Bone Augmentation Strategies for Implant-Site Development: Materials, Techniques, and Clinical Implications

Dania Oday Essam
College of dentistry, University of Baghdad, Baghdad, Iraq
Daniaoudy@avic.uobaghdad.edu.iq

ABSTRACT

Alveolar bone augmentation plays a pivotal role in ensuring predictable implant rehabilitation by restoring lost bone dimensions critical for both function and esthetics. Guided Bone Regeneration (GBR) remains a key approach for achieving graft stability, space maintenance, and tension-free closure in complex defects. Integrating minimally invasive techniques and biologically compatible grafts has enhanced regenerative predictability, reduced complications, and supported long-term implant success. This review explores various bone graft materials, including autografts, allografts, xenografts, and alloplasts, highlighting their biological properties, osteoconductive and osteoinductive potential, and their clinical applications. A coherent and detailed search was done using terms “Autograft”, “Xenograft”, “Ridge Augmentation”, “Immediate implant”, “updates in bone graft application” from PubMed and google scholar database conducted till June 2025. Following that, all of publications were exhaustively investigated and well presented in this review. Implant therapy in compromised sites demonstrates high predictability when deficient alveolar bone is effectively reconstructed through Guided Bone Regeneration principles and the strategic selection of grafting materials. Clinical applications benefit from minimally invasive approaches and precise defect evaluation, leading to reduced complications and improved patient outcomes. Advances in biomimetic and bioactive graft materials are expected to further enhance bone regeneration, offering more predictable, minimally invasive, and long-lasting implant rehabilitation outcomes.

Keywords: Bone grafts, Osseodensification, Guided Bone Regeneration (GBR), Alloplasts, Immediate implant placement, Maxillary sinus floor elevation.

INTRODUCTION

Alveolar bone resorption represents a common clinical concern that may occur as either a physiological or pathological process. These resorptive changes and associated deformities can occur due to tooth loss following extraction, advanced periodontal disease, trauma, prolonged use of removable prostheses, anatomical defects, and pathological lesions [1]. Bone augmentation procedures are widely used to solve ridge and socket deficiencies through techniques such as block grafting, particulate grafting, membrane application, and distraction osteogenesis, used alone or in combination with each [2]. The advancement in implantology and the growing need for craniofacial reconstruction have led to greater use of bone grafts and substitutes [3]. More than half of anterior teeth (50.3%) required bone grafting for implant surgery, with anterior maxillary sextant showing the highest demands for grafting (77.2%) of cases. Guided bone regeneration was the most employed method for bone augmentation [4].

This review aims to summarize and evaluate the most used bone graft materials and GBR techniques, emphasizing their biological properties, clinical indications, and current innovations

1. Bone augmentation

Ridge defects may arise from trauma, infection, surgical intervention, or congenital malformations. Osseous replacement aims to maintain ridge contour, minimize dead spaces, and minimize the risk of post-operative infections. Thus, supporting optimal bony and soft tissue healing. Alveolar bone resorption that occurs from tooth loss due to the lack of intraosseous stimulation by periodontal ligaments [5]. bone grafting is surgical procedure that enables placement of bone substitute material within the defected site, promoting the integration as surrounding healthy bone tissue grow and fuse with the graft achieving complete healing. Bone substitutes can be natural or synthetic, often composed of mineralized bone matrix with no viable cells, which is able accomplish the same purpose [3]. The choice of the best grafting material depends on multiple factors, including surrounding tissue viability, shape, size and defect volume [6].

1.1 Graft incorporation

Incorporation describes biological interaction between the host site and the graft that results in new bone formation and mechanical integrity restoration. This healing process starts with inflammatory and/or immune response to surgical trauma and graft material, followed by cellular proliferation, migration, differentiation, and revascularization that lead to new bone formation and union between the host and graft. The extent and rate of incorporation rely on graft material, surrounding tissue, and host's systemic disease [7]. Bone grafts can be classified according to their physicochemical properties including osteoconduction, osteoinduction, osteogenesis, osseointegration, and structural support, each playing important role in bone healing. Osteoconduction refers to the ability of graft material to act as scaffold for new bone growth. All the bone grafts offer some degree of osteoconductive scaffold. Osteoinduction means that the host mesenchymal cells are recruited, proliferate and differentiate to osteoblasts. Osteogenesis is a biological process of bone formation by specialized cells, primarily osteoblasts. The most commonly used osteogenic bone graft is autogenous bone [8-10].

1.2 Classification of Bone graft materials according to the origin:

1.2.1 Autograft

Autogenous bone grafting refers to use of bone taken from the same individual receiving the graft. The graft is taken from nonessential donor sites such as iliac crest or mandibular symphysis [5]. It may be obtained in particulate form or block form, also cancellous or cortical bone or cortico-cancellous each react differently when grafted [3]. Autogenous bone was considered the gold standard grafting material due to its immunologic compatibility and osteoconductive, osteogenic and osteoinductive properties [11] However this type of graft has many disadvantages including the need for second surgical site, higher risk of complications, and a tendency for significant resorption [12,13].

