DOI: 10.7860/JCDR/2026/79896.23282

Review Article

Dentistry Section

Hard-tissue and Soft-tissue Management for Implant Site Development: A Narrative Review

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ABSTRACT

Loss of teeth may occur due to various causes, such as periodontitis, dental caries, or trauma. The extraction of a single tooth or multiple teeth can lead to significant changes in both hard-tissues and soft-tissues. When a tooth is absent, the alveolar process undergoes resorption, which is more pronounced on the buccal aspect of the ridge. Tooth loss adversely affects aesthetics, phonetics, and function, thereby becoming a major concern for affected individuals. The goal of implant dentistry has gradually evolved from merely achieving successful osseointegration to attaining final restorative outcomes that closely resemble natural dentition and the surrounding oral tissues. Implant placement becomes challenging in areas with insufficient bone, and improper placement may result in significant functional and aesthetic compromises following prosthetic rehabilitation. Insufficient bone volume, height, or width is the most common clinical challenge in dental implant rehabilitation and is a clear indication for bone grafting to enhance bone availability. Implant placement should be prosthetically driven, aiming to restore the natural position of the tooth and promote a natural emergence profile from the surrounding soft-tissues. To achieve optimal aesthetics and function, hard-tissue augmentation, soft-tissue augmentation, or a combination of both may be required. The present review provides an overview of evidence-based procedures undertaken to preserve hard-tissues and soft-tissues for the successful outcome and long-term survival of dental implants.

Keywords: Alveolar bone loss, Alveolar ridge augmentation, Bone regeneration, Dental implants, Guided bone regeneration, Osseointegration, Tooth extraction

INTRODUCTION

The alveolar process develops during tooth formation and undergoes atrophy following tooth loss. Predisposing factors influencing alveolar bone loss after extraction include age, gender, systemic conditions, facial morphology, and functional stress on the extraction site. Periodontitis, periapical pathology, or trauma to the teeth and supporting bone may result in alveolar bone loss even before tooth extraction [1]. Following tooth extraction, the alveolar ridge may undergo dimensional reduction in the vertical direction, horizontal direction, or both. Studies have shown that vertical bone loss on the buccal aspect ranges from 11% to 22% within six months, whereas horizontal bone loss is more pronounced, ranging from 29% to 63% within 6-7 months after extraction. The majority of bone resorption occurs within the first three months post-extraction, with dimensional loss continuing progressively throughout the subsequent year. As a result, the alveolar ridge becomes both narrower and shorter [1].

As dental implants are now the treatment of choice for replacing missing teeth, optimal implant placement requires the presence of adequate bone volume and density [2]. Preventing tissue loss following tooth extraction is essential for achieving ideal hard-tissues and soft tissue conditions at an aesthetic implant site. This may be accomplished through socket grafting procedures aimed at ridge preservation following extraction. Additionally, immediate implant placement into extraction sockets has been proposed as a method to help preserve alveolar bone volume after tooth removal [3].

In some cases, the implant site may present with inadequate horizontal or vertical bone dimensions, necessitating ridge augmentation procedures. These may include onlay bone grafts or Guided Bone Regeneration (GBR) using particulate bone grafts. Non-surgical alternatives, such as orthodontic extrusion or forced eruption, may also be considered in selected cases. Advances in tissue engineering have further enabled the application of biologic principles in the regeneration of hard-tissues and soft oral tissues. Consequently, optimal dental implant restoration often requires reconstruction of both bone and soft-tissues [2].

Both the extraction socket and the surrounding soft-tissues undergo dimensional changes following tooth removal [4]. Common soft-tissue challenges around dental implants include inadequate keratinised mucosa, volume deficiency, and peri-implant mucosal recession. These issues are particularly significant in the aesthetic zone, where soft-tissue grafting procedures are often essential to achieve favourable outcomes [5]. Therefore, clinicians must ensure harmony between hard-tissues and soft-tissues to achieve optimal aesthetic and functional results, particularly when replacing teeth with dental implants [4].

The present narrative review focuses on Alveolar Ridge Preservation (ARP), vertical and horizontal ridge augmentation, and briefly discusses soft-tissue management with an emphasis on aesthetic considerations.

