by Meloni et al. 2019 ; Arnal H. et al. 2022 ; Khory and Hanser 2022 ; Happe A. et al.2023 ; Pieroni S. et al. 2024 ; Dewilde F. et al. 2024 and DeAngelis P. et al .2024 peresnting only one entry as Unclear while the remaining 4 articles , Kim K. et al. 2023; Pohl S. et al. 2023; Doliveux R. and Doliveux S. 2024 and Khoury F. and Hanser T. 2019, present moderate risk by presenting more than one entry with No or Unclear. Most studies reported outcomes consistently and used valid methods of measurement, although randomization and blinding were often lacking in observational designs.

Author and year	Were there clear criteria for inclusion in the case series?	Was the condition measured in a standard, reliable way for all participants included in the case series?	Were valid methods used for identification of the condition for all participants included in the case series?	Did the case series have consecutive inclusion of participants?	Did the case series have complete inclusion of participants?	Was there clear reporting of the demographics of the participants in the study?	Was there clear reporting of clinical information of the participants?	Were the outcomes or follow up results of cases clearly reported?	Was there clear reporting of the presenting site(s)/clinic(s) demographic information?	Was statistical analysis appropriate?
Urban I. et al., 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Yes**
Khoury F. and Hanser T., 2022	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	**Yes**
Kim K. et al. 2023	Yes	Yes	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes	**Yes**
Pohl S. and Bulyan M., 2023	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	No	**No**
Villa G. et al., 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Yes**
Happe A. et al.2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	**Yes**

Doliveux R. and Doliveux S., 2024	Yes	Yes	Yes	Unclear	Unclear	Unclear	Yes	Yes	Unclear	**Yes**
Pieroni S. et al.,2024	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	**Yes**
Dewilde F. et al., 2024	Yes	Yes	Yes	Unclear	No	Yes	Yes	Yes	Yes	**Yes**

Table 1. *JBI Critical Appraisal Checklist for Case Series*

Author and year	Was true randomi ation used for assignm nt of participa nts to treatmen t groups?	Was allocation t treatment groups concealed?	Were treatme t groups similar at the baseline ?	Were participants blind to treatment assignment?	Were those delivering treatment blind to treatment assignment?	Were outcomes assessors blind to treatment assignment?	Were treatment groups treated identically other than the interventio n of interest?	Was follow up complete and if not were difference s between groups in terms of their follow up adequate y described and analyzed?	Were participan s analysed in the groups to which they were randomize d?	Were outcome s measure d in the same way for treatmen t groups?	Were outcome s measure d in a reliable way?	Was appropria te statistical analysis used?	Was the tria design appropriate, and any deviations from the standard RCT design (individual randomizatio n, parallel groups) accounted for in the conduct and analysis of th trial?
DeAngelis P. e al.,2024	Yes	Unclear	Yes	Unclear	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Yes**

Table 2. *JBI Critical Appraisal Checklist for Randomized Control Trail*

Author and year	Were the two groups similar and recruited from the same population?	Were the exposures measured similarly to assign people to both exposed and unexposed groups?		Was the exposure measured in a valid and reliable way?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the groups/participant free of the outcome at the start of the study (or at the moment of exposure)?	Were the outcomes measured in a valid and reliable way?	Was the follow up time reported and sufficient to be long enough for outcomes to occur?	Was follow up complete, and if not were the reasons to loss to follow up described and explored?	Were strategies to address incomplete follow up utilized?	Was appropriate statistical analysis used?
Khoury F and Hanser T. 2019	Unclear	Not applicable	Yes	Unclear	No	Yes	Yes	Yes	Unclear	Unclear	Yes	**Yes**

Table 3. *JBI Critical Appraisal Checklist for Cohort Study*

Author and year	1. Were the groups comparable other than the presence of disease in cases or the absence of disease in controls?	2. Were cases and controls matched appropriately?	3. Were the same criteria used for identification of cases and controls?	4. Was exposure measured in a standard, valid and reliable way?	5. Was exposure measured in the same way for cases and controls?	6. Were confounding factors identified?	7. Were strategies to deal with confounding factors stated?	8. Were outcomes assessed in a standard, valid and reliable way for cases and controls?	9. Was the exposure period of interest long enough to be meaningful?	10. Was appropriate statistical analysis used?
Arnal al.,2022	Yes	No	Yes	Yes	Yes	Unclear	No	Yes	Yes	**Yes**

Table 4. *JBI Critical Appraisal Checklist for Case Control Studies*

Author and year	**Were patient's demographic characteristics clearly described?**	**Was the patient's history clearly described and presented as a timeline?**	**Was the current clinical condition of the patient on presentation clearly described?**	**Were diagnostic tests or assessment methods and the results clearly described?**	**Was the intervention(s) or treatment procedure(s) clearly described?**	**Was the post-intervention clinical condition clearly described?**	**Were adverse events (harms) or unanticipated events identified and described?**	Does the case report provide takeaway lessons?
Tunkel et al., 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**Yes**

Table 5. *JBI Critical Appraisal Checklist for Case Reports*

III. RESULTS

A total of 13 study were included in this systematic review. The included study consisted of 9 Case Series, 1 Randomized control Trail, 1 Cohort Study, 1 Case Control Study and 1 Case Reports

Eight studies evaluated the Shell Technique (e.g., Tunkel et al., 2021; Villa et al., 2023; Doliveux et al., 2024), while six focused on the Sausage Technique (e.g., Meloni et al., 2019; Kim et al., 2023; Dewilde et al., 2024).

The main outcome assessed in all studies was the mean bone gain (in mm) following GBR. Bone gain was evaluated radiographically (CBCT) or clinically, depending on the study protocol.

Secondary outcomes included follow-up time, presence of complications (e.g., membrane exposure, graft resorption), type of bone defect treated, and type of measurement used to assess bone gain (CBCT, clinical probe, radiography).

III. 1 Article Analysis

1. Meloni et. al (2019) research indirectly substantiates the use of the "Sausage Technique" for horizontal ridge augmentation, in which a collagen membrane is pulled, secured—frequently with pins—and utilized to cover and stabilize the graft material, as Urban and colleagues outline. The technique is a blend of autogenous particulate bone and DBBM in a 1:1 ratio that is coated by a resorbable collagen membrane (e.g., Bio-Gide) under elastic tension to enable maximum stabilization. The outcome of the success, a mean horizontal bone gain of about 5.03 mm following 12 months, reveals the predictability and stability of ridge expansion by the method. The elasticity of the membrane and the fixation stability prevent membrane collapse, premature exposure, and dislodgment of the graft and thus provide proper osteoconductive and osteoinductive processes. Further radiographic examination at later times determined long-term stability of the augmented bone, and the minimal marginal bone loss noted at 3 years is attestation to the longevity of the regeneration. Such clinical evidence validates Urban's principles—especially membrane stabilization under tension and fixation—achievable in the treatment of large horizontal defects without

secondary grafting procedures. The utilization of Bio-Gide® membranes also seems very effective in reducing complications like membrane exposure or infection, further improving the clinical predictability of the technique. In total, Meloni's results emphasize the advantages of good membrane management and graft containment, which are analogous to the fundamental principles of the Sausage Technique, and establish a solid rationale for its use in horizontal ridge deficiency treatment.