1.2.2 Tooth-derived bone graft material

Teeth and bones show many similarities in composition, particularly dentin and bones. Dentine has 65% inorganic, 35% organic substances, and water. Also, alveolar bone has 65% inorganic and 35% organic substances. In addition to their potential of osteoinduction, osteoconduction and osteogenesis through growth factors in tooth [14,15]. Tooth derived graft has shown potential in regeneration procedures including sinus lift, socket preservation, and vertical and horizontal ridge augmentation [16]. In 2018 experimental rabbit study reported that particulate human tooth graft promoted significantly higher formation of new bones compared to deproteinized bone [17]. Auto-tooth bone is bio-recycled material derived from extracted teeth and has been processed to be used as an autogenous bone graft. Unlike synthetic grafts, it shows both osteoinductive and osteoconductive properties promoting rapid remolding and bone formation. But because of limited amount of graft that can be reached from deciduous or supernumerary teeth, the authors recommend this method for small-medium sized unilateral alveolar defects [18].

1.2.3 Allografts

Allografts refers to bone grafts taken from one individual and transplanted after being processed into another. They are commonly used in two forms-freeze dried bone allograft (FDBA) and demineralized freeze-dried bone allograft (DFDBA) [19]. Allografts represent one of most frequently used materials for defective bone reconstruction. Their principal advantages are availability in different sizes and shapes, as well as no need for second surgical site to harvest the graft. However, lack of living cells in these grafts makes their osteogenic capacity less compared to autografts [20]. Allografts offer osteoconductive properties and some forms have osteoinductive properties particularly demineralized freeze-dried bone (DFDBAs) due to releasing of bone morphogenetic proteins (BMPs) [21]. There is still concern about immune rejection, possible transmission of infectious diseases and blood incompatibility. The processing method also can reduce their mechanical and biological characteristics in addition to high processing costs [6].

1.2.4 Xenografts

Xenografts refer to grafts obtained from non-human sources, usually osteoconductive and exhibit limited resorption potential [22,23]. A well-known example is Bio-Oss commercially available bovine bone graft that undergoes processing to remove almost all organism parts while preserving some natural bone minerals. After chemical and heat treatment inorganic phase remains largely hydroxyapatite (HA), maintaining the porous architecture. The porous structure of the graft facilitates capillary formation throughout osteoblastic proliferation and migration [24]. However, the heat treatment applied during graft processing damage bone components, reduces osteoinductive potential, and alters scaffolds structure via enlarging the size of hydroxyapatite (HA) crystals. Some studies have reported poor performance of xenografts including poor integration and graft loosening. The results remain controversial as other research has shown favorable performance [25].

1.2.5 Alloplasts

Alloplastic grafts are synthetic bone substitutes used widely in dental procedures, such as periodontal and bone regeneration. They contain some chemical constitutes of natural bone (e.g., phosphate and calcium) which enable bone regeneration. These grafts are favored due to their high safety profile, readily available, and easily modeled to fit surgical sites. Alloplastic grafts are osteoconductive providing scaffolds to support the new bone formation [26]. Alloplastic grafts are commonly fabricated from hydroxyapatite, which is a natural mineral that constitutes bone. With no risk of disease transmission or cross infection which is possible with the use of xenograft or allograft [27]. Since the regenerative ability is limited, they are often combined with growth factors and/or membranes. The osteoconductive capability is influenced by several factors crystal structures, manufacturing methods and their composition, pore sizes, and absorption rates [28]. As mentioned above, Hydroxyapatite (HA) has a very close composition to bone making it favorable material to build bone tissue due to its osteoconductivity and osteoinductivity. However, its brittleness and poor mechanical stability limit its use in non-load-bearing bone defects [29]. nanotechnology has introduced new possibilities for development of nano-bone graft. Significant attention has been directed toward n-HA crystals, which induce less inflammatory response in compared to porous HA and offer good biocompatibility, enhanced resorption and bioactivity to support new bone growth. Consequently, n-HA-based nanocomposites offer better and faster healing [30]. Tricalcium phosphates (TCP) is effective in repairing bony defects but because of its low brittleness and tensile strength that limits its application in load-bearing areas. TCP exist in two forms: α-TCP and β-TCP, β-TCP is more frequently employed because of its greater stability and higher biodegradation rate. In other hand, its rapid degradation may outpace new bone formation, limiting its effectiveness [31]. Bioactive glass (BAG) is considered one of the most promising bone graft materials. Its mechanical properties enable bonding with host bone and as result promoting bone and blood vessels formation [32].

2. Guided Bone Regeneration (GBR)

Guided bone regeneration (GBR) employs resorbable or non-resorbable barrier membranes to enhance vertical and horizontal height of atrophic ridge, thereby restoring its original dimensions and promoting new bone deposition in defected site [33]. The primary function is guiding the regeneration of both hard and soft tissue by preventing invagination of connective and epithelial tissue into the bone defect. Ensuring protection of blood clots, support the development of surrounding tissue and preserve the necessary space for osteoblasts for vascularization and regeneration [34]. The barrier membrane should offer the following criteria: adhere to surrounding tissue without mobility, easy to handle, preventing the growth of soft tissue, maintain the space, and exhibit biocompatibility [35]. Non-resorbable (N-RES) membrane, for example titanium meshes and polytetrafluoroethylene (PTFE) membranes provide reliable and long-term outcomes for GBR. They can maintain their structures and shapes. And offer good space maintenance while serving as effective barrier. However, the main disadvantage of this type is a second surgical procedure for removal and higher susceptibility for complications like membrane exposure [36]. Resorbable membranes have different natural and synthetic sources all developed to overcome the drawbacks of non-resorbable barriers. Collagen membranes are commonly used due to their high biocompatibility and bioactivities such as supporting osteoblast adhesion and fibroblast chemotaxis. However, their limited volume stability and rapid degradation represent major limiting factors, that can decrease bone regeneration. Thus, strategies like chemical/enzymatic/physical and crosslinking methods have been used to improve mechanical properties and expand degradation time. Current research also emphasizes adding bioactive molecules to enhance regenerative outcomes [37].

