Quest Journals
Journal of Medical and Dental Science Research
Volume 11~ Issue 10 (2024) pp: 23-41
ISSN(Online) : 2394-076X ISSN (Print):2394-0751
www.questjournals.org

Research Paper

From Harvest to Healing: The Evolution of Bone Grafts In Oral Implantology

RICHA WADHAWAN[1], DEEPAK KUMAR GUPTA [2], SHILPI BANSAL [3], ADITI SHARMA[4], PRATIGYA PATIDAR [5], UDITA BHATTACHARYA[6]

1. *PROFESSOR, ORAL MEDICINE, DIAGNOSIS & RADIOLOGY, PDM DENTAL COLLEGE & RESEARCH INSTITUTE, BAHADURGARH, HARYANA, INDIA*
2. *DENTAL SURGEON, PB DENTAL, DURGAPUR, WEST BENGAL*
3. *POST GRADUATE, PERIODONTOLOGY, MAHARANA PRATAP COLLEGE OF DENTISTRY & RESEARCH CENTRE, GWALIOR, MADHYA PRADESH*
4. *DENTAL SURGEON, INSTITUTE OF DENTAL EDUCATION & ADVANCE STUDIES, GWALIOR, MADHYA PRADESH*
5. *DENTAL SURGEON, INSTITUTE OF DENTAL EDUCATION & ADVANCE STUDIES, GWALIOR, MADHYA PRADESH*
6. *DENTAL SURGEON, INSTITUTE OF DENTAL EDUCATION & ADVANCE STUDIES, GWALIOR, MADHYA PRADESH*

Corresponding author: wadhawanricha1@gmail.com

Abstract: *Bone grafts are surgical procedures that involve the transplantation of bone tissue to repair or reconstruct damaged bones. They are commonly used in various medical fields, including dentistry, orthopedics, and particularly within oral and maxillofacial surgery, prosthodontics, and oral radiology, to promote healing and support the integration of implants. This review embarks on a transformative journey through the evolution of bone grafting techniques in oral implantology, beginning with the rudimentary harvesting methods and their inherent limitations. It transitions to modern innovations, spotlighting synthetic and bioengineered materials that enhance biocompatibility and minimize patient morbidity. Key advancements in minimally invasive techniques and guided bone regeneration are meticulously examined, along with the revolutionary impact of 3D imaging and printing technologies on graft customization. The review underscores the synergy between biological principles and cutting-edge technology, illustrating how these breakthroughs not only lead to superior surgical outcomes but also foster improved patient healing and satisfaction. Ultimately, the evolution of bone grafts marks a significant paradigm shift towards more effective, patient-centered strategies in oral implantology. This exploration highlights the pivotal role of advanced bone grafting methods in bolstering osseointegration and ensuring overall implant success, showcasing a commitment to enhancing both clinical efficacy and patient experience for prosthodontists, periodontists, oral and maxillofacial surgeons,oral radiologists, and dentists alike.*

Keywords: *Oral implantology, Bone grafts, Osseointegration, Biomaterials, Implant success, Bone remodelling, Complications*

R*eceived 02 Oct., 2024;* ***R****evised 12 Oct., 2024;* ***A****ccepted 14 Oct., 2024 © The author(s) 2024.*
P*ublished with open access at* ***www.questjournas.org***

I. Introduction:

Patterns of alveolar bone resorption are influenced by various factors, including tooth loss, periodontal disease, and the mechanical load applied to the jawbone. Following tooth extraction, the surrounding alveolar bone experiences a predictable pattern of resorption, typically characterized by a rapid reduction in bone volume during the first six months, followed by a slower, ongoing resorption over time.[1] Bone resorption is primarily mediated by osteoclasts, which are specialized cells that break down bone tissue. They attach to the bone surface, creating an acidic environment that dissolves mineral components and releases enzymes to degrade the organic matrix, leading to the release of calcium and phosphorus into the bloodstream. (**Figure 1**).[2]

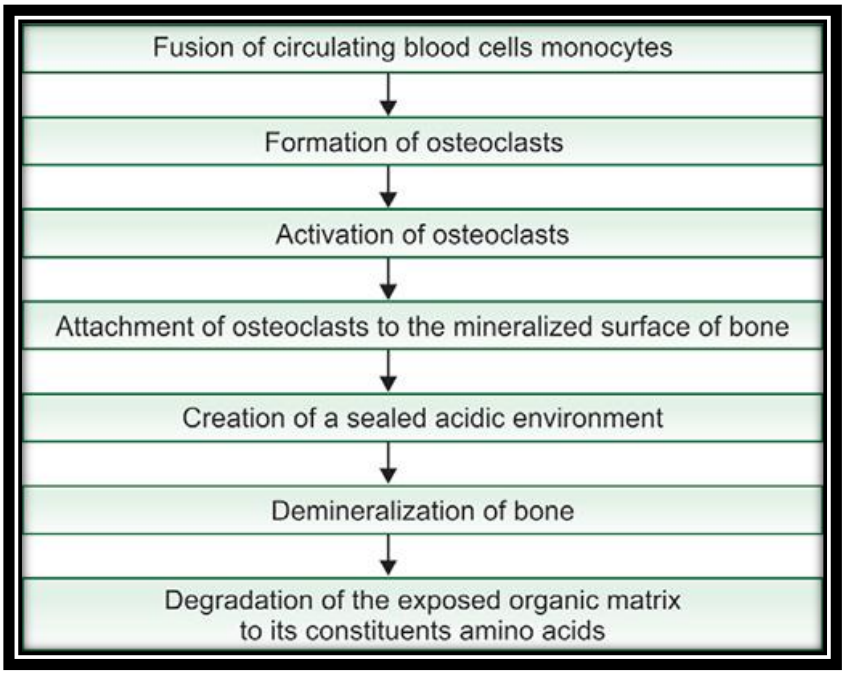


Figure 1: Mechanism of alveolar bone resorption
Courtesy: https://www.jaypeedigital.com/book/9789386261731/chapter/ch24

This phenomenon often leads to a decrease in both vertical and horizontal dimensions of the alveolar ridge, which can complicate future implant placement and negatively impact aesthetics and function. The extent and direction of resorption can also be affected by individual anatomical variations, the presence of adjacent teeth, and the quality of the remaining bone.[3] Additionally, the type of grafting materials and techniques used during augmentation procedures play a crucial role in mitigating resorption and promoting bone regeneration, ultimately influencing long-term outcomes in dental implant therapy.[4] The classification of alveolar bone for implant placement is essential for determining the most suitable surgical techniques and implant types, with the widely recognized. Lekholm and Zarb classification categorize alveolar bone into four types (**Figure 2**).[5]

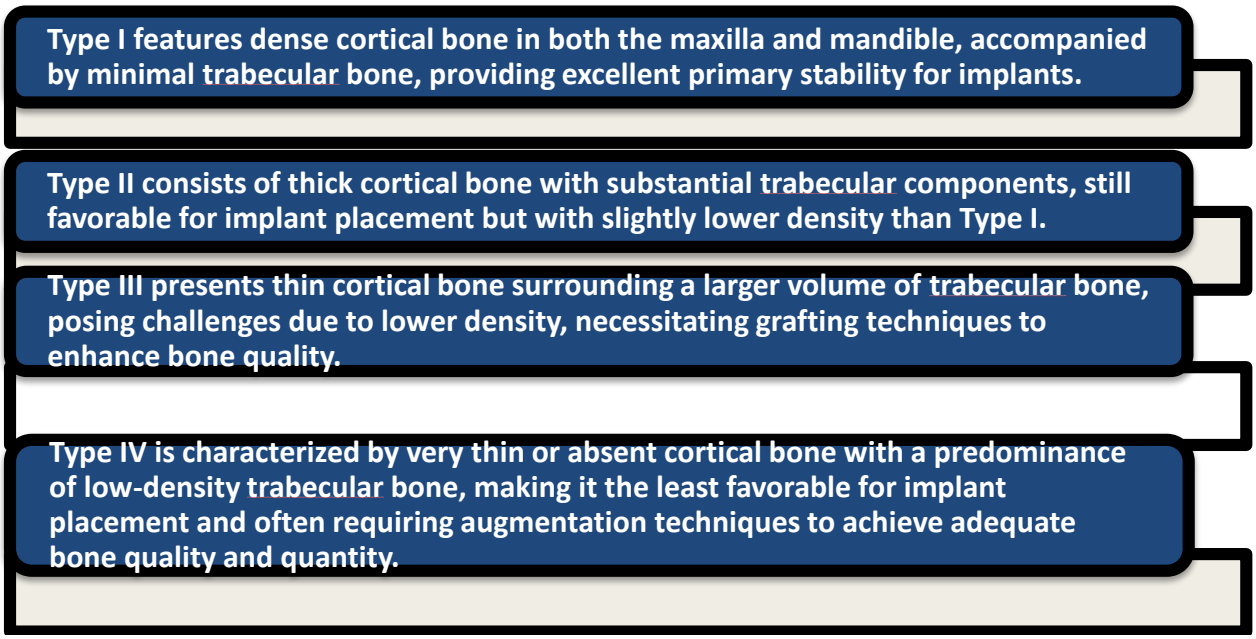


Figure 2: Lekholm and Zarb classification of alveolar bone

Additionally, the bone quality classification delineates bone density through D1 to D4 categories (**Figure 3**): D1 signifies very dense bone (Type I), D2 denotes dense bone with some trabecular components (Type II), D3 indicates moderately dense bone (Type III), and D4 corresponds to poor-quality bone (Type IV).[6]

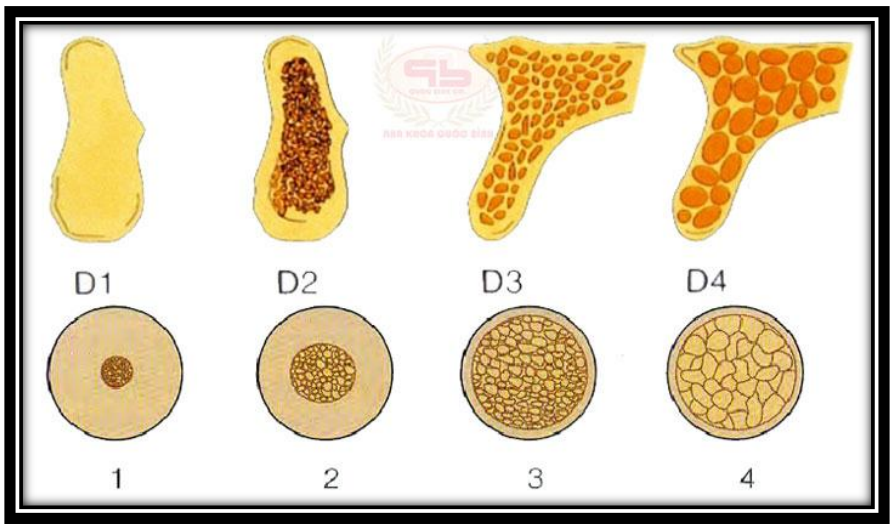


Figure 3: Categories of bone density through D1 to D4
Courtesy: https://nhakhoaquocbinh.com/en/jaw-bone-standard-dental-implant/