Alveolar Ridge Preservation (ARP)

Alveolar ridge preservation was first described as “bone maintenance” in 1982 and is also referred to as socket preservation, ridge preservation, socket grafting, or socket augmentation [6]. The primary aim of ARP is to support residual hard-tissues and soft-tissues, maintain sufficient bone volume for optimal functional and aesthetic outcomes, and facilitate subsequent treatment procedures [7]. Hämmerle CH et al., defined ARP as “preserving the ridge volume within the envelope existing at the time of extraction,” clearly distinguishing it from ridge augmentation, which is defined as “increasing the ridge volume beyond the skeletal envelope existing at the time of extraction” [8].

ARP scaffolds are commonly constructed using various grafting materials. Autologous bone possesses osteogenic, osteoinductive, and osteoconductive properties, does not elicit an immune response, and is considered the gold standard in tissue engineering. However, because ARP requires a substantial volume of graft material to fill the extraction socket, the limited availability of autogenous bone has led to the use of alternative grafting materials, including allografts, xenografts, and alloplasts. Guided

Tissue Regeneration (GTR) techniques form the basis for the use of barrier membranes in ARP. These membranes prevent graft material exposure and displacement while inhibiting the ingrowth of epithelial and connective tissues into the extraction socket, thereby facilitating optimal bone regeneration [8].

Spontaneous Healing of Extraction Socket

A Cochrane review reported that, in terms of socket dimensional changes, the mean difference between a ARP and extraction alone was 1.18 mm horizontally and 1.35 mm vertically [9]. In a systematic review, Van der Weijden F et al., documented an average clinical loss in ridge width of 3.87 mm and a loss in height of 1.67-2.03 mm clinically and 1.53 mm radiographically following tooth extraction [10].

Araujo MG and Lindhe J (2005) demonstrated marked dimensional changes of the alveolar ridge during the first three months after extraction, with changes being more pronounced on the buccal aspect [11]. Schropp L et al., also observed that, in addition to changes in bony architecture, there were significant alterations in the overlying soft-tissues [12]. According to Mayfield's classification, the terms immediate, delayed, and late describe implant placement at time intervals of 0 weeks, 6-10 weeks, and 6 months or more after tooth extraction, respectively [13].

Immediate Implant Placement

Immediate implant placement refers to the insertion of an implant into a fresh extraction socket. This approach offers advantages such as a reduction in the number of surgical interventions and overall treatment time. It also helps preserve bone at the extraction site, thereby facilitating optimal soft-tissue aesthetics. Contraindications for immediate implant placement include the presence of active infection, insufficient bone availability (≤3 mm beyond the tooth socket), and gingival recession.

Paolantonio M et al., recommended immediate implant placement without the use of additional socket preservation techniques, such as barrier membranes, to minimise alveolar bone changes [14]. A three-year retrospective study by Gelb DA on immediate implant surgery reported a 98% implant survival rate, with implants remaining osseointegrated and functional, thus supporting the predictability of immediate implant placement [15]. However, Wang RE et al., demonstrated that implants placed in fresh extraction sockets did not prevent alveolar bone resorption [16]. Furthermore, a systematic review and meta-analysis evaluating implant failure rates and marginal bone loss concluded that implants placed in fresh extraction sockets carry a higher risk of failure compared to implants placed in healed sites [17].

Timing for Placement of Implant

In a consensus report by the International Team for Implantology (ITI) in 2004, a classification for implant placement timing based on the morphological, dimensional, and histological changes following tooth extraction was proposed by Hämmerle CH et al., [18]. The rationale behind this classification was that implants placed in close contact with socket walls could provide functional stimulation to help limit bone resorption [Table/Fig-1] [18].

Studies evaluating the clinical efficacy of early implant placement in comparison with immediate and delayed placement have shown that early implant placement yields outcomes comparable to both immediate and delayed placement. Additionally, early placement demonstrated superior peri-implant hard-tissue stability when compared with immediate implant placement [19].

Techniques for Extraction Socket Preservation (ESP)

Extraction socket preservation is performed following tooth extraction to maintain vertical and horizontal alveolar bone dimensions and prevent ridge atrophy [20]. Socket preservation may be classified as short-term or long-term preservation [Table/Fig-2] [21].