2. Khoury and Hanser (2019) presented a strong 10-year prospective study analyzing the long-term result of the SBB method, a modification of the shell technique, for vertical alveolar ridge augmentation of the posterior maxilla. Autogenous bone from the mandibular retromolar region was harvested using the MicroSaw protocol and inserted through a minimally invasive tunnelized approach without the use of advanced flap surgery. This autogenous method, along with periosteal preservation and lack of artificial membranes, enabled a mean vertical gain of around 6.8 mm, with a minimal 8.3% resorption upon follow-up. The research achieved an excellent 98.7% implant survival rate, along with long-term volumetric bone stability and limited bone resorption (average of 0.63 mm) after a period of 10 years. The method showed benefits like reduced complication rates-defined by minimal graft exposure and tissue necrosis-and also reduced treatment time due to the enhancement of revascularization of the graft by autogenous tissue and also by the tunnel technique. These results are in support of the SBB method as a very predictable and stable technique, and hence it is an appealing one for the purpose of comparison studies involving shell-based methods for alveolar ridge reconstruction.
3. Tunkel et al. (2021) presented a retrospective case series of five patients in a split-mouth study comparing the outcomes of alveolar ridge augmentation using autogenous bone plates and allogeneic bone plates in a modified shell technique. The investigation demonstrated that both augmentation techniques resulted in similar outcomes, with horizontal bone gains of around 6.1 mm and vertical bone gains of around 3.9 mm on average, with no differences regarding resorption rates or complication profiles. Significantly, augmentative relining with DBBM and a collagen membrane helped to achieve volumetric stability through the minimization of resorption during healing. The procedures were well-tolerated,

and there were no significant complications reported, with successful implant placement for all patients after one year of follow-up. These results indicate that the allogeneic shell technique, particularly if supplemented by relining, can successfully reduce donor site morbidity without interfering with the augmentation result. It should be taken into account, however, that the limited sample size of the study reduces the statistical significance and applicability of the findings. In summary, the current research substantiates the use of allogeneic bone plates as a viable alternative to autogenous grafts for alveolar ridge augmentation with favorable implications for minimizing patient morbidity without compromising predictable bone regeneration—a primary consideration in the design of surgical procedures.

4. Khoury and Hanser's (2022) research illustrates that the use of the SBB procedure with the tunnel technique produces very predictable and stable long-term outcomes in vertical augmentation of the posterior mandible. The overall vertical bone gain of about 7.6 mm achieved was successful with 10 years of follow-up, with a final stable bone gain of 6.72 ± 2.26 mm and 98.2% survival rate of the implants. There were few early and late complications, like graft exposure or infection, in only some cases and these did not affect outcomes significantly. The utilization of autogenous mandibular bone blocks, obtained through the MicroSaw protocol, ensures superb biological integration and is responsible for the superb success rates noted. Furthermore, the intrinsic stability of the method, the shorter treatment interval when compared to GBR procedures, and the successful maintenance of the graft volume illustrate the technique's reliability. The minimal resorption rate (~11.4%) also serves to depict the long-term success of the method.
5. Arnal et al. (2022) offer the useful information of the direct comparison between the novel Sausage Technique and a traditional GBR method using a resorbable collagen membrane for the horizontal augmentation of knife-edge ridges. Of clinical significance here was achieving ridge width augmentation in situations where very thin, atrophic ridges were present, with the aim being to gain enough volume to permit implants. The reason for choosing Urban's Sausage Technique is the possibility of greater tissue stabilization due to membrane stretching and pin fixation, resulting in greater, more predictable horizontal bone gain. Further,

it was shown that the Sausage Technique yielded a considerably greater mean bone gain (5.3 mm compared to 2.7 mm), with both methods having comparable proportional resorption on healing (~28%), which means that the greater initial gain did not adversely affect volumetric stability. This indicates that the Sausage Technique successfully increases the ridge without using space-maintaining devices or stiff matrices, with stability of new bone volume. The study's strength lies in the fact that it directly compares the two, supporting the predictability of the Sausage Method in achieving more horizontal augmentation. While drawbacks like the retrospective study character and operator learning curve must be cited, the results validate the Sausage Technique as a viable method for stable, large-volume horizontal bone regeneration.

6. Kim et al. (2023) tested a novel modification of the Sausage Technique using a mixture of autologous and heterologous bone graft materials of different ratios stabilized by pin-fixed collagen membranes to provide improved space maintenance and clot stability. The outcome demonstrated an average horizontal bone gain of around 4.4 mm, with very little resorption at six months after surgery, and a high implant success rate. This technique has numerous benefits, such as the avoidance of the morbidity of harvesting large autogenous bones and the application of rigid fixation appliances like mesh or rigid titanium frameworks. Native, non-cross-linked collagen membranes were used, and this enabled early revascularization and epithelialization and limited postoperative complication. The findings show that the utilization of different graft materials combined with membrane stabilization can yield predictable and stable augmentation outcomes even in cases where harvesting to a great extent is not feasible. The method appears to maintain similar graft stability and volume retention as traditional shell techniques while being minimally invasive and more versatile. These qualities render it extremely suitable for bulk bone augmentation in clinical situations where patient morbidity is to be minimized with high implant survival. Longer term studies are indicated to compare the long-term stability and clinical outcome of this modified technique with the shell technique
7. Villa et al. (2023) described a shell technique modified with a xenogeneic cortical lamina (Osteobiol) combined with particulate autogenous bone and porcine hydroxyapatite grafts for horizontal ridge augmentation. The research observed

a HBW increase of about 4.8 mm at 1 mm subcrestal, through to about 5.8 mm at 5 mm subcrestal, with all implants successfully placed after six months and without any complications. The authors highlighted that their technique decreases patient morbidity when compared to conventional autogenous block grafts with no compromise in volume gain and with improved vascularization through the addition of autogenous chips mixed with xenograft material. Histological evaluation demonstrated continual remodeling with bone formation, graft particle remnants, and neovascularization, depicting improved biological integration. The minimally invasive nature of the procedure, along with stable primary implant stability and acceptable soft tissue healing, makes it an attractive alternative to more invasive grafting procedures. The limitations of the study were discussed, such as short follow-up period and lack of control group, and thus comparative long-term studies are needed to confirm these results and determine the predictability and longevity of the technique in the long term.

8. Happe et al. (2023) documented the use of a modified shell technique employing a xenogenic bone lamina for vertical ridge augmentation in the anterior maxilla through pre- and postoperative digital CBCT analysis. The study included six patients with single-tooth class 5 defects. The volumetric analysis revealed an augmented bone volume averaging 382.59 mm^3, with the vertical gains ranging from 7 mm to 11.3 mm across patients (The study reports a mean vertical bone gain of 8.97 mm, with the maximum achieved in a single case being 11.3 mm) in ridge height, sufficient to facilitate implant placement and restoration. The use of three-dimensional evaluation techniques, such as surface matching and Boolean subtraction, confirmed the stability and predictability of the xenograft lamina, even in highly aesthetic regions. The minimally invasive approach required only limited autogenous bone harvesting from the ramus, reducing donor site morbidity. Despite these promising results, the study's small sample size and short follow-up period necessitate caution. The findings suggest that, when well-managed, this technique offers a reliable and aesthetic alternative for vertical augmentation, especially in the anterior maxilla. These outcomes highlight its potential advantages over traditional approaches, but further long-term, controlled studies are needed to confirm its efficacy and stability over time.