Grasping these classifications allows clinicians to customize their approach to implant placement effectively, increasing the chances of successful osseointegration and enhancing long-term outcomes for patients.[7] Bone grafting has become a crucial technique in oral implant ology, significantly improving the success rates of dental implants and enhancing patient outcomes.[8] The term "bone graft" is derived from two words: "bone," referring to the hard, dense connective tissue that makes up the skeleton, and "graft," which refers to a piece of tissue that is transplanted from one location to another, typically to repair or reconstruct damaged areas. Thus, "bone graft" specifically denotes a transplantation of bone tissue to aid in healing or reconstruction in medical procedures (**Figure 4**).[9]

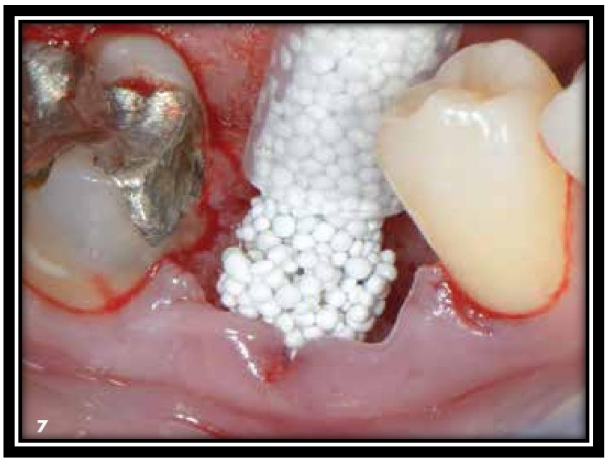


Figure 4: Bone grafts inserted into mandibular socket
Courtesy: Horowitz RA, Leventis M, Rohrer MD, Prasad HS. Bone grafting: history, rationale, and selection of materials and techniques. Compend Contin Educ Dent. 2014; 35(4 Suppl):1-6; quiz 7.

In recent decades, dental rehabilitation for patients with partial or complete tooth loss through oral implants has established itself as a reliable treatment option, consistently yielding long-term success.[10] However, challenging local conditions of the alveolar ridge—resulting from bone loss, periodontal disease, and trauma—often lead to inadequate bone volume and unfavorable vertical, horizontal, and sagittal jaw relationships, complicating implant placement and compromising both function and aesthetics.[11] To address these critical issues, five primary techniques have been identified to enhance bone volume in deficient areas: (1) osteoinduction, which employs specific growth factors to stimulate bone formation; (2) osteoconduction, where grafting materials serve as scaffolds for new bone development; (3) distraction osteogenesis, a surgical technique that induces fractures and gradually separates bone fragments to promote natural regeneration; (4)

guided bone regeneration (GBR), which utilizes barrier membranes to maintain spaces for bone filling; and (5) revascularized bone grafts, where a vital bone segment is transferred to the recipient site with its blood supply intact, ensuring immediate viability without the need for remodeling or substitution (**Figure 5**).[12]

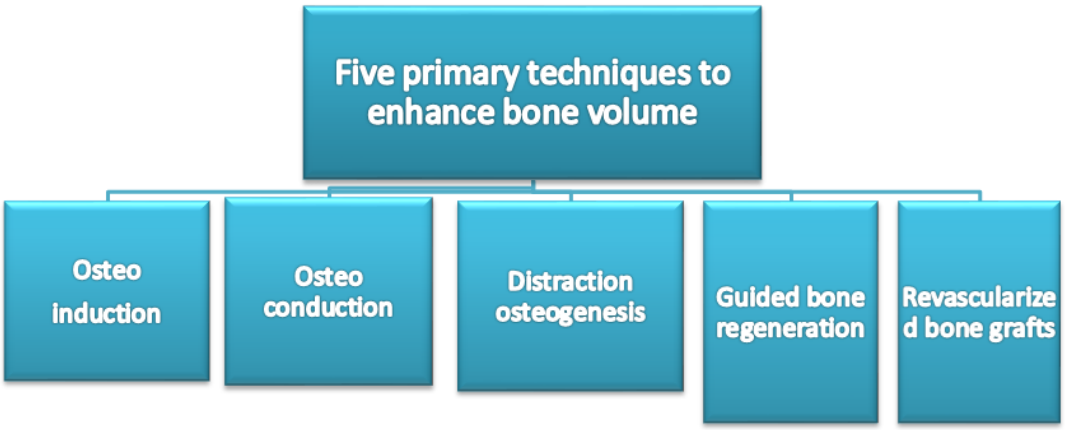


Figure 5: Five primary techniques to enhance bone volume

Despite the wide range of bone graft materials available, the debate over the most suitable options for clinical practice continues.[13] Nearly 50 years after the introduction of bone grafts in implant dentistry, establishing a universal gold standard material or technique remains elusive due to anatomical variations, cost considerations, diverse clinical scenarios, and rapid technological advancements.[14] The selection of the most appropriate bone graft material is influenced by the patient's overall health, the surgical site, and socioeconomic factors, while the surgeon's experience and preferences play a vital role in determining the choice of technique.[15] For example, although GBR is the preferred method for managing periodontal defects, the specific materials used—whether autograft, allograft, xenograft, or alloplast—can vary significantly among practitioners (**Figure 6**).[16]

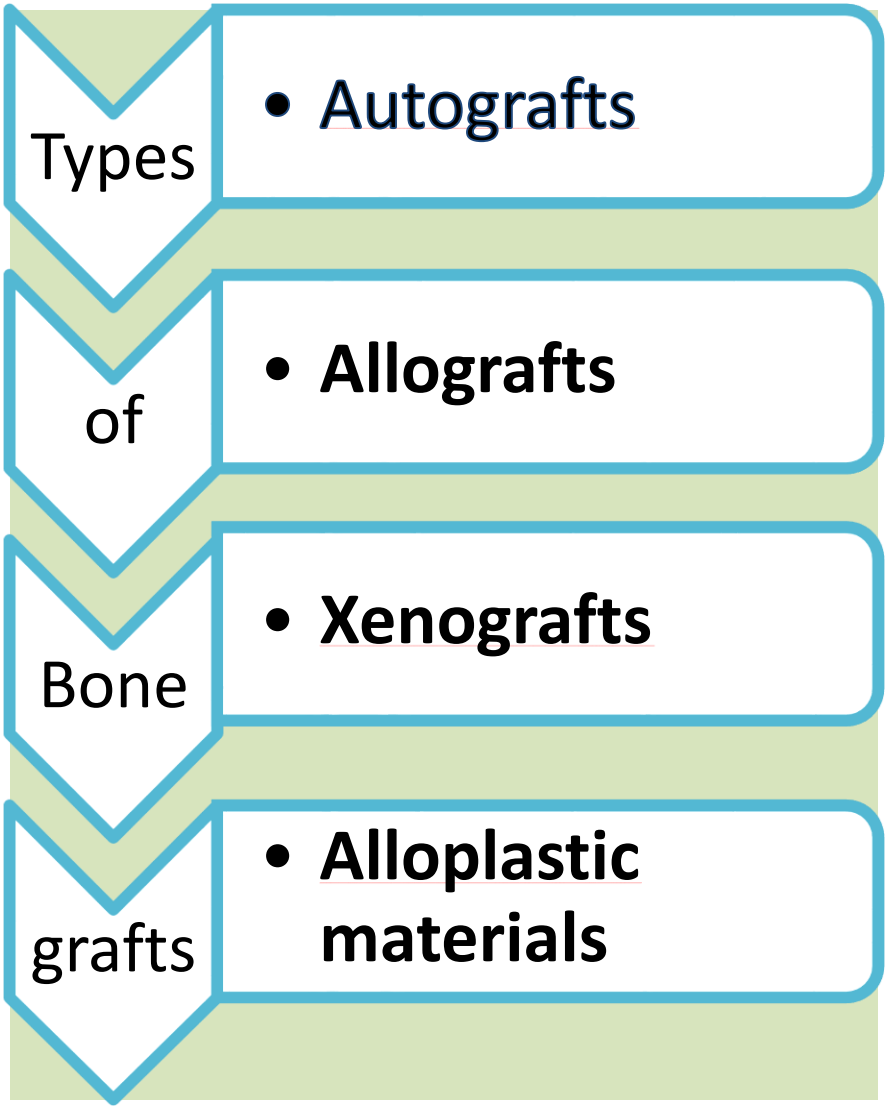


Figure 6: Types of bone graft material

As a result, a universal "gold standard" for all cases is impractical, leading each clinician to develop a personalized "standard protocol" that incorporates their expertise and experience.[17] Remarkably, successful outcomes can still be achieved despite the diversity of methods employed.[18] To advance this discussion, the Korean Academy of Implant Dentistry (KAID) hosted a conference on "Bone Grafts for Implant Dentistry" on October 7, 2018, where four leading Korean clinicians gathered to share their standard protocols and preferred graft materials. This consensus paper distills their insights and strengthens the theoretical framework through a comprehensive literature review of past, present, and future graft materials in implant dentistry, highlighting the crucial role of bone grafts in modern oral implantology.[19] Historically, the practice of bone grafting can be traced back to ancient methods, with early techniques primarily involving autografts, which remain the gold standard due to their biocompatibility and integration capabilities.[20] Limitations related to bone harvesting, such as pain and morbidity, prompted the exploration of alternatives like allografts, sourced from deceased donors, and xenografts, derived from other species, typically bovine.[21] Today, several types of bone grafts are utilized: autografts offer superior compatibility and healing potential; allografts provide a biological scaffold; xenografts ensure safety and biocompatibility; and synthetic grafts mimic natural bone properties.[22] Recent decades have seen significant transformations in bone grafting techniques, driven by advances in minimally invasive surgical methods, such as GBR, which effectively prevents soft tissue interference during healing (**Table 1**).[23]