Classification	Definition	Advantages	Disadvantages
Type 1	Implant placement immediately following tooth extraction and as part of the same surgical procedure	• Reduced number of surgical procedures • Reduced overall treatment time • Optimal availability of existing bone	• Site morphology may complicate optimal placement and anchorage • Thin tissue biotype may compromise optimal outcome • Potential lack of keratinised mucosa for flap adaptation • Adjunctive surgical procedures may be required. • Procedure is technique-sensitive
Type 2	Complete soft-tissue coverage of the socket (Typically 4-8 weeks)	• Increased soft-tissue area and volume facilitates soft-tissue flap management • Resolution of local pathology can be assessed	• Site morphology may complicate optimal placement and anchorage • Treatment time is increased • Socket walls exhibit varying amounts of resorption • Adjunctive surgical procedures may be required • Procedure is technique-sensitive
Type 3	Substantial clinical and/or radiographic bone fill of the socket (typically 12 to 16 wk)	• Substantial bone fill of the socket facilitates implant placement • Mature soft-tissues facilitate flap management	• Treatment time is increased • Adjunctive surgical procedures may be required • Socket walls exhibit varying amounts of resorption
Type 4	Healed site (typically more than 6 weeks)	• Clinically healed ridge • Mature soft-tissues facilitate flap management	• Treatment time is increased • Adjunctive surgical procedures may be required • Large variations are present in available bone volume

[Table/Fig-1]: Protocols for implant placement in extraction sockets and their advantages and disadvantages as given by Hammerle HF et al., [18].

Classification of Socket Preservation		
Long term socket preservation: Involves non- resorbable materials when only prosthetic restoration is planned, without immediate implant placement.	**Slowly Resorbable Materials:** Allow for implant placement after initial healing, indiacted when implantation is significantly postponed.	**Short-term Preservation:** Maintains tissue volume during initial healing phases, with implant placement occurring shortly thereafter.

[Table/Fig-2]: Classification of socket preservation [21].

ESP can be achieved through atraumatic tooth extraction techniques or by the use of bone grafts, tooth-derived grafts, barrier membranes, or a combination of these methods [20].

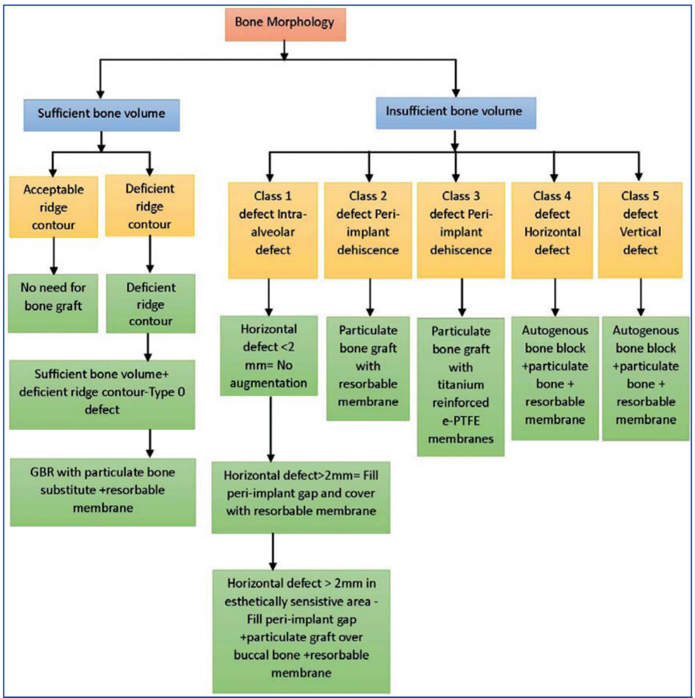
Goals for Alveolar Ridge Preservation (ARP)

The primary goals of ARP include the elimination or reduction of post-extraction ridge alterations, promotion of soft and hard-tissue healing within the former extraction socket, and facilitation of dental implant placement in a prosthetically ideal position without the need for additional augmentation procedures [22].

Post-extraction socket preservation remains a subject of controversy [23]. Kim YK and ku JK reported several advantages of ESP, including minimisation of ridge atrophy after tooth extraction, reduced need for additional bone grafting procedures, facilitation of implant placement, and improvement in marginal bone loss as well as implant survival and success rates [23]. When ESP is performed in the maxillary posterior region, sinus elevation procedures may be minimised or avoided, thereby allowing for flapless implant placement.