3. Clinical application and scenarios for augmentation and GBR

3.1 Socket preservation application

Socket preservation techniques after tooth extraction have become increasingly common in recent years [38]. To have successful and long stability implantation results, three main factors should be obtained: adequate bone volume, enough keratinized gingiva surrounding the implant neck, and prosthetically proper implant position. Therefore, preserving maximum amount of alveolar bone at time of tooth extraction is essential. This way will minimize ridge resorption and subsequent bone remodeling [39]. Within the first six months after tooth removal, about 11–22% vertical bone loss and 29–63% horizontal bone loss occurs, with greater resorption in buccolingual dimension (4.5–6.1 mm) in comparison with mesiodistal dimension. This volumetric reduction of the buccal cortical plate will affect the overlying soft tissue, and as result influencing the functional outcomes of subsequent prosthetic rehabilitation. Studies have shown that ridge width decreases by 2.46–4.56 mm in sites of extraction without socket preservation compared to sites with preservation show lower reduction of 1.14–2.5 mm. additionally immediate socket preservation reduces the possibility need for future ridge augmentation [40]. According to conventional protocols, a healing period of 3-4 months is required for healing of the socket after extraction. In addition to prosthetic treatment, the patient often needs to wait up to 1 year for complete replacement of the missing tooth. So different approaches like immediate implant have been taken to shorten the length of treatment time [41]. Biomaterials used for grafting the socket include allograft, autograft, xenograft, and synthetic grafts. Bone graft with low resorption rate are favorable to provide long term dimensional stability [42].

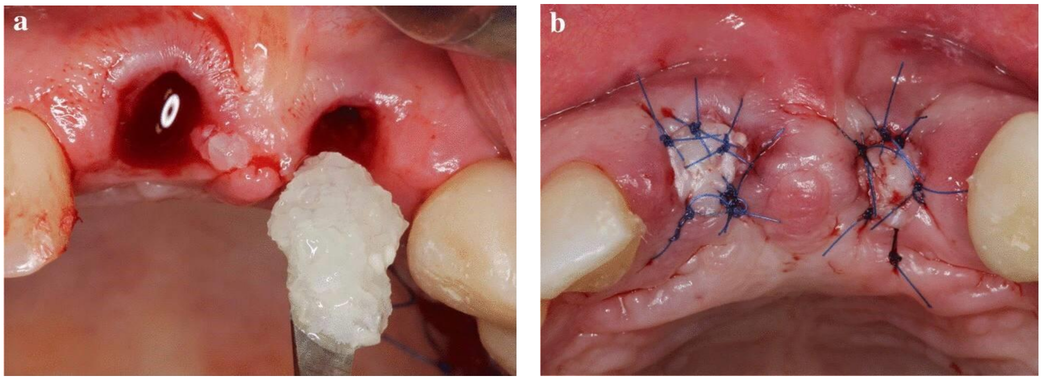

Figure 1: (a) Alveolar ridge preservation performed by disinfected auto-tooth bone graft, (b) the socket covered by FGG transplants. Adapted from Ref. [43] with permission.

3.2 immediate implant

Immediate implants have become reliable approach with positive outcomes, since better understanding of healing process and advancement in implant designs. Clinical trials indicate survival rates close to that with conventional protocols. On other hand, some systematic reviews emphasize that immediate implants should be used carefully on selected cases to lower the possibility of complications. Favorable anatomical requirements such as the presence of intact buccal bony wall (>1mm thickness) and thick gingival phenotype play an important role in preserving peri-implant tissue. When implant stability or buccal contour are challenged the application of GBR is recommended [44,45]. Immediate implants placement right after extraction combined with bone augmentation has been reported to give successful results like delayed implant placement [2].