Graft	Description	Key benefits
Autografts	Grafts taken from the patient's own body	Superior compatibility and healing potential
Allografts	Grafts from a donor of the same species	Provides a biological scaffold
Xenografts	Grafts from a different species	Ensures safety and biocompatibility
Synthetic Grafts	Man-made materials that mimic natural bone properties	Mimics natural bone properties

Table 1: Key benefits of each type of graft

Innovations in 3D imaging and printing allow for the creation of custom grafts tailored to detailed anatomical data, enhancing surgical precision and patient satisfaction.[24] A critical factor in the success of bone grafts is biocompatibility, with autografts inherently possessing high compatibility, while allografts and xenografts require careful processing to ensure safety.[25] The integration of bioengineered materials—incorporating growth factors or stem cells—further enhances the healing potential of grafts.[26] The evolution of bone grafts has significantly impacted clinical practice, leading to improved surgical outcomes, reduced morbidity, and accelerated healing times, with high rates of osseointegration being essential for the long-term success of dental implants (**Figure 7**).[27]

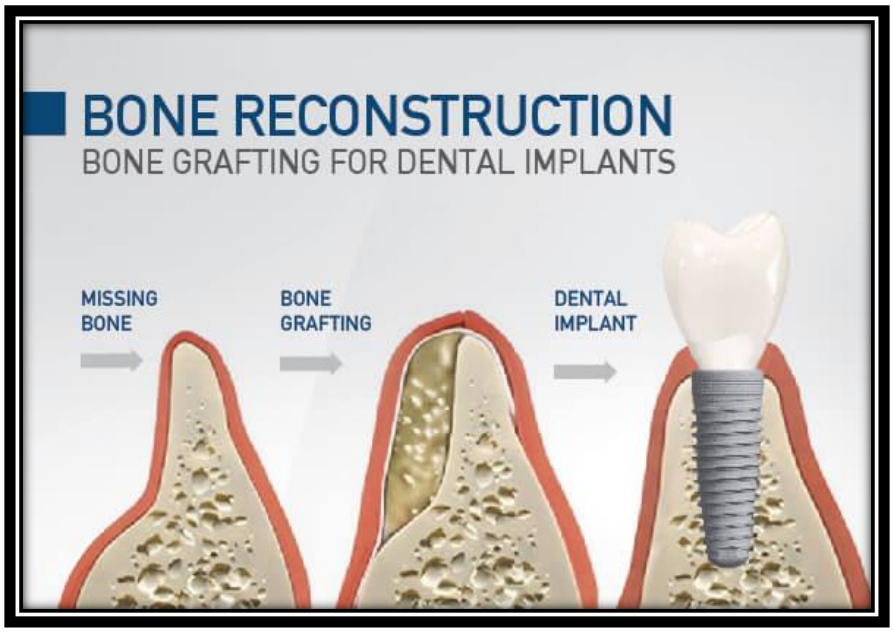


Figure 7: Bone graft augmented osseointegrated implant
Courtesy: https://westcoastinternational.com/bone-graft-dental

The journey of bone grafts reflects a remarkable evolution driven by innovation and a steadfast commitment to improving patient care. [28]As technology continues to progress, the future of bone grafting holds immense promise for even greater advancements, ultimately enhancing the efficacy and safety of dental implant procedures. [29] This review critically examines the progression of bone grafting methods, tracing their evolution from basic harvesting techniques to advanced innovations that utilize cutting-edge technologies and biological principles. This comprehensive exploration underscores the critical importance of ongoing research and development in this dynamic field, signaling a new era of patient-centered approaches that address the needs of both clinicians and patient's alike.[30]

II. Discussion

Dental implants have become the standard for tooth replacement due to their durability, functionality, and aesthetic appeal. However, the success of implant placement is significantly influenced by the quality and quantity of bone available at the implant site.[31] In cases where patients lack sufficient bone volume, bone

grafting procedures have become essential for creating a suitable environment for implant integration (**Figure 8**).[32]

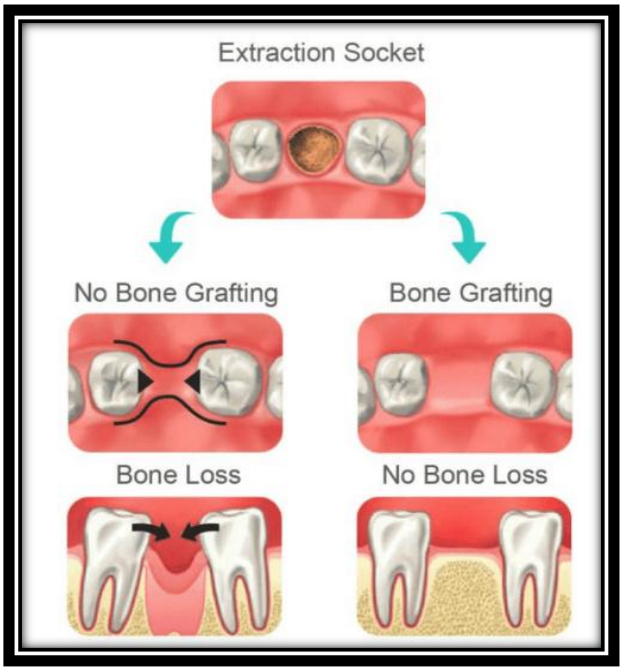


Figure 8: Importance of bone grafting in bone volume
Courtesy: https://dentalimplantsolutionz.com/autogenous-dentin-grafting/

The evolution of bone grafts in oral implantology has seen a remarkable transformation, moving from basic techniques to sophisticated, precision-driven methods.[33] Initially dependent on autogenous sources, clinicians soon recognized the importance of biocompatibility and integration for effective osseointegration.[34] As time progressed, the introduction of allogenic and synthetic materials broadened the options available, providing varying levels of osteoconductivity and osteoinductivity.[35] Innovations in surgical techniques and imaging technology have further improved graft harvesting and placement, leading to better healing outcomes. This review highlights the key milestones in the development of bone grafts, underscoring their vital role in achieving optimal results in implant dentistry and the continuous pursuit of enhanced materials and techniques.[36]

Types of bone graft materials in dentistry:

In dentistry, several types of bone graft materials are used to augment bone volume and promote bone regeneration for various procedures, including dental implants, periodontal surgeries (**Figure 8**), and oral reconstructive surgeries**.** [37] These materials can be categorized into different groups based on their source and composition. Here are some common types of bone graft materials used in dentistry. [38]

Autogenous Tooth Bone Graft

High-quality bone graft materials possess essential attributes, including the ability to revascularize, osteoconductivity, osteoinductivity, angiogenic potential, appropriate density, and the remodeling of the grafted bone matrix.[39] They must also resist infection, be cost-effective, and allow for ease of handling.[40] Among these attributes, angiogenesis and osteogenesis are critical, as their reproducibility significantly impacts long-term outcomes, fostering healthy tissue that minimizes the risk of wound dehiscence and infection while promoting early stabilization and epithelialization. [41] Historically, autogenous bone has been viewed as the gold standard due to its outstanding osteogenic properties and robust infection resistance.[42] However, the harvesting process can be challenging, often resulting in inevitable volume loss over time.[43] In contrast, widely used xenogenic bone graft materials can facilitate sufficient bone formation under optimal regenerative conditions, such as socket preservation (**Figure 9**) or sinus lifts (**Figure 10**). Nevertheless, they come with risks, including the potential for infection that may necessitate complete removal of the xenograft (**Table 1**) .[44]

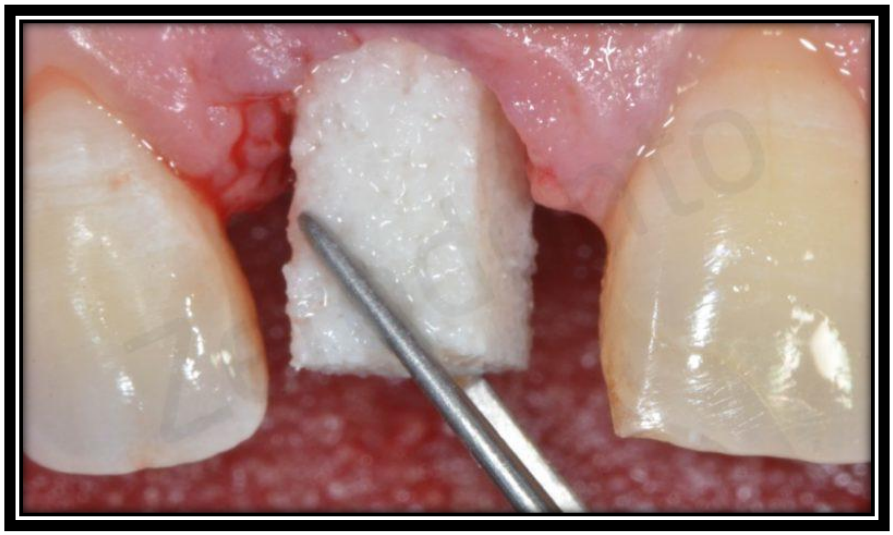


Figure 9: Socket preservation of maxillary anterior region using bone graft
Courtesy: https://www.zerodonto.com/en/2019/01/socket-preservation/

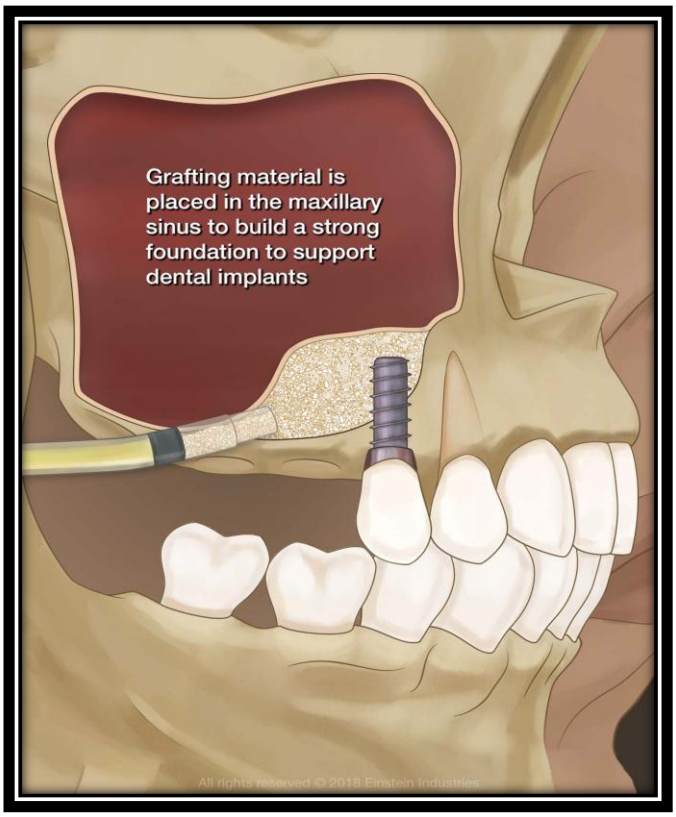


Figure 10: Bone graft inserted into maxillary sinus for implant insertion

Courtesy: https://www.hodgesortho.com/blog/2022/12/18/sinus-lift-recovery-timeline-what-214421/