Socket sealing techniques protect bone graft materials and contribute to soft-tissue healing through the use of autogenous gingival tissues, barrier membranes, collagen sponges, and similar materials. However, Kim YK and Ku JK also highlighted certain disadvantages, noting that while ESP can reduce bone resorption, it cannot completely prevent it. Additionally, bone substitutes may impair natural bone healing, and no significant differences have been observed in implant feasibility, marginal bone loss, or implant survival and success rates between sites treated with or without ESP [23].

It has been suggested that placing graft material both within and slightly beyond the extraction socket and covering it with a barrier membrane may help reduce bone loss. A clinical decision tree for socket preservation has been developed to assist clinicians in identifying appropriate indications and selecting optimal treatment protocols following tooth extraction [Table/Fig-3] [24].



[Table/Fig-3]: Decision pathway for socket preservation [24].

Socket Sealing and Evidence-based Outcomes

The European Federation of Periodontology conducted a study to evaluate which socket sealing technique offers the greatest potential benefit for ARP. The study concluded that placement of a bone graft substitute alone within an extraction socket provides little or no benefit in maintaining ridge width. Effective ridge preservation requires sealing the socket and covering the graft material. Autogenous tissues, such as a coronally advanced flap, Free Gingival Graft (FGG), or Connective Tissue Graft (CTG), were found to be the most effective covering methods, significantly reducing horizontal post-extraction ridge shrinkage [25].

A recent Cochrane review by Atieh MA et al., reported that ARP may be an effective approach for promoting bone formation in preparation for future implant placement. However, no clinically significant differences were observed between various grafting materials or membrane types. Consequently, there is currently no consensus regarding the optimal selection of surgical techniques or materials, as these choices often depend on clinician preference, patient-specific factors, economic considerations, and cultural or educational backgrounds [26].

As ARP aims to minimise post-extraction bone resorption, a systematic review comparing Leukocyte and Platelet-Rich Fibrin (L-PRF) with Recombinant Human Bone Morphogenetic Protein-2 (rhBMP-2) demonstrated comparable outcomes for both approaches, with fewer complications associated with L-PRF [27].

A study by Solyom E et al., on the efficacy of biologics for alveolar ridge preservation/reconstruction and implant site development concluded that the application of biologics contributed to attenuation of post-extraction alveolar ridge atrophy in most investigations [28]. Since 1998, multiple studies have demonstrated a statistically significant difference between ARP and unassisted healing; however, the clinical significance of these differences remains unclear [29-31].

Socket Shield Technique (SST)

In 2010, Hürzeler MB et al., proposed the Socket Shield Technique (SST), which involves partial retention of the buccal root fragment to preserve the buccal bone plate, with immediate implant placement palatal to the retained root segment. They demonstrated the formation of cementum and osseointegration on implant surfaces in direct contact with intentionally retained root fragments [32]. A subsequent systematic review and meta-analysis reported that SST is a highly technique-sensitive procedure. The available evidence was deemed insufficient to support its routine clinical application, and further long-term studies are required to establish its predictability and safety [33].

Horizontal Ridge Augmentation

Horizontal ridge augmentation is a surgical procedure aimed at increasing the width of the alveolar ridge to facilitate proper dental implant placement. It is indicated in cases of bone loss resulting from tooth extraction, periodontal disease, or trauma, which otherwise preclude stable implant placement. Such defects are classified as Class IV ridge defects [Table/Fig-4] [34].

Class of defect	Morphology of defect
Class 0	Optimal ridge contour and sufficient bone volume for implant placement
Class 1	Intra-alveolar defect with space between implant surface and neighbouring bone
Class 2	Peri-implant dehiscence with five-walled defect morphology. Here, volume stability of area to be augmented is provided by neighbouring bone walls
Class 3	Peri-implant dehiscence with four-walled defect morphology. Here, volume stability of area to be augmented is not provided by neighbouring bone walls
Class 4	Horizontal ridge defect
Class 5	Vertical ridge defect