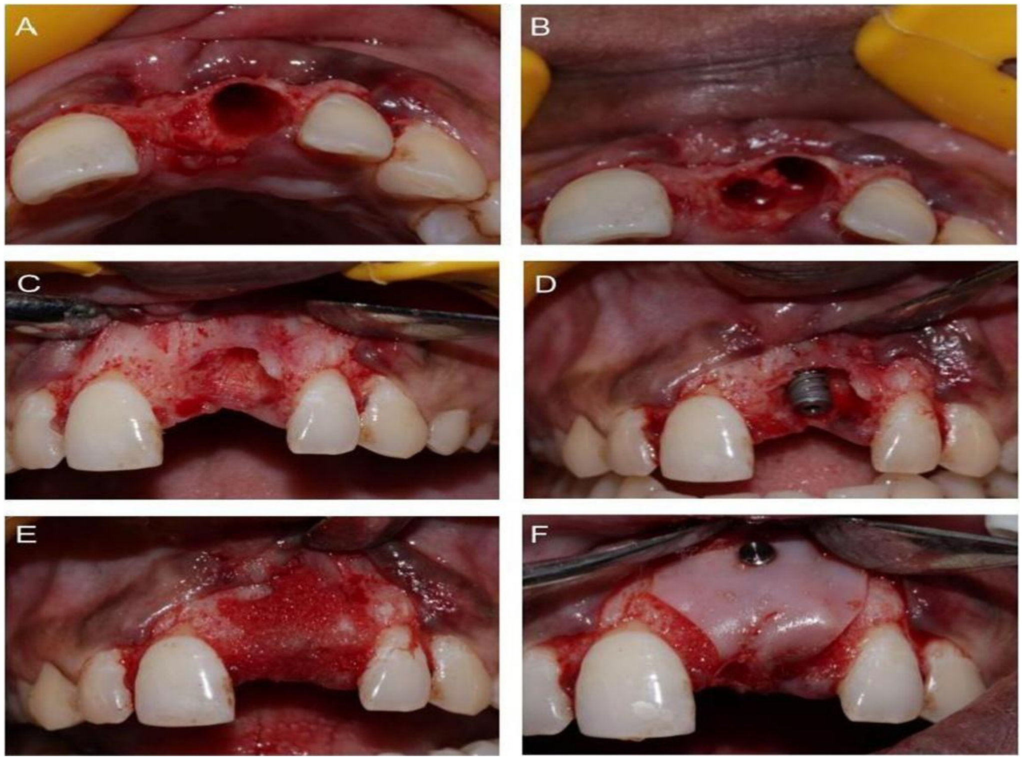

Figure 2: (a) the socket after tooth extraction, (b) preparation of implant site, (c) bony defect noticed following atraumatic extraction, (d) placement of immediate implant, (e) alloplastic bone graft has placed with GBR, (f) collagen membrane secured with tac pin. Adapted from Ref. [46] with permission.

3.3 Ridge augmentation application

Alveolar ridge reconstruction (ARR) is surgical procedure aims to restore extraction sites that have alveolar defects before implant placement [33][47]. bone grafting of alveolar ridge performed to achieve sufficient width, height and contour, thereby providing proper health for peri-implant tissue and favorable esthetic for implant placement [48]. Defect morphology is important in determination of ridge augmentation techniques. Intrabony defects facilitate space maintenance, augmented site stabilization and protection, and soft tissue closure making procedures like bone augmentation and sinus lifting more predictable. Conversely, extrabony defects show more clinical challenges in vertical and lateral augmentations [49]. During Horizontal grafting techniques demonstrated high predictable results with lower complications possibility and range of implant survival 97% and 100%. In other hand, vertical ridge augmentation (VRA) is more challenging technique with less consistent results and higher complications possibilities. For this reason, short dental implants have been introduced. However, there is also limitation in use of short implants in inadequate residual bone height and anterior upper region due to high esthetic requirements [50]. The inlay or sandwich method has shown to be potential alternative for vertical ridge augmentation. First used in 1974 atrophic mandibles management, then modified in 1989 for maxillary reconstruction. This technique takes advantage of the intrabony environment to minimize graft exposure and improve vascularization. By the placement of interpositional bone grafts between mobilized bone segments, that will support the integration of bone graft and enhance blood supply. With all the advantages presented by this method, it still needs advanced surgical skills careful planning to reduce the complications that may occur. In comparison with onlay procedures, inlay grafts based on the inherent vascularity of the mobilized segment, that leads to more potential bone formation and minimize the resorption with time [51]. In recent years, progress in digital technology and material studies have introduced significant advancement in GBR techniques. Customized titanium meshes produced by computer-aided design/manufacturing (CAD/CAM) with selective laser melting (SLM) made a significant advancement in ridge reconstruction. These meshes are designed to fit the patient's anatomy, get better graft stability and defect coverage. In comparison to traditional non-resorbable membranes, designed titanium meshes show higher mechanical strength, better adaptation to defect sites, and the ability to pre-determining graft volume during the diagnosis of the case [52].

3.4 maxillary sinus augmentation

Maxillary sinus floor augmentation (MSFA), is effective approach to compensate for the deficiency in bone height in posterior maxilla, thus facilitating implant placement. Success rates using this technique in implants procedures reach 97.2%. Depending on remaining bone height, implants may be placed at the same time with sinus augmentation or after heling period [53]. Maxillary sinus is lined with membrane called Schneiderian membrane, the membrane normally measures 0.13–0.5 mm in thickness (average 0.8 mm). the risk of perforation relies on the angle between medial and lateral sinus walls, narrower angles come with greater incidence of perforations. Also overfilling with bone graft may lead to membrane necrosis, graft displacement into the sinus and sinusitis [54]. MSFA can be achieved with two techniques: external sinus elevation (using lateral window in anterior wall of the maxillary sinus) or internal sinus elevation (transcrestally via the crest of edentulous ridge) [55,56]. Lateral window (direct) surgical technique focuses on flap design, window location and dimensions, as well as rotary and piezoelectric instrumentation. Following that careful elevation of the membrane and placement of particulate bone graft [57]. The window shape is usually oval, with dimensions of 15 mm apicocoronally and 20mm mesiodistally which is sufficient to provide good surgical access. Care should be taken to ensure that there are no sharp edges to avoid membrane perforation [54]. A variety of complications documented with lateral window method, such as Schneiderian membrane perforation, graft site infection, sinusitis, and technical and/or mechanical problems associated with functional loading on implant in the grafted sinus region. For these reasons other less invasive techniques have been explored to avoid the risks inherent to the lateral window procedure. These include piezoelectric surgery, antral membrane balloon elevation, osseodensification, and hydraulic sinus elevation. Although these approaches show promising potential, long-term follow-up studies that prove their efficacy are still scarce (58).