Table 1: Comparative overview of various graft types and their attributes

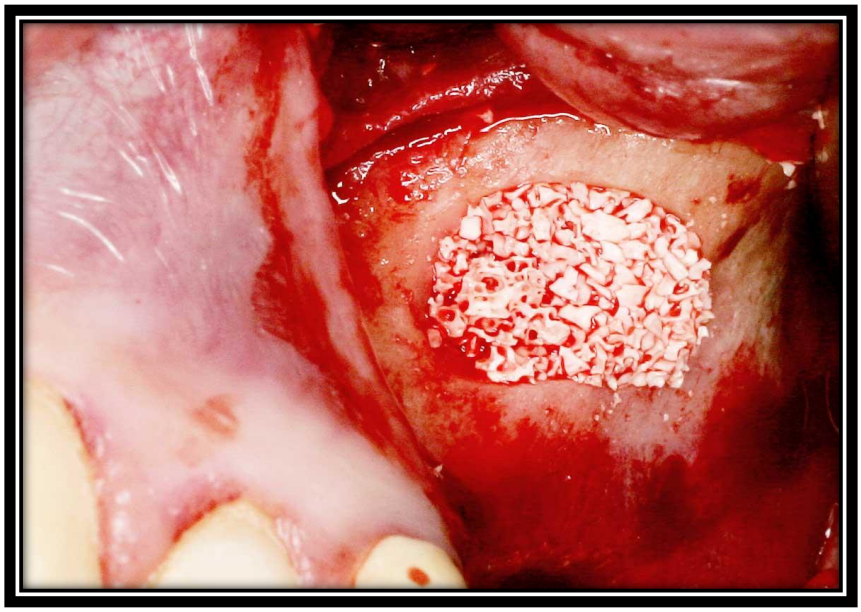
Type	Source	Advantages	Disadvantages	Common Uses
Autograft	Patient's own body	Excellent biocompatibility; promotes osteogenesis; no risk of disease transmission	Surgical site morbidity; limited quantity; possible resorption	Bone defects, implants, sinus lifts

Xenograft	Animal (usually bovine)	Abundant supply; similar properties to human bone	Risk of disease transmission; possible immune response; less osteogenic potential	Socket preservation, sinus lifts
Allograft	Donor (human)	No additional surgery required; greater availability	Risk of disease transmission; potential immune reaction	Bone grafting, joint reconstruction
Alloplast	Synthetic materials	No disease transmission risk; customizable properties	Biocompatibility varies; may lack osteogenic properties	Bone regeneration, filling defects, augmentations

The utilization of teeth as graft materials offers a groundbreaking alternative that significantly enhances bone regeneration and integration in a variety of clinical settings.[45] The high mineral content of teeth, especially in dental tissues, not only provides vital structural support but also delivers bioactive properties that effectively promote osteoconduction and osteoinduction.[46] Additionally, the unique collagen matrix present in teeth facilitates cellular attachment and proliferation, fostering a healing environment conducive to recovery. This innovative approach has the potential to transform grafting techniques, leading to improved outcomes in implant dentistry.[47] Furthermore, the capacity of dental grafts to support angiogenesis— the formation of new blood vessels— amplifies their effectiveness in reconstructive procedures.[48] As research delves deeper into the mechanisms that underpin the efficacy of teeth as graft materials, their role in tissue engineering and regenerative medicine is poised to expand, paving the way for novel solutions to complex clinical challenges.[49] This evolution could redefine the landscape of dental restoration and regenerative therapies, offering patients enhanced healing and long-lasting results.[50] It is an outstanding collagen-rich bone substitute that facilitates robust tissue regeneration and boasts strong infection resistance. It can be processed into block or particulate forms for diverse applications, and its organic components, including bone morphogenic protein, enhance its osteoinductive properties.[51] Research in animals has demonstrated the osteogenic potential of particulate dentin, suggesting benefits comparable to allogenic graft materials.[52] Clinically, autogenous tooth bone graft can be readily harvested due to its advantageous composition, leading to excellent crestal bone stability in various scenarios, such as maxillary sinus augmentation and ridge augmentation.[53] It is particularly effective in transmucosal GBR with immediate implantation after tooth extraction and volumetric enhancement in peri-implant defects, showcasing its ability to heal without infection, even in secondary healing situations without membrane coverage.[54] As a space maintainer, autogenous bone graft supports horizontal bone augmentation through a sturdy matrix, enabling successful vertical augmentation without the necessity for titanium mesh space maintainers.[55] When employed as a sinus graft, autogenous bone graft initially presents lower bone density, which gradually stabilizes over time.[56] Future developments in autogenous bone grafts should focus on integrating computer-guided surgical techniques with other bone graft materials, emphasizing the importance of immediate temporalization to optimize surrounding volume.[57] Additionally, it's essential to acknowledge the strong affinity these materials have for host tissue during the healing phase to ensure successful integration and improved outcomes.[58] It offers a compelling solution for preserving both soft and hard tissue morphology in jaw defects, exhibiting a strong affinity for soft tissue and osteogenic activity in extracted sockets, periodontal defects, and sinus grafts without infection.[59] It effectively induces rigid bone regeneration in sinus grafts and periodontal augmentations, achieving successful bone formation around immediate temporalization, making it an ideal substitute for digital bone grafting.[60]

Xenograft bone substitutes:

Several advanced techniques have been utilized to enhance bone volume, such as maxillary sinus floor elevation (**Figure 11**), bone grafting, ridge expansion osteotomy (REO) (**Figure 12**), GBR, and various types of bone grafts, including onlay, inlay, and socket augmentation. [61]



Graft material inserted after sinus floor elevation
Courtesy: https://botiss.com/product/sinus-lift/

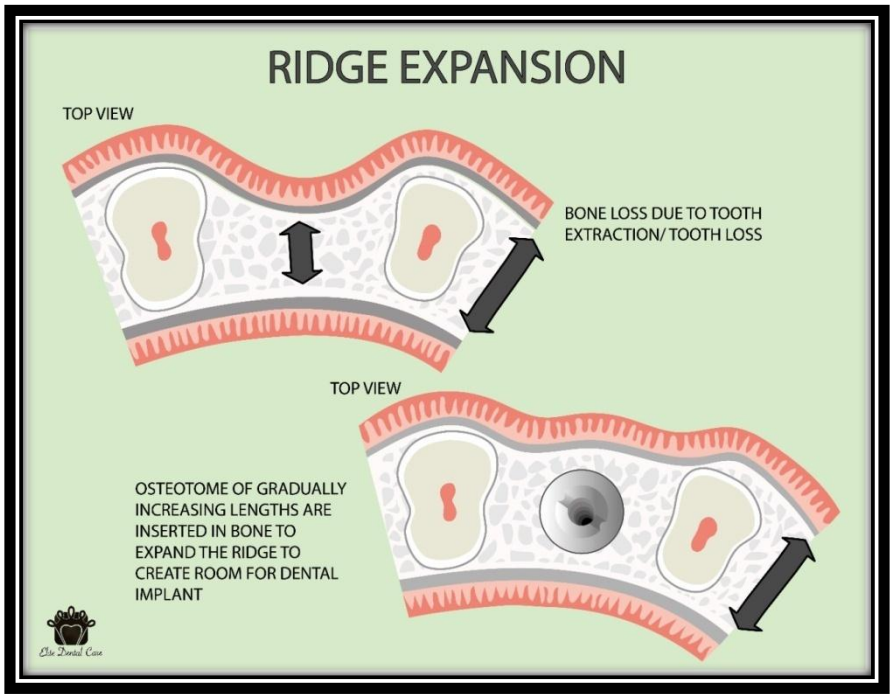


Figure 12: Rigid expansion osteotomy
Courtesy: https://theelitedental.com/ridge-expansion-and-technique-elite-dental-care-tracy/

However, these procedures are highly technique-sensitive, and the absence of prospective randomized studies complicates the assessment of the effectiveness of various methods.[62] The intricacies involved in comparing materials and techniques in clinical practice pose significant challenges, as numerous factors affect the treatment of alveolar defects.[63] Clinicians must possess a thorough understanding of these variables, including the origin of growth factors, the function of the extracellular matrix, dynamics of inflammatory cells, behavior of osteoblasts, and the macro- and micro-structural properties of bone substitutes.[64] While postoperative outcomes are frequently emphasized, grasping histological results is equally vital for preventing unforeseen complications post-grafting. [65] From a fundamental perspective, an interface range of 10 to 100 nm is critical between host cells and bone substitute particles, with cell sizes ranging from 30 to 50 μm to several hundred micrometers.[66] This indicates that new bone formation is unlikely in environments that are either mobile or excessively fluid. Initially, manufacturers focused on replicating the macroscopic structure of human

bone, a trend that has persisted but has also evolved to include enhancements in microscopic and mesoscopic structures.[67] The formation of channels within these materials is essential for promoting rapid angiogenesis and facilitating the remodeling process needed for effective trabecular anastomosis. When selecting the optimal bone substitute, it is crucial to avoid materials with non-porous surfaces, high-temperature-damaged classified surfaces, or pebbled textures, as these characteristics can significantly impede grafting success.[68]

Several environmental factors should be considered by clinicians prior to the bone grafting procedure (**Figure 13**):

1. Wound Opening: Consideration of whether the wound is open or closed during surgery.
2. Defect Shape: Assessment of whether the defect is of the contained or non-contained type.
3. Grafting Material: Decision on whether the grafting material will be mixed with another substance.
4. Type of Barrier Membrane: Choice between a resorbable or non-resorbable membrane for covering the defect.
5. Wound Closure: Consideration of whether the wound will remain open or be closed.[69]