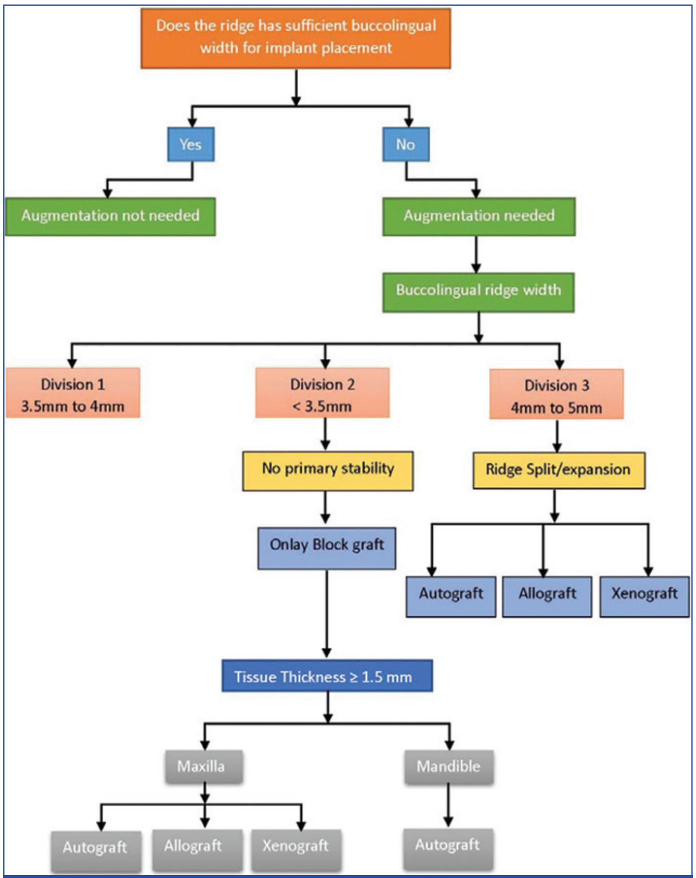
[Table/Fig-4]: Classification of Bone defects [34].

Various techniques and materials are employed for horizontal ridge augmentation, including GBR, ridge expansion, and block grafting procedures. A decision tree for horizontal ridge augmentation has been developed to assist clinicians in selecting appropriate surgical approaches based on the severity of ridge deficiency, soft-tissue conditions, and prosthetic requirements [Table/Fig-5] [35].

Guided Bone Regeneration (GBR)

The GBR is a surgical technique that utilises barrier membranes with or without particulate bone grafts and/or bone substitutes. Osseous regeneration achieved through GBR depends on the migration of pluripotential and osteogenic cells such as osteoblasts derived from the periosteum, adjacent bone, or bone marrow to the defect site, while excluding cells that impede bone formation, including epithelial cells and fibroblasts.

For successful bone regeneration, the rate of osteogenesis advancing from the adjacent bony margins must exceed the rate of fibrogenesis from the surrounding soft-tissues. In clinical practice, predicting the outcome of ridge augmentation can be challenging. To optimise GBR outcomes, four fundamental principles must be



[Table/Fig-5]: Decision pathway for Horizontal Bone Augmentation [35].

fulfilled: exclusion of epithelium and connective tissue, maintenance of space, stability of the fibrin clot, and achievement of primary wound closure [36]. Recent studies investigating autologous tooth bone grafts have shown that human dentin and bone consist of approximately 65% inorganic and 35% organic components. The inorganic phase contributes to osteoconduction and space maintenance, while the organic matrix of mineralised dentin is responsible for its osteoinductive properties [37].

Onlay Grafting

Autogenous bone grafting techniques, including onlay grafting, are currently regarded as the gold standard for ridge reconstruction due to their excellent biocompatibility, strong osteogenic, osteoinductive, and osteoconductive properties. Bone blocks harvested from the mandibular symphysis, lateral ramus, ramus of the mandible, or extraoral donor sites such as the ilium are commonly used for onlay grafting, particularly in the management of horizontal alveolar ridge defects [36]. Elsayed AO et al., compared the efficacy of autogenous onlay and inlay grafts and reported that inlay block grafting was a successful treatment modality for horizontal ridge augmentation in the maxillary arch [38].