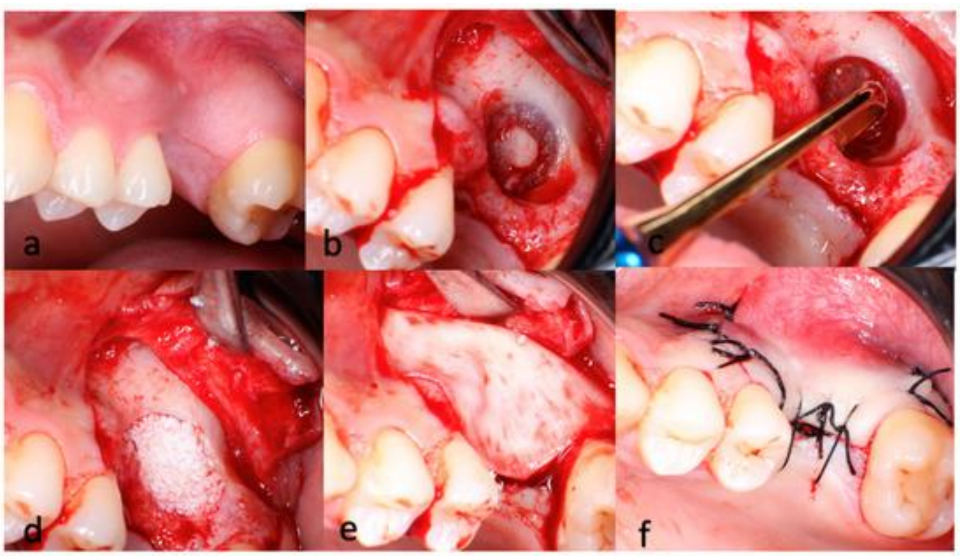

Figure 3: (a–f) Surgical steps of maxillary sinus augmentation by lateral window technique, (b) outlining of the lateral wall with trap-door technique, (c) Dissection and elevation of the membrane with special instruments, (d) placement of bone graft under the elevated membrane, (e) placing the collagen membrane above the lateral window, (f) suturing for primary flap closure. Adapted from Ref. [58] with permission.

In other hand, the transcrestal approach (Indirect) can minimize surgical morbidity by avoiding the use of lateral osteotomy and more a more site-specific sinus floor elevation. It often allows for immediate implant placement, avoiding the need for second surgical step. The rate of membrane perforation with this technique is reported to be lower in compared to lateral approach. However, because it regarded as a "blind" method, it's possible that there are some cases of perforation undetected and unreported. Transcrestal technique uses variety of instruments and methods such as manual Summers osteotomes, hydrodynamic devices, and osseodensifying drills [59].

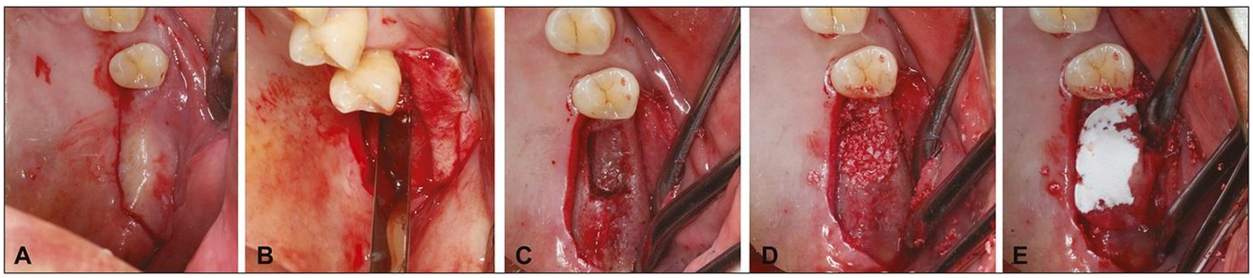

Figure 4: Transcrestal method procedure. (a) Palatal crestal and a vertical relieving incision, (b) trancrestal window preparation, (c) outlining the window and lifting the membrane, (d) the graft material placed (Deproteinized cancellous bovine bone), (e) collagen membrane used to cover the window. Adapted from Ref. [60] with permission.

Transcrestal maxillary sinus membrane elevation using osseodensification (TSMEOD) proposed as technique that facilitates the surgical procedure and improves primary stability of the implant with reducing the need for extensive ridge augmentation. TSMEOD procedure involves specially designed drills rotating in counterclockwise pumping motion with copious irrigation, producing hydrodynamic compaction of bone debris that progressively elevates the sinus membrane. Many long-term studies reported a significant endo-sinus bone gain, high implant survival, and low incidence of complications following TSMEOD [61,62].

CONCLUSIONS:

The predictability of implant therapy in compromised sites largely depends on the successful reconstruction of deficient alveolar bones. Careful selection of grafting materials, combined with the principles of Guided Bone Regeneration, provides a reliable foundation for achieving stable bone regeneration and long-term implant success. Clinical applications such as maxillary sinus elevation, immediate implant placement, ridge augmentation, and socket preservation particularly benefit from this integrated approach. Moreover, the adoption of minimally invasive techniques and precise defect assessment has contributed to reducing postoperative complications and improving patient-centered outcomes. Collectively, the synergy between material science, regenerative protocols, and refined surgical strategies establishes a comprehensive and evidence-based framework for functional and esthetic implant rehabilitation. Future directions focus on developing biomimetic and bioactive graft materials that enhance osteogenesis and integration.

Conflict of interest

The author declares that there is no conflict of interest.