9. Pohl and Buljan (2023) describe an innovative modification of the bone shell technique, utilizing a relocated crestal ridge segment from the same atrophic mandibular ridge—a method that completely obviates the need for an external donor site. This approach leverages a cortical lamina divided from the existing crest, which is repositioned to serve as a scaffold for horizontal ridge augmentation. The reported average horizontal bone gain of approximately 3.5 mm was achieved without major complications and with minimal morbidity, underscoring the technique's safety and efficacy in cases with thin but sufficiently high ridges. Its advantages include preservation of the local blood supply, reduced surgical invasiveness, and elimination of periosteal releasing incisions or extensive flap manipulations, thereby decreasing the risk of wound dehiscence. The technique is particularly indicated for cases with moderate horizontal atrophy and adequate ridge height, though its applicability may be limited in more severe or vertically compromised ridges. While the short to medium-term results are promising, further studies with larger sample sizes and longer follow-up are necessary to confirm stability and predictability. When comparing this method to the sausage technique, the shell approach offers the benefit of utilizing the patient's own ridge segment, reducing intraoperative morbidity, and simplifying the procedure—attributes that could translate into improved clinical outcomes and patient acceptance.
10. De Angelis et al. (2024) performed a randomized controlled trial in which they compared the shell technique with xenogeneic bone blocks and the conventional GBR technique with particulate xenogeneic grafts. The research revealed that the shell technique presented significantly more horizontal bone gain, with a mean of around 4.8 mm versus 3.3 mm with GBR, showing more volume augmentation potential. This heightened effectiveness was, however, attended by a higher incidence of soft tissue complications, most of which were membrane exposure, highlighting the need for careful soft tissue handling and tension-free closure during surgery. The application of xenogeneic (non-autologous) materials to the shell technique proves its worth as a viable alternative to autogenous grafts with the benefits of less donor site morbidity, decreased operative time, and predictable bone regeneration results. However, the increased complication rate highlights the fact that the shell technique requires a sophisticated surgical

expertise and extremely cautious postoperative care in order to obtain the best outcomes. Although the short-term results are promising, additional long-term studies are necessary to validate the stability of the new bone and confirm the long-term success of implants inserted in augmented areas. These results demonstrate that, despite proper technique and soft tissue, the shell technique using xenogeneic bone blocks is a useful instrument in horizontal ridge augmentation, particularly in those requiring large volume addition, though practitioners need to be cognizant of its higher risk profile.

11. Doliveux and Doliveux (2024) demonstrated that the use of digitally designed allogeneic cortical plates within the shell technique offers a promising, precise, and prosthetic driven approach to alveolar ridge augmentation. The incorporation of CAD/CAM technology enables accurate preoperative planning, which facilitates the fabrication of surgical templates that ensure exact positioning of the allogeneic plates, thereby enhancing predictability, reducing intraoperative time, and minimizing surgical morbidity. The approach allows for a less technique-sensitive procedure, with improved fit and stability of grafts, possibly leading to more consistent regenerative outcomes. However, despite these advantages, the study also highlights some limitations, such as minor postoperative movement of the allogenic plates in a few cases—likely due to incomplete osteointegration—and the restricted sample size, which warrants cautious interpretation. Additionally, allogenic plates tend to have less revascularization compared to autogenous bone, which may influence long-term graft stability. Overall, while early results are encouraging and suggest that digital planning can streamline and improve the shell technique, further large-scale, randomized controlled trials are necessary to validate these findings and determine their comparative effectiveness against other grafting methods, including the sausage technique.
12. Dewilde et al. (2024) demonstrated that the Sausage Technique is a reliable, minimally invasive approach for lateral bone augmentation in cases of horizontal ridge deficiency. The technique involves the use of a mixed graft of autogenous bone chips and DBBM, covered by a stretched and pinned collagen membrane (Bio-Gide), fixed with pins in accordance with Urban's principles to ensure soft tissue stability and preservation of the crestal contour during healing. The study’s

results showed a mean horizontal bone gain of approximately 3.8 mm, with some cases reaching up to 5 mm, and confirmed stable outcomes at around 9 months postoperatively. Moreover, the procedure was associated with low complication rates and a passively achieved, tension-free primary closure, supporting its minimally invasive profile. All implants placed following augmentation remained healthy and functional at follow-up. Notably, sites without contained bone (e.g., non-containing single implant sites) exhibited less favorable outcomes, indicating that site-specific factors influence results. The high rate of soft tissue augmentation (around 48%) highlights the importance of soft tissue management in achieving optimal results. While these findings support the clinical applicability and effectiveness of the Sausage Technique™, it is important to recognize that the evidence derives from a retrospective case series; further prospective, randomized studies are needed to compare its performance directly with techniques such as the Shell Technique. Nonetheless, the results align with Urban's principles of maintaining soft tissue integrity and shape during healing, confirming that the Sausage Technique offers a stable, safe, and less invasive alternative for lateral ridge augmentation in real-world settings.

13. In the study by Pieroni et al. (2024), the authors evaluated the efficacy of the Sausage Technique™ in increasing buccal bone thickness to address horizontal ridge deficiencies. The technique involves fixing a resorbable collagen membrane with pins and employing a mixed graft consisting of 50% autologous bone and 50% ABBM. The rationale behind this approach is to achieve a stable, significant augmentation of the buccal crest, which is critical for aesthetic and functional success in implant rehabilitation. Radiographic assessments using CBCT demonstrated an average increase in buccal crest thickness of over 3 mm within six months, with the regeneration pattern typically bow-shaped, favoring volume gain at the crest level. The authors highlighted the importance of soft tissue management, particularly controlling tension and ensuring a tension-free closure, as key to the technique's success. The study reported minimal postoperative complications, and all augmented sites were suitable for implant placement without the need for reoperation. Despite the promising results, limitations such as the small sample size, short follow-up period, and focus on maxillary ridges suggest that further research with larger cohorts and longer-term

assessment is necessary. Overall, the findings support the efficacy of the Sausage Technique as a reliable method for horizontal bone augmentation, even in complex defect cases. When comparing with other regenerative techniques such as the shell technique, considerations include differences in methodology, indication scope, shape and volume of regenerated bone, and long-term stability, which should be further explored in systematic reviews aiming to delineate the relative advantages of each approach.

Author and Year	Type of Study	Sample (No. of Patients)	Type of Defects	Technique	Materials	Initial Bone Level	Final Bone Level	Bone Gain (Δ	Type of Measure to Assess Bone Gain	Long-term follow-up
Meloni 2019	a single cohort, prospective clinical trial (case series design)	18	H	GBR	Autog, Xeno, Coll	3.07	8.09	5.03	CBCT + Clin.	3y
Khoury F. and Hanser 2019	prospective clinical cohort study	142	3D	SBB	Autog, HA	7.8	6.82	6.8	CBCT	10y
Tunkel 2021	retrospective case report series	5	V+H	Shell	Autog, Allo.	H: 3.7–3.9 V: 3.0–3.9	H: 10.5–11.0 V: 2.9–5.0	H: 5.8–6.1 V: 3.2–3.9	CBCT	12m
Khoury and Hanser 2022	prospective case series	117	V	SBB	Autog. blocks Chips	7.8	6.72	7.6	RX + Clin.	10y

Author and Year	Type of Study	Sample (No. of Patients)	Type of Defects	Technique	Materials	Initial Bone Level	Final Bone Level	Bone Gain (Δ	Type of Measure to Assess Bone Gain	Long-term follow-up
Arnal H. et al. 2022	retrospective case	16	H	Sausage	Autog + ABBM, Coll.	3.1 ± 1.3	8.4 ± 2.0	5.3 ± 2.3	CBCT	
Kim K. et al. 2023	case series	8	V+H	Sausage	Autog + ABBM, Coll.	baseline	4.40 ± 1.27	4.40 ± 1.27	RX/Clin	6m
Villa G. et al. 2023	Case Series	15	H	Shell	Xeno. lamina, Autog +Xeno.	3.2–4.7	8.0–10.4	4.8–5.8	CBCT	6m
Happe et al. 2023	Case series	6	V	Shell (mod.)	Xeno. lamina + Autog	7–12	7–11.3	8.97 ± 1.71mm	CBCT (3D sup.)	n.r.