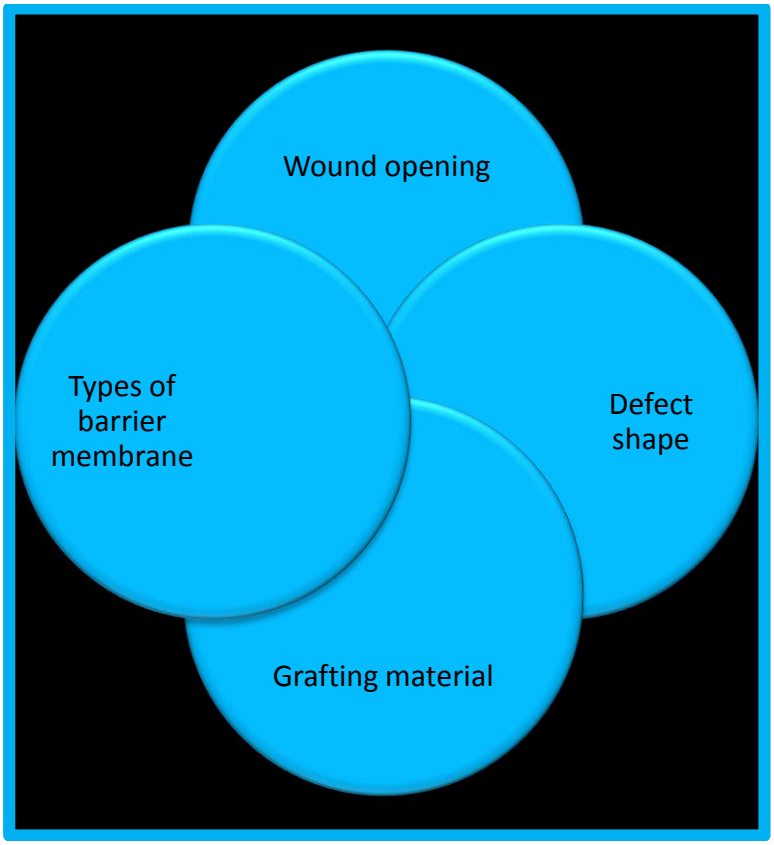


Figure 13: Environmental Factors to Consider Before Bone Grafting

Histological evaluations post-bone grafting can complicate the differentiation between favorable and unfavorable outcomes compared to clinical findings from a clinician's perspective. Clinicians often categorize the density of newly formed tissue during osteotomy, as biopsy results typically take days to weeks.[70] This delay can lead to confusion when correlating clinically positive findings with histologically questionable results, making it essential to reference Kim and Lee's report in 2017 to categorize remodeling patterns of newly formed tissue based on graft activity, mesenchymal organization, inflammatory cell infiltration, and trabecular bone anastomosis.[71, 72] Moreover, it is highly recommended to utilize the patient's own pristine natural bone areas whenever possible during dental implant placement in previously augmented sites.

The lack of histological evaluation before implant surgery is particularly concerning.[73] Few clinicians focus on the physicochemical properties of grafting materials. Checking the pH value of grafting materials before surgery and correlating clinical findings with pH levels can be beneficial, especially if the pH deviates from the normal range.[74] In 2018, Ham's study of xenograft bone substitutes revealed critical insights into their pH values and clinical implications. Most materials—bovine, porcine, and equine—fell within a neutral pH range of 6.79 to 8.07. However, the exceptions, TiOss and Cerabone, with pH levels soaring to 9.80 and 10.32 respectively, raised significant concerns.[75] Biopsies from these high-pH materials demonstrated a troubling absence of new bone formation, marked by severely degenerated fibrous stroma and a lack of host reaction.[76]

Interestingly, the use of collagenous foreign materials like Gelfoam (**Figure 14**) in socket preservation showcased sclerosed fibrous tissue without inflammatory response. This raises a pivotal discussion among surgeons advocating for collagenous materials to maintain soft tissue profiles, enabling dental implant placement within 4 to 8 weeks.[77]

Figure 14: Gelfoam
Courtesy: https://midwestdental.com/gelfoam-12box-size-4-2cm-x-2cm-x-7mm

However, a gap in research exists regarding the performance of various collagenous materials on the market. In surgical practice, the focus should be on enhancing angiogenesis and ensuring wound stabilization.[78] While bleeding is essential for healing, excessive hemorrhage can undermine stability, as a conducive environment is vital for tissue regeneration.[79] Hence, applying high pressure on graft materials is discouraged, as it can compromise the critical spaces for stromal tissue and disrupt angiogenic pathways.[80] Currently, animal-origin bone substitutes are the go-to choice in dentistry for augmenting diverse defects, with no significant adverse events reported.[81] However, clinicians must be discerning in their selection of xenograft materials, prioritizing those with robust clinical and histological documentation. The choice should be tailored based on the defect's characteristics—shape, size, and location—whether used alone or in conjunction with autogenous bone or other substitutes.[82] The evidence strongly supports the efficacy of xenograft bone substitutes in intraoral bone grafting (**Figure 15**). Their potential to enhance healing and structural integrity in challenging scenarios makes them invaluable assets in modern dental practice.[83]

Figure 15: Xenografts for intraoral grafting
Courtesy: https://salvin.com/product/salvinoss-xenograft-bone-graft-material/

Alloplastic graft bone substitutes: Alloplastic grafts have surged in popularity due to their remarkable effectiveness and pivotal role as scaffolds, particularly with the incorporation of growth factors. This review delves into the critical need for alloplastic grafts, their clinical applications, inherent limitations, and promising advancements aimed at overcoming these obstacles.[84] The World Congress of Biomaterials has outlined essential requirements for alloplastic grafts: interconnected macro-porosity, surface micro-roughness, and a synergistic blend of beta-tricalcium phosphate, hydroxyapatite , and calcium silicate, which are fundamental for ensuring the successful integration and functionality of grafts in clinical settings.[85] The evolution of alloplastic materials has been profound, particularly in their manufacturing and microstructural design, with Osteon™ (Genoss) from Korea exemplifying this evolution.[86] Osteon I, the pioneering version, features a hydroxyapatite scaffold created using a replica method, showcasing 77% porosity with pore sizes of 300 to 500 μm, though its utility in particulate form was limited.[87] Osteon II (**Figure 16**) addressed this limitation by offering a reinforced microstructure with interconnected porosity and a reduced pore size of less than 250 μm, resulting in a biphasic scaffold of hydroxyapatite and beta-tricalcium phosphate.[88]

Figure 16: Osteon II bone graft
Courtesy: https://www.aegisdentalnetwork.com/id/products/dentium/osteon-ii

Although challenges in impurity removal during production persisted, advancements continued with Osteon III, which leveraged a simplified air-bubble technique to further enhance bone formation while maintaining biphasic properties.[89] In clinical applications, the long-term maturation of alloplastic bone grafts is paramount; Osteon I yielded promising results with block grafts, effectively maintaining volume due to its non-resorbable hydroxyapatite composition, while Osteon II was engineered for versatility, suitable for socket preservation, sinus grafting, and ridge augmentation, despite some volumetric reduction linked to its beta-tricalcium phosphate content.[90] Osteon III rectified this by optimizing the hydroxyapatite and β beta-tricalcium phosphate ratio, enhancing interconnectivity and crystallinity, with studies in animal models demonstrating its superior scaffold properties and effective bone regeneration, especially when used with resorbable membranes (**Figure 17**).[91]

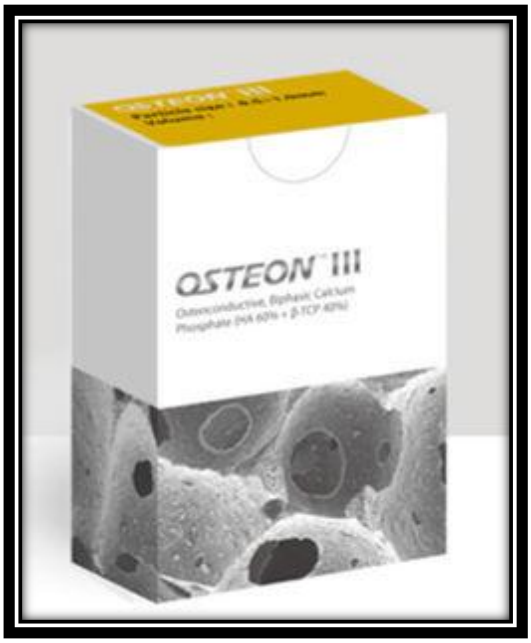


Figure 17: Osteon III bone graft
Courtesy: https://www.medicalexpo.com/prod/genoss/product-84497-908033.html

Historically, alloplastic grafts have been confined to small or contained defects due to limited osteoinductivity, with particle size playing a crucial role; optimal dimensions of 0.5 to 1 mm have been identified to minimize tissue absorption.[92] While issues with moldability compared to other bone substitutes exist, combining porcine collagen has significantly improved graft stability.[93] Contouring augmentation, necessary for sufficient volume, has shown excellent outcomes in socket preservation and sinus grafting, attributed to bioabsorption and gradual replacement by autogenous bone.[94] This augmentation can be performed with or without collagen membranes, though recent trends favor membrane use for enhanced wound stability, as each type of alloplastic graft offers unique advantages based on its composition, with particulate grafts enriched with collagen exhibiting accelerated bone formation.[95] The recommended approach involves applying Osteon III adjacent to implants, covered with a membrane, to ensure volumetric stability and optimal healing.[96] The future of alloplastic grafts is promising, with advancements leading to block forms suitable for large defects, requiring designs that facilitate trimming, drilling, and screw fixation, while many grafts now feature collagen coatings to enhance handling.[97] The advent of 3D printing technology could revolutionize the field by enabling customizable graft designs tailored to specific alveolar defects, thereby improving operability. Additionally, enhancing bone quality through innovative additives like Deoxyribonucleic Acid (DNA) or glycoproteins holds great potential; for instance, polydeoxyribonucleotide has shown promise in accelerating healing through angiogenesis. Continued research and technological advancements will be vital to validate these innovations for clinical application, paving the way for a new era in bone grafting.[98] Oral and maxillofacial surgeons have employed unilateral ramal bone harvests for moderate to severe atrophy or defects involving one to four teeth, while iliac bone harvests are selected for more extensive defects.[99] Among 216 patients who underwent ramal harvesting, approximately 15% reported sensory disturbances immediately post-surgery, but none experienced them after six to nine months, highlighting the transient nature of these effects.[100] Donor site infections were minimal, occurring in less than 10% of cases, while complications such as wound dehiscence affected around 6%. [101] In a cohort of 49 patients undergoing iliac harvesting, 24% experienced an average of eight days of gait disturbance, yet no permanent complications arose from either ramus (**Figure 18**) or iliac harvests, emphasizing the relative safety of these procedures.[102]

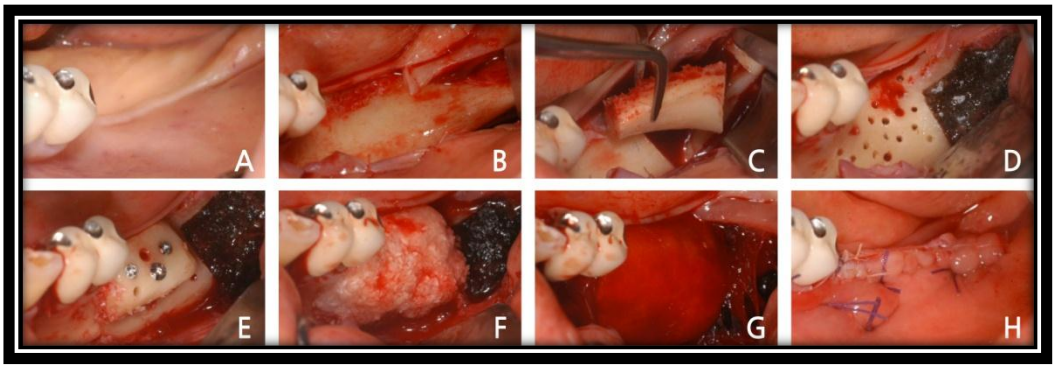


Figure 18: Ramal harvesting
Courtesy: Chee Y. Vertical ridge augmentation with mandibular ramus block bone for implant surgery. Implantology. 2021; 22:36.