REFERENCE:

1- Deshpande S, Deshmukh J, Deshpande S, Khatri R, Deshpande S. Vertical and horizontal ridge augmentation in anterior maxilla using autograft, xenograft and titanium mesh with simultaneous placement of endosseous implants. J Indian Soc Periodontol. 2014 Sep;18(5):661-5. https://doi.org/10.4103/0972-124x.142469

2- Mcallister B S, Haghighat K. Bone augmentation techniques. Journal of periodontology. 2007; 78(3): 377-396. https://doi.org/10.1902/jop.2007.060048

3- Zhao R, et al. Bone grafts and substitutes in dentistry: a review of current trends and developments. Molecules, 2021, 26.10: 3007. https://doi.org/10.3390/molecules26103007

4- Cha HS, Kim JW, Hwang JH, Ahn KM. Frequency of bone graft in implant surgery. Maxillofac Plast Reconstr Surg. 2016 Mar 31;38(1):19. https://doi.org/10.1186/s40902-016-0064-2

5- Kumar P, Vinitha B, Fathima G. Bone grafts in dentistry. Journal of Pharmacy and Bioallied Sciences. 2013; 5(1): S125-S127. https://doi.org/10.4103/0975-7406.113312

6- Ferraz M P. Bone grafts in dental medicine: an overview of autografts, allografts and synthetic materials. Materials. 2023; 16(11): 4117. https://doi.org/10.3390/ma16114117

7- Bauer T W, Muschler G F. Bone graft materials: an overview of the basic science. Clinical Orthopaedics and Related Research. 2000; 371: 10-27. https://journals.lww.com/clinorthop/abstract/2000/02000/bone_graft_materials__an_overview_of_the_basic.3.aspx

8- Santoro A, et al. Bone defect treatment in regenerative medicine: exploring natural and synthetic bone substitutes. International Journal of Molecular Sciences. 2025; 26(7): 3085. https://doi.org/10.3390/ijms26073085

9- Fillingham Y, Jacobs J. Bone grafts and their substitutes. Bone Joint J. 2016 Jan; 98-B (1 Suppl A):6-9. https://doi.org/10.1302/0301-620x.98b.36350

10- Roberts T, Rosenbaum A J. Bone grafts, bone substitutes and orthobiologics: the bridge between basic science and clinical advancements in fracture healing. Organogenesis. 2012; 8 (4): 114-124. https://doi.org/10.4161/org.23306

11- Park SY, Yi SM, On SW, Che SA, Lee JY, Yang BE. Evaluation of low-crystallinity apatite as a novel synthetic bone graft material: In vivo and in vitro analysis. J Dent. 2025 Mar;154:105597. https://doi.org/10.1016/j.jdent.2025.105597
12- Wang K, Zhang J, Ding M, Xie Y, Wang Y, Jin C, Yan M, Liu L, Ding C, Chen X. Comparative evaluation of porcine and bovine bone xenografts in bone grafting: a systematic review and meta-analysis. Int J Implant Dent. 2025 Jun 9;11(1):45. https://doi.org/10.1186/s40729-025-00630-w
13- Calder D, et al. Universal Hydrogel Carrier Enhances Bone Graft Success: Preclinical and Clinical Evaluation. Advanced Healthcare Materials. 2025; 14(12): 2403930. https://doi.org/10.1002/adhm.202403930
14- Kim YK, Lee J, Um IW, Kim KW, Murata M, Akazawa T, Mitsugi M. Tooth-derived bone graft material. J Korean Assoc Oral Maxillofac Surg. 2013 Jun;39(3):103-11. https://doi.org/10.5125/jkaoms.2013.39.3.103
15- Janjua OS, Qureshi SM, Shaikh MS, Alnazzawi A, Rodriguez-Lozano FJ, Pecci-Lloret MP, Zafar MS. Autogenous Tooth Bone Grafts for Repair and Regeneration of Maxillofacial Defects: A Narrative Review. Int J Environ Res Public Health. 2022 Mar 20;19(6): 3690. https://doi.org/10.3390/ijerph19063690
16- Obulareddy V T, et al. Tooth as a Bone Graft Material: A Narrative Review. European Journal of General Dentistry. 2023; 12(2): 072-081 https://doi.org/10.1055/s-0043-1771533
17- Minetti E, et al. New Classification of Autologous Tooth-Derived Grafting Materials: Fundamental Concepts. International Journal of Dentistry. 2025; 2025(1): 6646405. https://doi.org/10.1155/ijod/6646405
18- Wursching T, et al. Long-Term Results of Autologous Tooth Bone Grafting in Alveolar Cleft Reconstruction: A Retrospective Cohort Study. Biomedicines. 2025; 13(7): 1735. https://doi.org/10.3390/biomedicines13071735
19- Grover V, et al. Bone allografts: a review of safety and efficacy. Indian Journal of Dental Research. 2011; 22(3): 496. https://doi.org/10.4103/0970-9290.87084.
20- Stopa Z, et al. Evaluation of the safety and clinical efficacy of allogeneic bone grafts in the reconstruction of the maxilla and mandible. In: Transplantation Proceedings. Elsevier, 2018. p. 2199-2201. https://doi.org/10.1016/j.transproceed.2018.02.122

21- Miron Richard J., et al. The development of non-resorbable bone allografts: Biological background and clinical perspectives. Periodontology 2000, 2024, 94.1: 161-179. https://doi.org/10.1111/prd.12551

22- Sheikh Z, Hamdan, N, Ikeda Y, Grynpas M, Ganss B, Glogauer M. Natural graft tissues and synthetic biomaterials for periodontal and alveolar bone reconstructive applications: a review. Biomaterials research. 2017; 21(1): 9 https://doi.org/10.1186/s40824-017-0095-5

23- Haque T. Assessment of Bone Regeneration Around Implants Using Different Bone Substitute Materials. Journal of Pharmacy and Bioallied Sciences. 2025 Jun 1;17(Suppl 2): S1258-60. https://doi.org/10.4103/jpbs.jpbs_79_25.