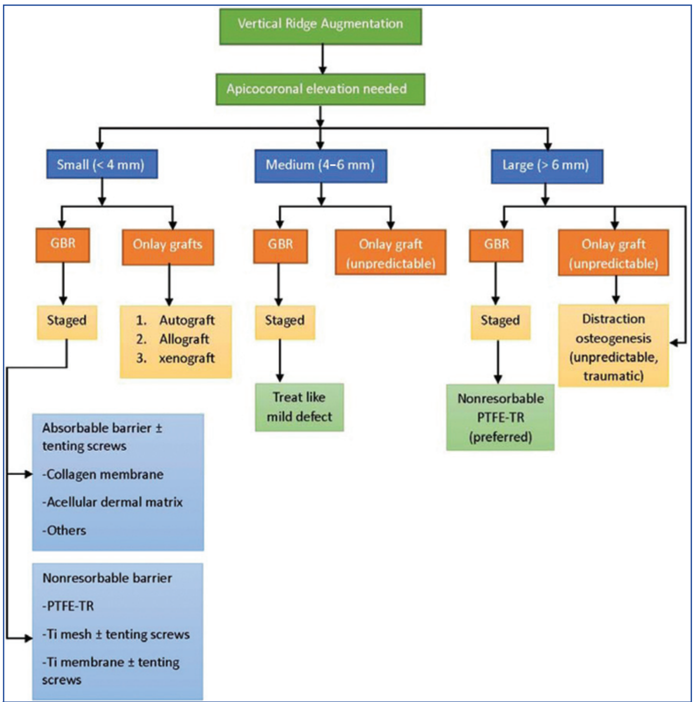
Ridge Split Technique

The ridge split or ridge expansion technique was first introduced in the early 1970s and involves controlled expansion of the cortical plates to increase ridge width while preserving periosteal attachment. Ridge splitting is particularly advantageous in the maxilla compared with the mandible due to the presence of more cancellous bone and is indicated for narrow edentulous ridges measuring greater than 3.5 mm, allowing predictable implant placement [39].

Hilt Tatum developed a bone spreading or ridge splitting technique in the 1970s that employed specialised instruments such as tapered channel formers and D-shaped graduated osteotomes or wedges. These osteotomies utilise the compressive capacity of trabecular bone to achieve osteocondensation and create sufficient space for implant placement. By exposing cancellous bone and marrow, this technique enhances revascularisation and promotes healing [40]. A systematic review and meta-analysis evaluating the efficacy of alveolar ridge splitting reported that contemporary ridge split techniques are effective methods for bone augmentation, providing adequate horizontal width gain and high implant survival rates. However, further long-term studies and well-designed randomised controlled trials are required to strengthen the evidence base [41].

Vertical Ridge Augmentation

Vertical ridge augmentation is indicated for the reconstruction of severely atrophic edentulous ridges where residual bone volume is insufficient to allow implant placement in an optimal prosthetic position, even with the use of short or narrow implants. Various reconstructive and regenerative techniques have been proposed, including distraction osteogenesis, maxillary sinus floor elevation, onlay grafting using intraoral or extraoral autogenous bone blocks, GBR with resorbable or non-resorbable membranes (e.g., polytetrafluoroethylene) with or without tenting screws, and protected bone regeneration using customised or non-customised titanium meshes [42]. A vertical ridge augmentation decision tree has been developed to provide a structured, evidence-based approach for managing vertical bone deficiencies and selecting appropriate treatment modalities [Table/Fig-6] [43].



[Table/Fig-6]: Decision tree for vertical ridge augmentation [43].

Distraction Osteogenesis

In 1992, McCarthy proposed distraction osteogenesis for specific maxillofacial surgical applications. Alveolar Distraction Osteogenesis (ADO) is based on a bone regeneration mechanism involving gradual distraction performed in multiple minor steps, resulting in a substantial increase in callus tissue between two osteotomised alveolar bone segments. Although favourable success rates have also been reported for its use in the maxilla, vertical deficiencies of the anterior mandible remain the primary indication for ADO [44].

Inlay/Sandwich Technique

A viable alternative for vertical ridge augmentation is the inlay or "sandwich" technique. This approach utilises an intrabony environment to minimise graft exposure and promote enhanced vascularisation. It was first proposed by Schettler in 1974 for augmentation of atrophic mandibles and was later modified by Sailer in 1989 for maxillary reconstructions [45]. A systematic review evaluating the inlay technique for alveolar ridge augmentation concluded that this method provides effective vertical bone augmentation with high implant survival rates and fewer complications compared with other reconstructive techniques. However, longer follow-up studies are required to substantiate its long-term efficacy and to assess marginal bone loss over time [45].