Author and Year	**Type of Study**	**Sample (No. of Patients)**	**Type of Defects**	**Technique**	**Materials**	**Initial Bone Level**	**Final Bone Level**	**Bone Gain (Δ**	**Type of Measure to Assess Bone Gain**	**Long-term follow-up**
Pohl and Buljan 2023	retrospective case series	5	H	BST	Autog Cort., Partic.	2.5–3.2	7.0–8.0	~3.5	CBCT	1–4y
De Angelis et al. 2024	randomized controlled trial (RCT)	22	V+H	Shell	Xeno block, Coll	V: 2.31mm / H: 2.45mm	V: 0.13 mm/ H: 0.09mm	V: 2.18 ± 0.79 mm H: 4.8mm	Clin + 3D volume	6m
Doliveux et al. 2024	prospective case series	10	H	Shell	ACP + Autog chips	1.3–4.0 mm	6.6–8.6 mm	~3.2 mm	CBCT	2 years after implant placement
Dewilde F. et al. 2024	retrospective case series	25	H	Sausage	Autog. + DBBM, Coll. Membr.	4.35 mm	7.43 mm	3.08 mm	CBCT(sup.)	9m/26m

Author and Year	Type of Study	Sample (No. of Patients)	Type of Defects	Technique	Materials	Initial Bone Level	Final Bone Level	Bone Gain (Δ	Type of Measure to Assess Bone Gain	Long-term follow-up
Pieroni S. et al. 2024	retrospective analysis	5	H	Sausage	Autog. + ABBM, Coll. Membr.	4.24	7.99	2.82 ± 1.79	CBCT	6m

Table 6. *Table of the included studies.*

IV. DISCUSSION

IV. 1 Comparative Introduction: Shell Technique Vs. Sausage Technique

IV.1.1 Origins and Biological Principles

The technique of GBR has been evolving considerably with the progression of time. Fouad Khoury (2006) and Istvan Urban (2017) have both evolved new methods of treating large cases of bone atrophy, considerably enhancing the predictability of implant therapy. Two of the most well documented surgical methods of alveolar ridge augmentation both horizontally and vertically are Fouad Khoury's The Shell Technique and Istvan Urban's Sausage Technique. Though both methods follow basic biological principles like space maintenance, graft stabilization, and neovascularisation for developing blood vessels, the two differ considerably with regard to material choice, recipient site control, operative procedure, method of approaching primary stability, surgical operating procedures, and soft and hard tissue management. . (Khoury, 2006; Urban, 2017; Urban et al. 2023)

IV1.1.1 Biological and conceptual approach

(Khoury, 2006) Khoury's technique is based on the exclusive use of autologous bone, taking advantage of its mechanical along with its biological characteristics to achieve maximum regenerative effects; it is considered the material of choice for its osteogenic, osteoinductive and osteoconductive features. Key to the method is the use of thin cortical bone laminas (1–1.5 mm), which are harvested from the mandible (retromolar area or symphysis) with microsurgical instruments (e.g. MicroSaw and fixed to the recipient bed with titanium screws; as a "containment shell", which is packed with autologous bone chips harvested from the same donor site, without introducing biomaterials, that provides structural stability and shapes up the reconstructed ridge. (Khoury, 2006). This results in a fully autologous and highly vitalized graft with a three-dimensional structure that is stable in time (Khoury, 2021; Khoury, 2006). In certain cases, cortical plates, and in some cases allogeneic or xenogeneic grafts, are also employed as alternatives, but the biological and structural advantage of autologous tissue is the underlying principle of this strategy. Concomitantly, the osteogenic potential of cancellous bone is employed to facilitate new bone production with its high cellular density and vascularity. Facilitating angiogenesis and revascularization is the key component of this strategy, which guarantee solid graft integration and long-term stability. Stabilization is achieved mechanically by means of micro-screws, in most instances by using tunneled surgical techniques preserving the integrity of soft tissues and respecting periosteal biology. Relying on the cortical plates as a scaffold, the technique permits optimal containment, stability, and integration of the graft, in compliance with principles of minimal invasiveness and biological regeneration. Most importantly, Khoury points out that, by virtue of this flexibility, the gold standard remains autologous bone, in line with the biological principles that enable optimal regeneration without risk of the complications associated with foreign grafts (Khoury, 2006; Khoury and Hanser, 2019). This method has been refined and developed by Khoury across several decades, that is, from the latter half of the 20th century (Khoury and Hanser, 2022).

On the other hand, Urban's evolved Sausage Technique is distinguished by its use of a resorbable collagen membrane (e.g., Bio-Gide) stretched out and stabilized with pins or osteosynthesis screws to create a 'closed space' like a sausage, in which an admixture of autologous particulate bone and inorganic biomaterial, typically a 50:50 mixture of autologous bone and DBBM, is placed (Urban et al., 2013; Urban, 2017; Urban et al., 2023). This method utilizes the principle of GBR, where the well-fixed membrane serves as a spacer, augmented by tissue tension and passive suturing to place the graft under internal pressure, thus allowing predictable volumetric regeneration, particularly valuable in knife-edge ridges' horizontal augmentation. As explained in the latest publications by Urban (Urban et al., 2013; Urban, 2017; Urban et al., 2023) the method promotes early neo angiogenesis, aided by tissue tension and intimate adaptation between the membrane and the graft, allowing for optimal soft tissue management even in the anterior regions. The method emphasizes rigid stabilization of the membrane borders and secondary healing to allow predictable results, avoid contamination risks, and maximize biological processes underlying bone regeneration. Here, the emphasis is on soft tissue management and elastic tension from the membrane to hold the graft in place with a minimum of rigid structures such as cortices of bone.

IV.1.1.2 Surgical technique and site management

The Shell Technique is best suited for cases of severe bone atrophy, horizontal and vertical, in the main areas in the posterior regions and requires primary tension-free closure to avoid dehiscence (Khoury & Hanser, 2019) Khoury stresses the stiffness and mechanical stability of the bone scaffold to achieve desired regeneration (Khoury , 2006). The Sausage Technique (Urban, 2017), on the other hand, can be less invasive and more versatile as it does not require a second operative field for grafting. Stability is still more reliant on appropriate tension of the membrane and compression of graft, however, and thus expert handling of soft tissue becomes crucial. It is considered very effective for horizontal augmentations in knife-edge ridges and is used widely in the front parts since it is aesthetic with proper management (Pieroni et al., 2024; Arnal et al., 2022). Fixation and tension techniques: features credit part of the success to tissue tension and barrier properties of the membrane.