At the recipient site, mild complications were also present, with less than 10% experiencing wound dehiscence, graft removal due to infection, or partial graft failure.[103] When utilizing a one-stage procedure with an autogenous block bone graft, precise selection of the implant's path and position is possible, although unexpected resorption may occur around the implant.[104] Conversely, a two-stage procedure allows for implantation under clinically stable conditions four to nine months post-graft.[105] Various studies are conducted over years on survival rates of various graft materials (**Table 2**).[106]

Table 2: Graft Types and Survival Rates

Study/Author	Type of Graft	Population	Findings	Survival Rates
Cordaro et al.	Autogenous bone graft	Various patients	Resorption rates range from 0% to 25%; up to 42% vertical resorption within 6 months.	Not specified
Levin et al.	Ramal block bone graft	129 implants	88% five-year cumulative survival rate after grafting.	88% at 5 years
Schwartz-Arad et al.	Ramus block bone graft	633 implants	83% eleven-and-a-half-year cumulative survival rate.	83% at 11.5 years

Future Prospects: The future of bone grafts in oral implantology promises remarkable advancements driven by ongoing research and technological innovation. The development of advanced bioengineered materials is poised to revolutionize grafting by mimicking natural bone properties while promoting cellular activity and enhancing osseointegration. These materials, enriched with growth factors and stem cells, aim to stimulate healing and regeneration, potentially reducing recovery times and improving patient outcomes. As our understanding of patient biology evolves, personalized medicine will allow for customized grafts tailored to individual anatomical and biological needs, enhancing compatibility and clinical results. The continued shift towards minimally invasive surgical techniques is expected to reduce discomfort and accelerate recovery, with innovations like endoscopic and robotic-assisted procedures refining surgical approaches.[107] Advancements in 3D printing and imaging technologies will enable the creation of highly accurate, patient-specific grafts that integrate seamlessly with existing bone. Additionally, the integration of digital health tools, such as telemedicine and remote monitoring, will enhance postoperative care and patient engagement, optimizing healing processes. Longitudinal research and data analysis will provide valuable insights into the efficacy and safety of various graft materials and techniques, refining treatment protocols. The intersection of oral implantology and regenerative medicine holds immense promise, with research into biomaterials that promote tissue regeneration potentially leading to innovative solutions that could eliminate the need for grafts in certain scenarios.[108]

III. Conclusion:

The evolution of bone grafts in oral implantology signifies a groundbreaking advancement in dental medicine, transforming implant procedures and significantly improving patient outcomes. From basic harvesting techniques to sophisticated methodologies, this field has evolved through technological innovation and a deeper understanding of biological principles. The shift from autografts to allografts, xenografts, and synthetic materials has addressed earlier shortcomings while enhancing the effectiveness of grafting through innovations like guided bone regeneration. The integration of 3D imaging and printing exemplifies a commitment to personalized care, allowing precise customization of grafts for optimal fit and integration. As research progresses, the advancement of bioengineered materials and growth factors holds great potential to further improve healing capabilities. Ultimately, this evolution represents a paradigm shift toward more effective, patient-centered approaches in oral implantology, prioritizing clinical efficacy alongside patient satisfaction. The future of bone grafting is not merely about restoring function; it's about transforming lives, ensuring that those seeking dental restoration receive the highest quality of care and paving the way for lasting oral health.

Financial support and sponsorship Nil

Conflicts of interest There are no conflicts of interest

References:

[1]. Cypher TJ, Grossman JP. Biological principles of bone graft healing. J. Foot Ankle Surg. 1996; 35:413–417.
[2]. Elsalanty ME, Genecov DG. Bone Grafts in Craniofacial Surgery. Craniomaxillofacial Trauma Reconstr. 2009; 2:125–134.
[3]. Wadhawan R, Gupta DK, Jain A, Ullah AHM, Sengar H, Valiyaveettil GA. Envisioning perpetual developments and sustained efficacy of implant maintenance. Int J Appl Dental Sci. 2024; 10(3):377-390.
[4]. Abhay S, Haines SJ. Repairing holes in the head: A history of cranioplasty. Neurosurgery. 1997; 40:588–603.
[5]. Kumar P, Fathima G, Vinitha B. Bone grafts in dentistry. J. Pharm. Bioallied Sci. 2013; 5:125–127.
[6]. Pommer B, Zechner W, Watzek G, Palmer GWAR. To Graft or Not to Graft? Evidence-Based Guide to Decision Making in Oral Bone Graft Surgery. Bone Grafting. 2012; 2012:1–25.
[7]. Cha HS, Kim JW, Hwang JH, Ahn KM. Frequency of bone graft in implant surgery. Maxillofac. Plast. Reconstr. Surg. 2016; 38:1–4.
[8]. Wanschitz F, Nell A, Patruta S, Wagner A, Ewers R. Influence of three currently used bone replacing materials on the in vitro proliferation of human peripheral blood mononuclear cells. Clin. Oral Implants Res. 2005; 16:570–574.
[9]. Wadhawan R, Brar AD, Singh M, Maniar A, Gaba N. Management of ailing & failing implants: A review. IOSR J Dent Med Sci. 2016; 15(3):101-109.
[10]. Bhatt RA, Rozental TD. Bone Graft Substitutes. Hand Clin. 2012; 28:457–468.
[11]. Wang W, Yeung KW. Bone grafts and biomaterials substitutes for bone defect repair: A review. Bioact. Mater. 2017; 2:224–247.
[12]. Haugen HJ, Lyngstadaas SP, Rossi F, Perale G. Bone grafts: Which is the ideal biomaterial? J. Clin. Periodontol. 2019; 46:92–102.
[13]. Ratnayake JT, Ross ED, Dias GJ, Shanafelt KM., Taylor SS, Gould ML, Guan G, Cathro PR. Preparation, characterisation and in-vitro biocompatibility study of a bone graft developed from waste bovine teeth for bone regeneration. Mater. Today Commun. 2020; 22:100732.
[14]. W R Moore 1, S E Graves, G I Bain. Synthetic bone graft substitutes. ANZ J Surg. 2001; 71:354–61.
[15]. Kao ST, Scott DD. A Review of Bone Substitutes. Oral Maxillofac. Surg. Clin. North Am. 2007; 19:513–521.
[16]. Wadhawan A, Gowda TM., Mehta DS. Gore-tex® versus resolut adapt® GTR membranes with perioglas® in periodontal regeneration. Contemp. Clin. Dent. 2012; 3:406.
[17]. Kolk A, Handschel J, Drescher W, Rothamel D, Kloss F, Blessmann M, Heiland M, Wolff KD, Smeets R. Current trends and future perspectives of bone substitute materials—From space holders to innovative biomaterials. J. Cranio Maxillofac. Surg. 2012; 40:706–718.
[18]. Roberts TT, Rosenbaum AJ. Bone grafts, bone substitutes and orthobiologics: The bridge between basic science and clinical advancements in fracture healing. Organogenesis. 2012; 8:114–124.
[19]. Horch HH, Sader R, Pautke C, Neff A, Deppe H, Kolk A. Synthetic, pure-phase β-tricalcium phosphate ceramic granules (Cerasorb®) for bone regeneration in the reconstructive surgery of the jaws. Int. J. Oral Maxillofac. Surg. 2006; 35:708–713.
[20]. Buser D, Hoffmann B, Bernard JP, Lussi A, Mettler D, Schenk RK. Evaluation of filling materials in membrane-protected bone defects. A comparative histomorphometric study in the mandible of miniature pigs. Clin. Oral Implant. Res. 1998; 9:137–150.
[21]. Nevins M, Parma-Benfenati S, Janke UW, Kleyer A, Rasperini G, Tinti C, Schupbach P, Kim DM. The efficacy of mineralized allograft cortical and cancellous chips in maxillary sinus augmentations. Int. J. Periodontics Restor. Dent. 2014; 34:789–793.
[22]. Toscano N, Holtzclaw D, Mazor Z, Rosen P, Horowitz R, Toffler M. Horizontal Ridge Augmentation Utilizing a Composite Graft of Demineralized Freeze-Dried Allograft, Mineralized Cortical Cancellous Chips, and a Biologically Degradable Thermoplastic Carrier Combined With a Resorbable Membrane: A Retrospective Evaluation of 73 Consecutively Treated Cases From Private Practices. J. Oral Implant. 2010; 36:467–474.
[23]. Fuentes R, Issa JPM, Iyomasa MM, Oporto G, Prieto R, Borie E. The Behavior of Demineralized Bone Matrix (DBM) in Post-Extraction Sockets. Int. J. Morphol. 2012; 30:394–398.
[24]. Hanes PJ. Bone Replacement Grafts for the Treatment of Periodontal Intrabony Defects. Oral Maxillofac. Surg. Clin. N. Am. 2007; 19:499–512.
[25]. Zitzmann NU, Schärer P, Marinello CP, Schüpbach P, Berglundh T. Alveolar ridge augmentation with Bio-Oss: A histologic study in humans. Int. J. Periodontics Restor. Dent. 2001; 21:288–295.
[26]. Ibrahim AM, Khalil MM, El Halawani GN. Evaluation Of Anterior Maxillary Horizontal Ridge Augmentation With Simultanous Implant Placement Using Cerabone® Versus Cerabone® Combined With Platelet Rich Plasma (Randomized Clinical Trial) Alex. Dent. J. 2022; 47(1):1-8.
[27]. Ewers R. Maxilla Sinus Grafting With Marine Algae Derived Bone Forming Material: A Clinical Report of Long-Term Results. J. Oral Maxillofac. Surg. 2005; 63:1712–1723.
[28]. Christian S, Doris M, Alexis S, Georgios L, Else S, Franz K, Karl D, Rolf E. The fluorohydroxyapatite (FHA) FRIOS® Algipore® is a suitable biomaterial for the reconstruction of severely atrophic human maxillae. Clin. Oral Implant. Res. 2003; 14:743–749.