24- Abushama A A, et al. Comparison of xenograft and allograft bone graft for oral and maxillofacial surgical preparation prior to dental implantation: A systematic review. F1000Research. 2025, 14: 718. https://f1000research.com/articles/14-718

25- Steijvers E, Ghei A, Xia Z. Manufacturing artificial bone allografts: a perspective. Biomaterials translational. 2022; 3(1): 65. https://doi.org/10.12336/biomatertransl.2022.01.007

26- Vlasa A, et al. Systematic Review Regarding the Clinical Implications of Allograft and Alloplastic Bone Substituents Used for Periodontal Regenerative Therapy. Journal of Clinical Medicine. 2025; 14.3: 894. https://doi.org/10.3390/jcm14030894

27- Nunn M E, et al. A systematic review of a novel alloplast carbonate apatite granules. Frontiers in Dental Medicine. 2024; 5: 1418039. https://doi.org/10.3389/fdmed.2024.1418039

28- Fukuka S, et al. Alloplastic bone substitutes for periodontal and bone regeneration in dentistry: Current status and prospects. Materials. 2021; 14.5: 1096. https://doi.org/10.3390/ma14051096

29- Wang H, et al. Biocompatibility and osteogenesis of biomimetic nano-hydroxyapatite/polyamide composite scaffolds for bone tissue engineering. Biomaterials. 2007; 28(22): 3338-3348. https://doi.org/10.1016/j.biomaterials.2007.04.014

30- Ashfaq R, et al. Developments in alloplastic bone grafts and barrier membrane biomaterials for periodontal guided tissue and bone regeneration therapy. International Journal of Molecular Sciences. 2024; 25(14): 7746. https://doi.org/10.3390/ijms25147746

31- De-Pace R, et al. Bone regeneration: A review of current treatment strategies. Journal of Clinical Medicine. 2025; 14(6): 1838. https://doi.org/10.3390/jcm14061838

32- Conde R A, et al. Can Bioactive Glass Replace Bone Grafts After Curettage of Benign Bone Tumors? A Systematic Review and Meta-analysis of Randomized Controlled Trials. Journal of Orthopaedics. 2025 Jun 3; 69:208-215. https://doi.org/10.1016/j.jor.2025.05.061

33- Arora M., et al. The Effectiveness of Platelet Rich Fibrin in Alveolar Ridge Reconstructive or Guided Bone Regenerative Procedures: A Systematic Review and Meta-Analysis. Journal of dentistry. 2024;153: 105548. https://doi.org/10.1016/j.jdent.2024.105548

34- Lima-Sanchez B, et al. Advances in Synthetic Polymer Membranes for Guided Bone Regeneration in Dental Implants: A Scoping Review. Journal of Functional Biomaterials. 2025; 16.5: 149. https://doi.org/10.3390/jfb16050149

35- Liu J. Kerns D G. Mechanisms of guided bone regeneration: a review. The open dentistry journal. 2014; 8: 56. https://doi.org/10.2174/1874210601408010056

36- Patil S, et al. Evaluation of efficacy of non-resorbable membranes compared to resorbable membranes in patients undergoing guided bone regeneration. Heliyon, 2023 Feb 4;9(3):e13488. https://doi.org/10.1016/j.heliyon.2023.e13488.

37- Ren Y, et al. Barrier membranes for guided bone regeneration (GBR): a focus on recent advances in collagen membranes. International journal of molecular sciences. 2022; 23(23): 14987. https://doi.org/10.3390/ijms232314987

38- Doonquah L, Holmes PJ, Ranganathan LK, Robertson H. Bone Grafting for Implant Surgery. Oral Maxillofac Surg Clin North Am. 2021 May;33(2):211-229. https://doi.org/10.1016/j.coms.2021.01.006

39- Stumbras A, et al. Alveolar ridge preservation after tooth extraction using different bone graft materials and autologous platelet concentrates: a systematic review. Journal of oral & maxillofacial research. 2019; 10(1): e2. https://doi.org/10.5037/jomr.2019.10102

40- Sivaraman K, et al. How effective is dentin autograft for socket preservation and implant site preparation: A systematic review protocol. F1000Research. 2024; 13: 204. https://doi.org/10.12688/f1000research.144522.2

41- Singh A, et al. Immediate placement of implant in fresh extraction socket with early loading. Contemporary clinical dentistry. 2012; 3 (Suppl 2): S219-S222. https://doi.org/10.4103/0976-237x.101099

42- Fee L. Socket preservation. British Dental Journal. 2017; 222(8): 579-582. https://doi.org/10.21608/ajdsm.2020.44274.1119

43- Radoczy-Drajko Z, Windisch P, Svidro E, Tajti P, Molnar B, Gerber G. Clinical, radiographical and histological evaluation of alveolar ridge preservation with an autogenous tooth derived particulate graft in EDS class 3-4 defects. BMC Oral Health. 2021 Feb 11;21(1):63. https://doi.org/10.1186/s12903-021-01429-y

44- Al-Aroomi O A., et al. Immediate implant placement with simultaneous bone augmentation versus delayed implant placement following alveolar ridge preservation: A clinical and radiographic study. Journal of Stomatology, Oral and Maxillofacial Surgery. 2023; 124(1): 101291. https://doi.org/10.1016/j.jormas.2022.09.012