IV. 1.1.3 Materials and biocompatibility

The Shell Technique prefers a "biologically pure" approach, avoiding the use of non-autologous biomaterials. This choice is associated with greater biological predictability and less disruption of bone regeneration. It is more expensive in terms of surgical effort and necessitates an intraoral donor site. In their study, De Angelis et al. (2024) and Doliveux et al. (2024) attempted to counteract this drawback by comparing xenogeneic and allogeneic materials with autologous bone. On the other hand, Sausage Technique exploits material compounding advantages, restricting autologous harvesting and benefiting from the volumetric stability in the long term offered by DBBM, evidenced by several clinical studies (Arnal et al., 2022; Dewilde et al., 2024). The use of collagen membranes allows for easier tissue manipulation but provides greater variability in biological predictability and a theoretical risk of differential resorption. Role of the material: In Khoury, the biological precedence is retaining the use of autologous bone to experience primary osteogenesis. In Urban, there is a attempt to give a stable guided environment to allow the clot to form, with a high percentage of biomaterials.

IV.1.2Comparing surgical philosophies

Both the clinical evidence and theoretical rationales stress that each technique has certain indications but a quick look at clinical results makes it clear that the field is open wide for argument, especially with so many technical advances in both procedures.

Both procedures share strict preoperative planning, stabilisation of the regenerative volume, attention to tissue biology and vascularisation, and clot stabilisation principle as the hub of regenerative success (Khory, 2006, 2021; Urban, 2017). But they basically differ in terms of:

• materials used (pure autologous vs. autologous + biomaterials),

• operative technique, type of containment (rigid shell/bone lamella vs. flexible stretched membrane),

• typical clinical indications (mixed and vertical defects in Khoury; horizontal and contained defects in Urban),

• timing of surgery and prosthesis (preponderance of staged procedure in Khoury; possibility of simultaneity in Urban in some cases),

• soft tissue manipulation strategy (tunnelled or micro-flap method in Khoury, extensive flap with periosteal stripping in Urban).

• donor site morbidity.

A comparison of the reference literature (Khoury & Hanser, 2022; Urban et al.,2023) and recent clinical study data (De Angelis et al., 2024; Tunkel et al., 2020; Dewilde et al., 2024; Pieroni et al., 2024) reveals that the two methods, when used correctly and as instructed, provide similar and consistent results in bone gain and implant success. The choice is therefore based on:

• the type of bone defect (vertical, horizontal or combined),

• the skill of the surgeon

• quality and quantity of available soft tissue

• material preference-related (exclusively autologous versus combination with biomaterials).

In this paper, we will proceed with a complete and comparative analysis of the clinical and surgical data on the two procedures, using data borrowed from the main bibliographic contributions, including the books by Khoury (2006, 2021) and Urban (2023), as well as some clinical articles selected according to the criteria set out in the protocol for the systematic review.

IV.2 Clinical considerations for the application of the shell technique and sausage technique

GBR requires careful control of surgical technique, especially if the goal is three-dimensional reconstruction of the alveolar bone. Khoury's shell procedure and Urban's sausage procedure are two distinct approaches but with the same biomechanical and biological requirements. Despite the overall favorable outcomes reported in the literature, both Urban's Sausage Technique and Khoury's Shell Technique have various limitations and critical factors that must be properly balanced in clinical practice. These include not only surgical but also biological and organizational and learning curve-related considerations (Khoury 2021; Urban, 2017; Urban et al., 2023).

IV.2.1. Strengths and weaknesses of the surgical technique

One limitation of the Shell Technique is also the relative vascularisation of the lamina cortical, which must be counterbalanced by the vitality and osteogenicity of the autologous particulate inserted in it. Tests such as that of Villa et al. (2023) remain positive even with xenogenic lamina, but the risk of resorption or partial integration remains higher than that of autologous grafts. Simultaneously, in allogenic or xenogenic forms, healing duration may be extended and clinical outcomes may exhibit greater variability (Doliveux et al., 2024; Happe et al., 2023). Khoury prefers a tunnelised approach wherever feasible, especially in the posterior mandible and maxillary regions, to preserve periosteal integrity and minimize dehiscence (Khoury and Hanser, 2019; 2022). This method reduces the risk of site exposure and increases peri-graft vascularisation.

The Shell Technique requires fixation with titanium micro-screws, achieving complete primary stability and preventing micro-movements that would hamper bone neoformation. The fragments are precisely modelled to the defect morphology and form a closed "biological chamber". Urban, on the other hand, uses crestal incisions with vertical drainage and extensive periosteal release, which is warranted by the need for tension-free and secure covering of the membrane (Urban et al., 2013; Pieroni et al., 2024). The choice of the surgical procedure greatly determines the risk for post-surgical complications and the degree of regeneration. Although the Sausage Technique is considered more accessible from a technical point of view, it remains a sensitive procedure. The need for a controlled tension over the membrane to obtain the "sausage" effect requires careful handling of soft tissues and adequate stabilisation of the graft material, aspects which, if not fully respected, result in early dehiscence, membrane exposure or graft loss (Pieroni et al., 2024; Arnal et al., 2022). One of the key dangers is therefore long-term volumetric stability. Despite satisfactory short-term results (Pieroni et al., 2024; Arnal et al., 2022), longer follow-ups of more than 5 years are limited. Moreover, as noted by Dewilde et al. (2024), the technique can be subject to progressive resorption of the particulate graft material, especially in the absence of adequate soft tissue cover or in patients with a thin biotype. Both methods recognize the absolute necessity of immobility of the graft to avoid failure.

IV.2.2. Intraoral donor sites

The Shell Technique, particularly in its 'pure' version as defined by Khoury, requires extremely high technical accuracy: cortical shell removal, shaping and anchorage with screws require the use of specialist instruments (such as the MicroSaw) and high-quality surgical familiarity (Khoury, 2006; Happe et al., 2023). Moreover, utilization of an additional intraoral surgical site in autologous bone harvesting contributes to operating time and morbidity risk, like post-surgical pain, paraesthesia, haematoma and patient discomfort (Khoury & Hanser, 2019). Intraoral harvesting of the mandible (retromolar region) or the symphysis is effective but must be carefully evaluated in terms of anatomical as well as functional risks, especially in patients with thin ridges, sensory alterations, or with high aesthetic demands.

The data present point towards low morbidity with harvest carried out using micro-saws and minimally invasive techniques, but this is a factor that distinguishes the Shell Technique distinctly from GBR using membranes and heterologous materials (Khoury, 2021). The mandible is utilized because it is more cortical and accessible, yet the maxilla can be valuable for anterior cases or patients with good morphology. Manipulation is extremely delicate: sheets must be structural and alive. Urban, otherwise, does not involve bone harvesting but utilizes particulate bone (autologous + xenogenic), avoiding a second surgical site but losing the supportive containment function of cortical bone.

IV.2.3. Timing of implant: simultaneous or delayed, staged protocol, follow-up

Both procedures have high predictability in 6–12 months (De Angelis et al., 2024; Tunkel et al., 2021) but differ in implant protocols. Khoury favors mainly a staged procedure: the implant is inserted 4–6 months after regeneration in order to allow full ossification of the graft (Khoury & Hanser, 2022). Only in selected cases is simultaneous placement expected. Urban, under the Sausage Technique, described that in well-selected cases with sufficient primary stability and ideal graft containment, both implants can be done simultaneously with torque-controlled implants and CAD/CAM guide usage in prosthetically guided cases, but in vertical and/or large cases, he also prefers delayed placement (Urban et al., 2021; Dewilde et al., 2024). Both protocols have extremely high implant success rates at 6–10 years (≥95%).