[29]. Yukna RA, Yukna CN. A 5-year follow-up of 16 patients treated with coralline calcium carbonate (Biocoral™) bone replacement grafts in infrabony defects. J. Clin. Periodontol. 1998; 25:1036–1040.
[30]. Kenney E, Lekovic V, Sa Ferreira J, Han T, Dimitrijevic B, Carranza F Jr. Bone formation within porous hydroxylapatite implants in human periodontal defects. J. Periodontol. 1986; 57:76–83.
[31]. Misch CM. Use of the Mandibular Ramus as a Donor Site for Onlay Bone Grafting. J. Oral Implant. 2000; 26:42–49.
[32]. Smith B, Rajchel J II. Anatomic Considerations in Mandibular Ramus Osteotomies. Modern Practice in Orthognathic and Reconstructive Surgery. WB Saunders; Philadelphia, PA, USA: 1992. pp. 2347–2360.
[33]. Misch CM. Autogenous Bone: Is It Still the Gold Standard? Implant. Dent. 2010; 19:361.
[34]. Pikos MA. Block autografts for localized ridge augmentation: Part II. The posterior mandible. Implant Dent. 2000; 9:67–75.
[35]. 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; 18:661.
[36]. Bostrom MPG, Seigerman DA. The Clinical Use of Allografts Demineralized Bone Matrices, Synthetic Bone Graft Substitutes and Osteoinductive Growth Factors: A Survey Study. HSS J. 2005; 1:9–18.
[37]. Palmer SH, Gibbons CLMH, Athanasou NA. The pathology of bone allograft. J. Bone Jt. Surgery. Br. Vol. 1999; 81:333–335.
[38]. Malinin T, Temple H, Garg A. Bone allografts in dentistry: A review. Dentistry. 2014; 4:1. 39. Amorfini L, Migliorati M., Signori A, Silvestrini-Biavati A, Benedicenti S. Block Allograft Technique versus Standard Guided Bone Regeneration: A Randomized Clinical Trial. Clin. Implant. Dent. Relat. Res. 2013; 16:655–667.
[39]. Pendarvis WT, Sandifer JB. Localized ridge augmentation using a block allograft with subsequent implant placement: A case series. Int. J. Periodontics Restor. Dent. 2008; 28:509–515.
[40]. Winkler T, Sass F, Duda G, Schmidt-Bleek K. A review of biomaterials in bone defect healing, remaining shortcomings and future opportunities for bone tissue engineering: The unsolved challenge. Bone Joint Res. 2018; 7:232–243.
[41]. El-Chaar ES. Demineralized bone matrix in extraction sockets: A clinical and histologic case series. Implant Dent. 2013; 22:120–126.
[42]. Uwagie EA, Awasum AC, Kene RC, Chilaka FC. Use of native bovine bone morphogenetic protein extract in healing segmental tibial bone defects in goats. J. Vet. Sci. Technol. 2016; 7:329.
[43]. Wadhawan R, Khandelwal V, Mishra S, Bansal S, Bhattacharya S, Thavalam Parambil A. Cutting-edge methods and new frontiers in maxillary sinus lifting for enhanced dental restoration and implants: An analytical review.
[44]. Fuentes R., Saravia D., Arias A., Prieto R, Dias F. Mandibular dental implant placement using demineralized bone matrix (DBM) Biomed. Res. 2017; 28:2656–2660.
[45]. Zhang M, Powers RM Jr, Wolfinbarger L Jr. Effect (s) of the demineralization process on the osteoinductivity of demineralized bone matrix. J. Periodontol. 1997; 68:1085–1092.
[46]. Giannoudis PV, Dinopoulos H, Tsiridis E. Bone substitutes: An update. Injury. 2005; 36:S20–S27.
[47]. Kozusko SD, Riccio C, Goulart M, Bumgardner J, Jing XL, Konofaos P. Chitosan as a Bone Scaffold Biomaterial. J. Craniofacial Surg. 2018; 29:1788–1793.
[48]. Oliveira G. Pignaton TB, de Almeida Ferreira CE, Peruzzo LC, Marcantonio E Jr. New bone formation comparison in sinuses grafted with anorganic bovine bone and β-TCP. Clin. Oral Implants Res. 2019; 30:483.
[49]. Scarano A, Degidi M, Iezzi G, Pecora G, Piattelli M, Orsini G, Caputi S, Perrotti V, Mangano C, Piattelli A. Maxillary Sinus Augmentation With Different Biomaterials: A Comparative Histologic and Histomorphometric Study in Man. Implant. Dent. 2006; 15:197–207.
[50]. Özkan Y, Akoğlu B, Kulak-Özkan Y. Maxillary Sinus Floor Augmentation Using Bovine Bone Grafts With Simultaneous Implant Placement: A 5-Year Prospective Follow-Up Study. Implant. Dent. 2011; 20:455–459.
[51]. Uzbek UH, Rahman SA, Alam MK, Gillani SW. Bone Forming Potential of An-Organic Bovine Bone Graft: A Cone Beam CT study. J. Clin. Diagn. Res. 2014; 8:ZC73–ZC76
[52]. Oryan A, Alidadi S, Moshiri A, Maffulli N. Bone regenerative medicine: Classic options, novel strategies, and future directions. J. Orthop. Surg. Res. 2014; 9:18.
[53]. Xu H.H., Simon C.G., Jr. Fast setting calcium phosphate–chitosan scaffold: Mechanical properties and biocompatibility. Biomaterials. 2005; 26:1337–1348.
[54]. Jebahi S, Oudadesse H, Ben Saleh G, Saoudi M, Mesadhi S, Rebai T, Keskes H, el Feki A., el Feki H. Chitosan-based bioglass composite for bone tissue healing: Oxidative stress status and antiosteoporotic performance in a ovariectomized rat model. Korean J. Chem. Eng. 2014; 31:1616–1623.
[55]. Shavandi A, Bekhit AE-DA, Sun Z, Ali MA. Injectable gel from squid pen chitosan for bone tissue engineering applications. J. Sol Gel Sci. Technol. 2015; 77:675–687.
[56]. Nie L, Deng Y, Li P, Hou R, Shavandi A, Yang S. Hydroxyethyl Chitosan-Reinforced Polyvinyl Alcohol/Biphasic Calcium Phosphate Hydrogels for Bone Regeneration. ACS Omega. 2020; 5:10948–10957.
[57]. Wadhawan R, Jain A, Kushwah V, Singh AD, Paul S, Shakya G. Tackling impediments: bespoke solutions for optimized implant outcomes. Quest J Med Dent Sci Res. 2024; 11(9):67-81.
[58]. Husain S, Al-Samadani KH, Najeeb S, Zafar MS, Khurshid Z, Zohaib S, Qasim SB. Chitosan Biomaterials for Current and Potential Dental Applications. Materials. 2017; 10:602.
[59]. Aguilar A, Zein N, Harmouch E, Hafdi B, Bornert F, Offner D, Clauss F, Fioretti F, Huck O, Benkirane-Jessel N, et al. Application of Chitosan in Bone and Dental Engineering. Molecules. 2019; 24:3009.
[60]. Kwon KJ, Seok H. Silk Protein-Based Membrane for Guided Bone Regeneration. Appl. Sci. 2018; 8:1214.
[61]. Cao Y, Wang B. Biodegradation of silk biomaterials. Int. J. Mol. Sci. 2009; 10:1514–1524.
[62]. Khan MR, Tsukada M, Gotoh Y, Morikawa H, Freddi G, Shiozaki H. Physical properties and dyeability of silk fibers degummed with citric acid. Bioresour. Technol. 2010; 101:8439–8445.
[63]. Cai Y, Guo J, Chen C, Yao C, Chung SM, Yao J, Lee IS, Kong X. Silk fibroin membrane used for guided bone tissue regeneration. Mater. Sci. Eng. C. 2017; 70:148–154.
[64]. Kweon H, Jo YY, Seok H, Kim SG, Chae WS, Sapru S, Kundu SC, Park NR, Che X, Choi JY. In vivo bone regeneration ability of different layers of natural silk cocoon processed using an eco-friendly method. Macromol. Res. 2017; 25:806–816.
[65]. Zafar MS, Al-Samadani K.H. Potential use of natural silk for bio-dental applications. J. Taibah Univ. Med. Sci. 2014; 9:171–177.
[66]. Ha YY, Park YW, Kweon H, Jo YY, Kim SG. Comparison of the physical properties and in vivo bioactivities of silkworm-cocoon-derived silk membrane, collagen membrane, and polytetrafluoroethylene membrane for guided bone regeneration. Macromol. Res. 2014; 22:1018–1023.