45- Peitsinis PR, Blouchou A, Chatzopoulos GS, Vouros ID. Optimizing Implant Placement Timing and Loading Protocols for Successful Functional and Esthetic Outcomes: A Narrative Literature Review. Journal of Clinical Medicine. 2025 Feb 21;14(5):1442. https://doi.org/10.3390/jcm14051442

46- RATHI, Manish; MANOHAR, Balaji. Management of Single Tooth Replacement in the Esthetic Region Using Immediate Implant Placement: A Case Report. Clinical Case Reports, 2025, 13.1: e70089. https://doi.org/10.1002/ccr3.70089

47- Ahmed BA, Fouad YA, Almalahy HG, Sarhan S. Alveolar Ridge Preservation Comparing Allograft, Alloplast, and Autogenous Tooth Graft: A Randomized Clinical Trial. Egyptian Dental Journal. 2025 Jan 1;71(1):303-15. https://dx.doi.org/10.21608/edj.2024.327835.3230

48- Troeltzsch M, et al. Clinical efficacy of grafting materials in alveolar ridge augmentation: A systematic review. Journal of Cranio-Maxillofacial Surgery. 2016; 44(10): 1618-1629. https://doi.org/10.1016/j.jcms.2016.07.028

49- Gultekin B A. Cansiz E, Yalcin S. Ridge augmentation techniques in preprosthetic implant surgery. In: A Textbook of Advanced Oral and Maxillofacial Surgery, Volume 3. IntechOpen, 2016. https://www.intechopen.com/chapters/50190

50- Cucchi A, et al. The influence of vertical ridge augmentation techniques on peri-implant bone loss: A systematic review and meta-analysis. Clinical Implant Dentistry and Related Research. 2024; 26(1): 15-65. https://doi.org/10.1111/cid.13282
51- Barausse C, et al. The Inlay Technique in Alveolar Ridge Augmentation: A Systematic Review. Journal of Clinical Medicine. 2025; 14(5): 1684. https://doi.org/10.3390/jcm14051684
52- Merli M, et al. The TACOS Technique: A Stepwise Protocol for Alveolar Ridge Augmentation Using Customized Titanium Mesh. Medicina. 2025; 61(1): 58. https://doi.org/10.3390/medicina61010058
53- Grün P, Meier M, Anderl A, Kleber C, Turhani F, Schiepek T, Islam SMRS, Fitzek S, Bandura P, Turhani D. Focused Analysis of Complications Associated with Bovine Xenohybrid Bone Grafts Following Maxillary Sinus Augmentation via the Lateral Approach: A Retrospective Cohort Study. Diagnostics. 2025; 15(16):2089. https://doi.org/10.3390/diagnostics15162089
54- Bathla SC, Fry RR, Majumdar K. Maxillary sinus augmentation. Journal of Indian Society of Periodontology, 2018, 22.6: 468-473. https://doi.org/10.4103/jisp.jisp_236_18
55- Saraç Atagün Ö, Çardakcı Bahar Ş, Ceylan Şen S, Ustaoğlu G. Research trends and mapping knowledge for maxillary sinus augmentation in oral and maxillofacial surgery. J Stomatol Oral Maxillofac Surg. 2025 Sep;126(4):102116.. https://doi.org/10.1016/j.jormas.2024.102116
56- Decker AM, Stuhr S, Testori T, Wang HL. Clinical and radiographic changes following transcrestal sinus augmentation: A scoping review of the last 25 years. Clin Implant Dent Relat Res. 2024 Dec;26(6):1338-1353. https://doi.org/10.1111/cid.13389
57- Scaini R, Saleh MHA, Lai HC, Sangiorgi M, Zucchelli G, Testori T. Indications and Regenerative Techniques for Lateral Window Sinus Floor Elevation With Ridge Augmentation. Clin Implant Dent Relat Res 2025 Jun;27(3):e7000. https://doi.org/10.1111/cid.70007
58- Sağlanmak A, Arısan V, Karabuda C, Özyuvacı H. Dental Implant Rehabilitation of Posterior Maxillary Edentulism via Sinus Augmentation Using the Lateral Window Technique: A Retrospective Analysis of 289 Implants Followed Up for 15 Years. J Funct Biomater. 2025 Feb 13;16(2):65. https://doi.org/10.3390/jfb16020065

59- Comuzzi L, et al. Radiographic analysis of graft dimensional changes in transcrestal maxillary sinus augmentation: A retrospective study. Materials, 2022, 15.9: 2964. https://doi.org/10.3390/ma15092964
60- Wang, M., Yan, M., Xia, H. & Zhao, Y. Sinus elevation through transcrestal win-dow approach and delayed implant placement in 1- to 2-mm residual alveolarbone: a case report. Implant Dent. 2016; 25: 866–869.
61- Starch-Jensen T, Østergaard KB, Bruun NH, Shino IL, Hallund MH. Transcrestal Maxillary Sinus Membrane Elevation using Osseodensification Compared with Alveolar Ridge Augmentation using the Lateral Window or Osteotome Technique: a Systematic Review and Meta-Analysis. J Oral Maxillofac Res. 2025 Jun 30;16(2):e1. https://doi.org/10.5037/jomr.2025.16201
62- aspar J, Mazor Z, Bonfante EA. Osseodensification technique in crestal maxillary sinus elevation-A narrative review. Clin Implant Dent Relat Res. 2025 Feb; 27(1):e13399. https://doi.org/10.1111/cid.13399