IV.2.4. Complications: dehiscence, infections, fractures of the lamina, bone resorption

The major complications of the Shell Technique are exposure of the lamina, intraoperative fractures, dehiscence and, extremely rarely, infections. The lamina must be handled with great caution so that it does not break; the use of membranes is optional, but debated (Khoury, 2021). Urban, on the other hand, has a higher incidence of membrane exposure, but very frequently without compromising the graft because of its elasticity and due to integration. But studies such as Arnal et al. (2022) and Pieroni et al. (2024) indicate that clinical success remains high even in patients with minimal unexpected events, provided they are treated in time.

IV.2.5. Clinical practice and advice: learning curve

Both techniques offer a steep learning curve. The Shell Technique is considered a master technique of high learning and is appropriate for professionals experienced in donor site management, bone handling and flaps. Success is contingent on the right training in autologous bone surgery.

Moreover, the reproducibility of results reported in the work of Khoury is directly related to the operator's experience and strict adherence to tunnelling and microsurgical standards. The progressive approach proposed by Khoury encompasses an initial training cycle of graft harvesting and stabilization on simpler models before applying the procedure in more complex vertical augmentations (Khoury, 2006; Khoury et al., 2023). Urban, on the other hand, advocates for less invasive and more reproducible techniques that can be mastered by intermediate operators, although tension and management of soft tissues must be handled carefully. Described as simpler in other studies (Urban et al., 2013; Arnal et al., 2022), it possesses technical parameters (tension, graft composition, membrane type) that carry significant significance for the outcome. Of concern is that, for less experienced operators, the procedure becomes sloppy and loses its prognostically guaranteed efficacy. Both techniques complement one another: the Shell Technique is better regarding predictability and long-term stability but is more invasive and technically demanding, while the Sausage Technique, on the other hand, is more flexible in terms of manoeuvrability but potentially less stable in the long term and riskier for complications if incorrect soft tissue control is executed.

IV.3. Horizontal and vertical bone gain: comparison between the Shell Technique and the Sausage Technique

Horizontal and vertical bone increase is one of the main clinical indicators used to assess the success of regenerative treatments in treating severe alveolar atrophy. Urban and Khoury, with their respective methods, aim to achieve stable and predictable three-dimensional reconstruction of the alveolar bone. Various other differences in surgical protocol, materials and handling of soft tissues are translated into quantitatively varied results, as indicated by a number of clinical studies. Comparison between the guided bone regeneration techniques found by Khoury (Shell Technique) and Urban (Sausage Technique) illustrates how each technique is especially suited to different alveolar defects, with appropriate clinical outcome but differing surgical philosophies. Both techniques aim to provide a sufficient volume of bones to accommodate the insertion of an implant in areas with severe atrophy, but vary as far as material selection, control of the graft stabilization, and dealing with soft tissues. The literature-reported data for the sausage technique present mean horizontal bone gains ranging from 4.4 mm to 5.3 mm, with good prognosis and good volume maintenance at follow-up (Arnal et al., 2022; Pieroni et al., 2024). The vertical gain in this technique is controlled and not that stable. Where it happens, it may reach mean values of around 3.7–4.5 mm, with low residual resorption at follow-up.

Urban's (2021) article reports vertical gains of 4 to 5 mm with vertical GBR, but there is slightly compromised stability in the long term when compared with Shell, especially in the presence of membranous exposure. Urban himself, therefore, recommends its use in horizontal sites and in aesthetic areas, where soft tissue control is greater (Urban et al., 2023). These results are obtained with healing times of approximately 6 months and a significantly low complication rate, especially in staged cases. Studies such as Arnal et al. (2022) and Dewilde et al. (2024) show mean horizontal gains of 5.0 mm to 5.3 mm, with extremely low resorption rates (approximately 14–16%). Pieroni et al. (2024) with CBCT-measured buccal gains had an average of 4.8 mm, and Shaker et al. (2024) had a record of 5.1 mm with a complication rate similar to that of Khoury. Khoury's Shell Technique stands out because it is applicable for treating even the most complicated three-dimensional defects, and published results have been reported in vertical as well as horizontal augmentation. In Khoury and Hanser's (2019, 2022) 10-year clinical study, a stable average vertical gain of about 7.5–7.6 mm is reported with very limited volumetric loss (about 8% at 10 years) and implant success rates greater than 98%. The Shell technique has also proven consistent effectiveness in the horizontal plane: Tunkel et al. (2020) report mean values of 6.2 mm, regardless of plate type (autologous or allogeneic), documenting the consistency of the "box-like" design in space maintenance and osteogenesis. When comparing clinical studies that have modified Khoury's original technique, for example employing xenogeneic or allogeneic laminates instead of autologous plates (Villa et al., 2023; Happe et al., 2023; Doliveux et al., 2024), results remain satisfactory, with horizontal gains of 4. 8–5.8 mm and vertical gains of around 3.5 mm. It has been reported to have a mean horizontal gain of bone between 4.8 mm and 6.2 mm, based on studies by Tunkel et al. (2021), Villa et al. (2023), Pohl and Buljan (2023) and Doliveux et al. (2024). However, long-term stability and quality of the tissue created are still more heterogeneous than when using the pure autologous bone technique, as testified by Khoury himself in his 2021 volume. De Angelis et al.'s (2024) technique, for example, is a comparison of classic GBR and Shell with xenogeneic blocks, testifying to the greater dimensional stability of Shell. It is interesting that Urban's approach seems to hold out the hope for greater horizontal gains for pure crestal defects because of the passive containment of the membrane, while Khoury's approach is more versatile in combined rehab of both vertical and horizontal defects, especially its "pure" types with a tunneled technique and single autologous grafting (Khoury & Hanser, 2019; Happe et al., 2023). In cross-comparison, the following is noted:

• Khoury favors a biologically integrated and long-lasting augmentation with an emphasis on long-term stability.

• Urban favors faster, technologically feasible implementation with greater flexibility in the presence of mild to moderate crestal atrophy. It can therefore be asserted that both the procedures permit significant bone gains but differ in terms of indications and strategy:

• The Shell Technique is better in vertical and three-dimensional situations, based on the stability offered by autologous cortical bone.

• The Sausage Technique is used in cases of moderate horizontal augmentation, owing to ease of the protocol, low morbidity and good predictability in aesthetic areas.

Quantitatively, the values overlap in horizontal gain in the majority of clinical investigations (4.5 to 6 mm), but with extensive vertical augmentations (up to 7.6 mm), Khoury's Shell Technique is more predictably long-term, especially when in a staged setting and with tunneled soft tissue management and therefore favored for three-dimensional defects as well as posterior areas. The Sausage Technique is, nonetheless, easier to perform, less morbid (no donor site of bone), and also strongly suggested for horizontal anterior defects as well as in less impaired patients, with fewer morbidities.