[67]. Sheikh Z, Hamdan, Abdallah MN, Glogauer M, Grynpas M. Natural and synthetic bone replacement graft materials for dental and maxillofacial applications. Adv. Dent. Biomater. 2019:347–376.
[68]. Wadhawan R, Trivedi P, Kumar A, Ughade V, Bansal D, Roy A. Trailblazing techniques in maxillofacial implants: a detailed layer-by-layer exploration. J Adv Med Dent Sci Res. 2024; 12(8):14-20.
[69]. Dua P, Grover M, Gupta A, Rawat S, Kaushik N, Chopra R. Single piece implant - rehabilitation within 72 hours. IJDSIR. 2024 ;7(3):1-6.
[70]. Lee K, Chang J, Kim J, You C, Kwon H, Lee D. The role of osteoclast in resorption of hydroxyapatite and β-tricalcium phosphate coating layer. Key Eng. Mater. 2009; 396:81–84.
[71]. Kim CK, Choi EJ, Cho KS, Chai JK, Wikesjö UM. Periodontal Repair in Intrabony Defects Treated With a Calcium Carbonate Implant and Guided Tissue Regeneration. J. Periodontol. 1996; 67:1301–1306.
[72]. Li Y. Local use of iontophoresis with traditional Chinese herbal medicine, e.g., Gu-Sui-Bu (Rhizoma Drynariae) may accelerate orthodontic tooth movement. Dent. Hypotheses. 2013; 4:50.
[73]. McPherson R. Bone Grafting with Coralline Hydroxyapatite. EC Dent. Sci. 2019; 18:2413–2423.
[74]. Shavandi A., Wilton V., Bekhit A.E.-D.A. Synthesis of macro and micro porous hydroxyapatite (HA) structure from waste kina (Evechinus chloroticus) shells. J. Taiwan Inst. Chem. Eng. 2016; 65:437–443.
[75]. Giuliani A, Manescu A, Larsson E, Tromba G, Luongo G, Piattelli ., Mangano F, Iezzi G, Mangano C. In Vivo Regenerative Properties of Coralline-Derived (Biocoral) Scaffold Grafts in Human Maxillary Defects: Demonstrative and Comparative Study with Beta-Tricalcium Phosphate and Biphasic Calcium Phosphate by Synchrotron Radiation X-Ray Microtomography. Clin. Implant. Dent. Relat. Res. 2013;16:736–750.
[76]. Karaismailoğlu TN, Tomak Y, Andaç A, Ergün E. Comparison of autograft, coralline graft, and xenograft in promoting posterior spinal fusion. Acta Orthop. Traumatol. Turc. 2002; 36:147–154.
[77]. Thorwarth M, Wehrhan F, Srour S., Schultze-Mosgau S, Felszeghy E, Bader R, Schlegel K. Evaluation of substitutes for bone: Comparison of microradiographic and histological assessments. Br. J. Oral Maxillofac. Surg. 2007; 45:41–47.
[78]. Sethmann I, Luft C, Kleebe HJ. Development of phosphatized calcium carbonate biominerals as bioactive bone graft substitute materials, part I: Incorporation of magnesium and strontium ions. J. Funct. Biomater. 2018; 9:69.
[79]. 77. Du B, Gao Y, Deng Y, Zhao Y, Lai C, Guo Z, Rong M, Zhou L. Local delivery of rhVEGF165 through biocoated nHA/coral block grafts in critical-sized dog mandible defects: A histological study at the early stages of bone healing. Int. J. Clin. Exp. Med. 2015; 8:4940–4953.
[80]. Diaz-Rodriguez P, López-Álvarez M, Serra J., González P, Landín M. Current stage of marine ceramic grafts for 3D bone tissue regeneration. Mar. Drugs. 2019;17:471.
[81]. Damien E., Revell P. Coralline hydroxyapatite bone graft substitute: A review of experimental studies and biomedical applications. J. Appl. Biomater. Biomech. 2004; 2:65–73.
[82]. Quiñones CR, Hürzeler MB, Schüpbachs P, Kirsch A, Blum P, Caffesse RG, Strub JR. Maxillary sinus augmentation using different grafting materials and osseointegrated dental implants in monkeys. Part II. Evaluation of porous hydroxyapatite as a grafting material. Clin. Oral Implant. Res. 1997; 8:487–496.
[83]. Titsinides S, Agrogiannis G, Karatzas T. Bone grafting materials in dentoalveolar reconstruction: A comprehensive review. Jpn. Dent. Sci. Rev. 2019; 55:26–32.
[84]. Galindo-Moreno P, Padial-Molina M, Lopez-Chaichio L, Gutiérrez-Garrido L, Martín-Morales N, O'Valle F. Algae-derived hydroxyapatite behavior as bone biomaterial in comparison with anorganic bovine bone: A split-mouth clinical, radiological, and histologic randomized study in humans. Clin. Oral Implant Res. 2020; 31:536–548.
[85]. Turhani D, Weissenböck M, Watzinger E, Yerit K, Cvikl B, Ewers R, Thurnher D. In vitro study of adherent mandibular osteoblast-like cells on carrier materials. Int. J. Oral Maxillofac. Surg. 2005; 34:543–550.
[86]. Smiler D, Soltan M, Lee JW. A histomorphogenic analysis of bone grafts augmented with adult stem cells. Implant Dent. 2007;16:42–53.
[87]. Ratnayake JTB, Mucalo M, Dias GJ. Substituted hydroxyapatites for bone regeneration: A review of current trends. J. Biomed. Mater. Res. Part B Appl. Biomater. 2017; 105:1285–1299.
[88]. Kübler A, Neugebauer J, Oh JH, Scheer M, Zöller JE. Growth and Proliferation of Human Osteoblasts on Different Bone Graft Substitutes An In Vitro Study. Implant. Dent. 2004;13:171–179.
[89]. Iezzi G., Degidi M., Piattelli A., Mangano C., Scarano A, Shibli JA, Perrotti V. Comparative histological results of different biomaterials used in sinus augmentation procedures: A human study at 6 months. Clin. Oral Implant. Res. 2011; 23:1369–1376.
[90]. Sivakumar M., Manjubala I. Preparation of hydroxyapatite/fluoroapatite-zirconia composites using Indian corals for biomedical applications. Mater. Lett. 2001; 50:199–205.
[91]. Poeschl PW, Ziya-Ghazvini F, Schicho K, Buchta C, Moser D, Seemann R, Ewers R, Schopper C. Application of Platelet-Rich Plasma for Enhanced Bone Regeneration in Grafted Sinus. J. Oral Maxillofac. Surg. 2012; 70:657–664.
[92]. Zhou AJJ., Clokie CML, Peel SAF. Bone Formation in Algae-Derived and Synthetic Calcium Phosphates With or Without Poloxamer. J. Craniofacial Surg. 2013; 24:354–359.
[93]. Herr G, Wahl D, Küsswetter W. Osteogenic activity of bone morphogenetic protein and hydroxyapatite composite implants. Ann. Chir. Gynaecol. Suppl. 1993; 207:99–107.
[94]. Luczyszyn SM, Papalexiou V, Novaes AB Jr, Grisi MF, Souza SL, Taba M Jr. Acellular dermal matrix and hydroxyapatite in prevention of ridge deformities after tooth extraction. Implant Dent. 2005; 14:176–184.
[95]. Chitsazi M., Shirmohammadi A, Faramarzie M., Pourabbas R, Rostamzadeh A. A clinical comparison of nano-crystalline hydroxyapatite (Ostim) and autogenous bone graft in the treatment of periodontal intrabony defects. Med. Oral Patol. Oral Cirugia Bucal. 2011; 16:e448–e453.
[96]. Kamboj M, Arora R, Gupta H. Comparative evaluation of the efficacy of synthetic nanocrystalline hydroxyapatite bone graft (Ostim®) and synthetic microcrystalline hydroxyapatite bone graft (Osteogen®) in the treatment of human periodontal intrabony defects: A clinical and denta scan study. J. Indian Soc. Periodontol. 2016; 20:423.
[97]. Ad De R, Meijer G, Dormaar T, Janssen N, Van Der Bilt A, Slootweg P, De Bruijn J, Van Rijn L, Koole R. β-TCP versus autologous bone for repair of alveolar clefts in a goat model. Cleft Palate Craniofacial J. 2011; 48:654–662.
[98]. Ogose A, Kondo N, Umezu H, Hotta T, Kawashima H, Tokunaga K., Ito T, Kudo N, Hoshino M., Gu W. Histological assessment in grafts of highly purified β-tricalcium phosphate (OSferion®) in human bones. Biomaterials. 2006; 27:1542–1549.
[99]. Wakimoto M, Ueno T, Hirata A, Iida S, Aghaloo T, Moy PK. Histologic Evaluation of Human Alveolar Sockets Treated With an Artificial Bone Substitute Material. J. Craniofacial Surg. 2011; 22:490–493.

[100]. Kakar A, Rao BHS, Hegde S, Deshpande N, Lindner A, Nagursky H, Patney A, Mahajan H. Ridge preservation using an in situ hardening biphasic calcium phosphate (β-TCP/HA) bone graft substitute-a clinical, radiological, and histological study. Int. J. Implant. Dent. 2017; 3:25.
[101]. Norton MR, Wilson J. Dental implants placed in extraction sites implanted with bioactive glass: Human histology and clinical outcome. Int. J. Oral Maxillofac. Implant. 2002; 17:249–257.
[102]. 109. Di Stefano D.A., Greco G., Gherlone E. A Preshaped Titanium Mesh for Guided Bone Regeneration with an Equine-Derived Bone Graft in a Posterior Mandibular Bone Defect: A Case Report. Dent. J. 2019;7:77.
[103]. Chacko NL, Abraham S, Rao HNS, Sridhar N, Moon N, Barde DH. A Clinical and Radiographic Evaluation of Periodontal Regenerative Potential of PerioGlas®: A Synthetic, Resorbable Material in Treating Periodontal Infrabony Defects. J. Int. Oral Health. 2014; 6:20–26.
[104]. Sugawara A, Fujikawa K, Kusama K, Nishiyama M, Murai S, Takagi S, Chow LC. Histopathologic reaction of a calcium phosphate cement for alveolar ridge augmentation. J. Biomed. Mater. Res. 2002; 61:47–52.
[105]. Stanton DC, Chou JC, Carrasco LR. Injectable calcium-phosphate bone cement (Norian) for reconstruction of a large mandibular defect: A case report. J. Oral Maxillofac. Surg. 2004; 62:235–240.
[106]. Maragos P, Bissada NF, Wang R., Cole BP. Comparison of three methods using calcium sulfate as a graft/barrier material for the treatment of Class II mandibular molar furcation defects. Int. J. Periodontics Restor. Dent. 2002; 22:493–501.
[107]. Petruskevicius J, Nielsen MS, Kaalund S, Knudsen PR, Overgaard S. No effect of Osteoset ®, a bone graft substitute, on bone healing in humans: A prospective randomized double-blind study. Acta Orthop. Scand. 2002; 73:575–578.
[108]. Prakash S, Sunitha J, Abid S. Evaluation of HTR polymer (Bioplant® HTR®) as a bone graft material in the treatment of interproximal vertical bony defects: A clinical and radiological study. Indian J. Dent. Res. 2010; 21:179.
[109]. Yukna RA, Yukna CN. Six-year clinical evaluation of HTR synthetic bone grafts in human grade II molar furcations. J. Periodontal Res. 1997; 32:627–633.
[110]. Abshagen K, Schrodi I, Gerber T, Vollmar B. In vivo analysis of biocompatibility and vascularization of the synthetic bone grafting substitute NanoBone® J. Biomed. Mater. Res. Part A. 2009; 91:557–566.