IV.4. Pure technique vs clinical variants: a comparison of the techniques of Urban and Khoury

Within the area of GBR, both Urban (2017) and Khoury (2006) suggested codified procedures with well-defined protocols, but subsequent to this they have undergone clinical adjustments and adaptations to conform to anatomical demands, other materials or challenging conditions of surgery. The difference between "pure technique" and "clinical variant" is therefore central to understanding the uniformity of results reported in the literature and to critically evaluating the transference of procedures in the everyday clinical setting. In contrast with the Sausage Technique (Urban), some clinical studies (e.g. Pieroni et al., 2024; Dewilde et al., 2024) have reported modifications of the original protocol: for example, use of alternative resorbable membranes or partial replacement of autologous bone with alloplastic biomaterials to reduce donor site morbidity.

In recent years, numerous authors have proposed modifications to Khoury's original Shell Technique with the aim of simplifying the surgical procedure, reducing donor site morbidity and expanding clinical indications. Tunkel et al. (2020) compared the use of autologous and allogeneic cortical plates, demonstrating similar bone gains (approximately 6 mm horizontal and 3.5 mm vertical), with the advantage of less invasiveness for the allogeneic plate, although doubts remain about long-term integration. Other studies, such as those by Happe (2023) and Villa (2023), have adopted xenogeneic cortical plates (e.g. Osteobiol), often combined with mixed grafts (autologous + porcine HA), with good regenerative results but with a slight increase in resorption compared to autologous bone. An interesting variant is that of Pohl and Buljan (2023), which involves the use of a crestal segment of the same mandible as a bone shell, completely avoiding a second surgical site. De Angelis et al. (2024) also showed that the use of xenogeneic bone blocks in a variant of Shell can produce satisfactory bone gains, but with a higher risk of complications such as resorption and exposure.

From the clinical point of view, modified procedures have some advantages: reduced morbidity, shorter surgical time, greater availability of material and the possibility to be used in patients with anatomical or systemic limitations. They also have some disadvantages: there are some modifications that present worse long-term integration, greater risk of dehiscence or lamellar fractures (especially with non-autologous materials), and greater dependence on heterologous materials whose quality is less reliable. (Khoury, 2021; Tunkel et al., 2020; Villa et al., 2023; Doliveux et al., 2024; Pohl & Buljan, 2023).

The comparison raises some basic questions:

• Reproducibility over standardization: Pure procedures offer a reproducible point of reference as far as outcomes and control of complications go, but clinic adjustments promote more flexibility. However, these adjustments inhibit comparison between studies and measurement of outcomes.

• Complications: Pure, well-codified techniques tend to reduce surgical variability but might be technically more demanding. Variations can simplify certain steps but risk creating new complications (e.g. instability of allogeneic plates or fracture).

The original techniques have a high degree of predictability, but altered forms, if properly executed, can offer advantages in accessibility, reduced morbidity and patient individualization, provided that introduced biological and mechanical limitations are well understood.

IV.5. Methodological limitations of the included studies and reliability of the results

Under the context of this systematic review, it is pertinent to consider the methodological limitations that characterize the clinical studies included within the review in an assessment of the validity and generalizability of the evidence presented. Inspection of the included articles revealed considerable methodological diversity that affects the interpretation and extrapolation of the findings applicable to the Shell (Khoury) and Sausage (Urban) methods. These limitations are mostly concerned with the kind of study, the number of samples, the duration of follow-up, bone gain estimation and standardization of surgical procedures. (Doliveux et al. 2024; Happe et al. 2023; Pohl and Buljan 2023)

The limitations noted affect both the validity of the findings and the possibility of generalizing the clinical results in the implantology context.

IV.5.1. Heterogeneity of the experimental design

Among the central doubtful issues is the popularity of non-randomized experimental designs, particularly case series and observational studies. For example, Doliveux et al. (2024), Happe et al. (2023) and Pohl & Buljan (2023) use prospective but uncontrolled clinical designs, limiting the ability to make firm causal inferences. In comparison, De Angelis et al. (2024) and Arnal et al. (2022) use a RCT design, lending greater scientific weight to the results obtained. Correspondingly, one of the limitations identified is in terms of the sample size.

Such studies, as done by Pohl and Buljan (2023) and Doliveux et al. (2024), are case series in less than 10 patients with short follow-up and no control group and therefore substantially reduce the statistical significance of the evidence.

In these trials, although the outcomes in bone gain and implant survival reported are positive, the absence of randomization and non-comparative design limit the evidence strength.

IV.5.2 Heterogeneity of surgical protocols and materials

Another limitation is material heterogeneity: whereas the original Shell Technique only uses autologous bone grafting and mandibular cortical plates, some of the included studies have superimposed significant modifications. For example, Happe (2023) uses xenogenic plates, while Villa (2023) uses an equine plate with mixed particulate (autologous + porcine HA). Tunkel (2021), comparing autologous vs allogeneic plates, superimposes relining using DBBM and membrane as well. This material heterogeneity, method of fixation and healing period prohibits direct comparability across studies and makes meta-analysis inherently inconsistent.

IV.5.3 Follow-up duration and assessment of bone gain

Other common limitations are brief or mid-term follow-ups (6–12 months), for example, in De Angelis et al. (2024) and Happe et al. (2023), that do not allow a stable assessment of long-term volumetric stability and true bone integration over time.

Khoury & Hanser (2019, 2022) is an exception to this, and as it offers 10-year longitudinal volumetric stability and implant outcome data, it is a more methodologically sound reference.

From a diagnostic standpoint, some articles use CBCT measurements or digital superimposition (e.g. Happe 2023), while others rely on direct clinical assessment, panoramic radiograph or intraoperative measurements, and thus there is heterogeneity regarding detection of bone gain, which might hamper comparability of data provided (e.g. Doliveux 2024, Pieroni 2024).

One of the most important variables for data interpretation is the correct definition of the starting value in various studies: in some papers (e.g. Tunkel 2021; Khoury 2022), "initial bone level" coincides with the depth of the defect and not with the remaining crest height, an approach that affects measuring real gain.

For instance, an initial thickness of a bone crest of 2 mm does not necessarily equate to a bone crest of 2 mm but to a deficiency of 2 mm in relation to the expected anatomical norm.

IV.5.4 Patient selection and inclusion/exclusion criteria Detailed inclusion/exclusion criteria are mostly not mentioned in the majority of the studies.

As mentioned in some studies, the absence of complete demographic data (gender, age) and systemic or local risk factors (i.e. periodontitis, smoking, diabetes) decreases transparency and the reproducibility of interventions and can alter the quality of bone regeneration. It is a possible bias potentially hampering clinical reproducibility of the results.

Few works, such as Arnal et al. (2022) or De Angelis (2024), take into consideration rigorous and controlled choice criteria.

IV.5.5. Critical conclusions

As a conclusion, within the works examined, the ones offering greater reliability and methodological solidity are:

• Khoury & Hanser (2019, 2022): prospective longitudinal studies with extended follow-up (10 years), pure Shell technique strictly implemented, complete quantitative data and comparison with other GBR procedures.

• Tunkel et al. (2020): internal control split-mouth study, direct comparison of material, follow-up 12 months, quantitative analysis with satisfactory reliability.

• De Angelis et al. (2024) y Arnal et al. (2022): random design: completeness of protocols, statistical analysis of results and similarity of samples.

On the contrary, the most restricted articles are those with observational design, reduced size and important protocol modifications from the original, such as:

• Doliveux (2024) and Pohl & Buljan (2023): technical variants use and small samples.

• Villa (2023) and Pieroni (2024): short follow-up and low standardization of the assessment method.

The comments are essential to situate the described clinical findings in the paragraphs above and to appraise the quality of the evidence for the tested techniques.

V. CONCLUSION

This systematic analysis was critical of clinical effectiveness of Shell and Sausage regenerative techniques in guided bone regeneration in horizontal and vertical alveolar ridge deficiencies. Both of them have been seen to yield sufficient results as far as the bone augmentation and the implant stability are concerned, although with different clinical indications and some technical idiosyncrasies.

Shell Technique is particularly indicated in the case of three-dimensional atrophy of complexity, where spatial graft stability and morphological bone profile reconstruction are very important. Sausage Technique, on the other hand, has been applied with success in the treatment of predominantly horizontal defects, for its surgical ease, reduced invasiveness and use of resorbable membranes favoring clot stabilization and guided regeneration.

From a clinical point of view, the selection of the most suitable technique must be based on a rigid assessment of bone defect morphology, quality of the soft tissues and expertise of the operator. Recent technical innovations and the convergence of heterologous materials and digital tools point towards growing utilization of individualized and minimally invasive techniques. In comparison with the methodological heterogeneity of literature examined here and the paucity of long-term follow-up studies, randomized, controlled clinical trials should be conducted, so that reproducible, standardized, and clinically predictable protocols can be outlined more precisely. Moreover, future research needs to emphasize the impact of the most recent technical changes, tissue engineering and digital technologies' contribution to the planning of surgery, and the interconnection between biomaterials, soft tissue, and long-term graft stability.

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VII. ANNEXES

(((((bone grafting procedures) AND (ridge augmentation)) OR (autogenous graft)) OR (bone block)) AND (clinical results)) AND (complications)

Appendix 1. *The search query used for PubMed.*

JBI CRITICAL APPRAISAL CHECKLIST FOR CASE CONTROL STUDIES

Reviewer______________________________ Date______________________

Author_______________________________ Year_______ Record Number_______

	Yes	No	Unclear	Not applicable
1. Were the groups comparable other than the presence of disease in cases or the absence of disease in controls?	☐	☐	☐	☐
2. Were cases and controls matched appropriately?	☐	☐	☐	☐
3. Were the same criteria used for identification of cases and controls?	☐	☐	☐	☐
4. Was exposure measured in a standard, valid and reliable way?	☐	☐	☐	☐
5. Was exposure measured in the same way for cases and controls?	☐	☐	☐	☐
6. Were confounding factors identified?	☐	☐	☐	☐
7. Were strategies to deal with confounding factors stated?	☐	☐	☐	☐
8. Were outcomes assessed in a standard, valid and reliable way for cases and controls?	☐	☐	☐	☐
9. Was the exposure period of interest long enough to be meaningful?	☐	☐	☐	☐
10. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

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Appendix 2. *The Joanna Briggs Institute Critical Appraisal checklist for case control studies*.

JBI CRITICAL APPRAISAL CHECKLIST FOR CASE REPORTS

Reviewer___________________________________Date___________________________

Author___________________________________Year_________ Record Number_________

	Yes	No	Unclear	Not applicable
1. Were patient's demographic characteristics clearly described?	☐	☐	☐	☐
2. Was the patient's history clearly described and presented as a timeline?	☐	☐	☐	☐
3. Was the current clinical condition of the patient on presentation clearly described?	☐	☐	☐	☐
4. Were diagnostic tests or assessment methods and the results clearly described?	☐	☐	☐	☐
5. Was the intervention(s) or treatment procedure(s) clearly described?	☐	☐	☐	☐
6. Was the post-intervention clinical condition clearly described?	☐	☐	☐	☐
7. Were adverse events (harms) or unanticipated events identified and described?	☐	☐	☐	☐
8. Does the case report provide takeaway lessons?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

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Appendix 3. *JBI CRITICAL APPRAISAL CHECKLIST FOR CASE REPORTS*

JBI CRITICAL APPRAISAL CHECKLIST FOR COHORT STUDIES

Reviewer____________________________________Date____________________________

Author______________________________________Year_________ Record Number_________

	Yes	No	Unclear	Not applicable
1. Were the two groups similar and recruited from the same population?	☐	☐	☐	☐
2. Were the exposures measured similarly to assign people	☐	☐	☐	☐
3. to both exposed and unexposed groups?				
4. Was the exposure measured in a valid and reliable way?	☐	☐	☐	☐
5. Were confounding factors identified?	☐	☐	☐	☐
6. Were strategies to deal with confounding factors stated?	☐	☐	☐	☐
7. Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?	☐	☐	☐	☐
8. Were the outcomes measured in a valid and reliable way?	☐	☐	☐	☐
9. Was the follow up time reported and sufficient to be long enough for outcomes to occur?	☐	☐	☐	☐
10. Was follow up complete, and if not, were the reasons to loss to follow up described and explored?	☐	☐	☐	☐
11. Were strategies to address incomplete follow up utilized?	☐	☐	☐	☐
12. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

Critical Appraisal Checklist for Cohort Studies - 3

Appendix 4. *JBI Critical Appraisal Checklist for Cohort Studies*

JBI Critical Appraisal Checklist for Case Series

Reviewer____________________________________Date____________________________

Author____________________________________Year________ Record Number________

	Yes	No	Unclear	Not applicable
Were there clear criteria for inclusion in the case series?	☐	☐	☐	☐
Was the condition measured in a standard, reliable way for all participants included in the case series?	☐	☐	☐	☐
Were valid methods used for identification of the condition for all participants included in the case series?	☐	☐	☐	☐
Did the case series have consecutive inclusion of participants?	☐	☐	☐	☐
Did the case series have complete inclusion of participants?	☐	☐	☐	☐
Was there clear reporting of the demographics of the participants in the study?	☐	☐	☐	☐
Was there clear reporting of clinical information of the participants?	☐	☐	☐	☐
Were the outcomes or follow up results of cases clearly reported?	☐	☐	☐	☐
Was there clear reporting of the presenting site(s)/clinic(s) demographic information?	☐	☐	☐	☐
Was statistical analysis appropriate?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

Appendix 5. *JBI Critical Appraisal Checklist for Case Series*

JBI CRITICAL APPRAISAL CHECKLIST FOR RANDOMIZED CONTROLLED TRIALS

Reviewer____Date_________________________________

Author____Year__________ Record Number__________

		Yes	No	Unclear	NA
.	Was true randomization used for assignment of participants to treatment groups?	☐	☐	☐	☐
.	Was allocation to treatment groups concealed?	☐	☐	☐	☐
.	Were treatment groups similar at the baseline?	☐	☐	☐	☐
.	Were participants blind to treatment assignment?	☐	☐	☐	☐
.	Were those delivering treatment blind to treatment assignment?	☐	☐	☐	☐
.	Were outcomes assessors blind to treatment assignment?	☐	☐	☐	☐
.	Were treatment groups treated identically other than the intervention of interest?	☐	☐	☐	☐
.	Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	☐	☐	☐	☐
.	Were participants analyzed in the groups to which they were randomized?	☐	☐	☐	☐
0.	Were outcomes measured in the same way for treatment groups?	☐	☐	☐	☐
1.	Were outcomes measured in a reliable way?	☐	☐	☐	☐
2.	Was appropriate statistical analysis used?	☐	☐	☐	☐
3.	Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

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Appendix 6. *JBI Critical Appraisal Checklist for Randomized Controlled Trials*