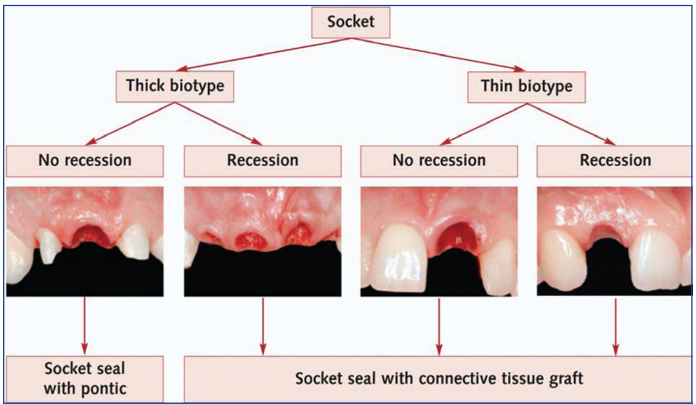
Maxillary Sinus Floor Elevation

Maxillary sinus augmentation, also referred to as sinus floor elevation, has gained widespread acceptance for facilitating dental implant placement in posterior maxillae with insufficient bone height resulting from trauma, alveolar bone atrophy, or sinus pneumatisation. In the 1970s, Hilt Tatum introduced the use of the maxillary sinus cavity to increase the volume of bone available for grafting, thereby enhancing the bone-implant contact area following graft maturation.

The choice of sinus elevation technique depends on the surgeon's preference and patient-specific anatomical considerations, including the amount of desired elevation and residual bone height. Two primary approaches are described: direct and indirect sinus floor elevation. Indirect techniques include minimally invasive transalveolar sinus approaches, osteotome sinus floor elevation, bone-added sinus floor elevation, and antral membrane balloon elevation, whereas the direct approach involves the lateral window technique [46].

Soft-tissue Augmentation

Several effective techniques are available for managing soft-tissue deficiencies in partially edentulous patients, including pedicle grafts, roll flaps, modified roll techniques, FGG, pouch grafts, interpositional grafts, and onlay grafts. A soft-tissue augmentation decision tree assists clinicians in selecting appropriate surgical techniques based on tissue thickness, width of keratinised mucosa, defect type, and aesthetic or prosthetic requirements [Table/Fig-7] [47].



[Table/Fig-7]: Decision tree for soft-tissue grafting [47].

DISCUSSION

Alveolar bone undergoes progressive resorption following tooth loss. The greatest degree of bone loss typically occurs in the horizontal dimension, particularly at the facial aspect of the ridge. Additionally, vertical ridge height reduction is observed, with the buccal aspect being most affected during the first six months post-extraction. Various techniques are available for socket preservation and ridge augmentation, including the use of bone grafts, barrier membranes, biological agents, GBR, inlay and onlay grafts for horizontal augmentation, ridge split techniques, distraction osteogenesis, sinus augmentation, three-dimensional printing, and socket preservation procedures.

Ridge preservation is a widely employed technique that effectively reduces post-extraction alveolar bone resorption, particularly in the aesthetic zone. Although it does not completely prevent dimensional changes, it decreases the need for subsequent augmentation procedures. In contrast, GBR offers more predictable vertical and horizontal bone augmentation, especially when used with space maintaining scaffolds and barrier membranes. The success of GBR depends on technique selection, graft materials, and patient-specific factors such as soft-tissue quality and gingival biotype. Ridge split and expansion techniques are less invasive than block grafting and allow for simultaneous implant placement; however, they are highly technique-sensitive and are primarily indicated for ridges with adequate height but limited width. Improper execution may result in complications such as cortical plate fracture.

According to the Consensus Report of the Italian Academy of Osseointegration on the use of graft materials in post-extraction sites, alveolar ridge preservation effectively minimises physiological bone loss, particularly in aesthetic regions. The report recommends covering xenograft materials with barrier membranes or autogenous soft tissue, and the use of adjunctive antibiotic therapy is advised [48]. The Consensus Report of Group 4 of the 15th European Workshop on Periodontology evaluated regenerative strategies for alveolar ridge defect reconstruction and concluded that augmentation procedures are effective, although some techniques are technically demanding and associated with an increased risk of postoperative complications [49].

The European Federation of Periodontology assessed the efficacy of various socket preservation techniques using Freeze-Dried Bone Allograft (FDBA) covered with collagen sponges (CS), FDBA covered with FGG, Demineralised Bovine Bone Mineral (DBBM) xenograft covered with FGG, and FGG alone. The findings indicated that collagen sponges were as effective as FGG in preserving hard-tissue when used as socket-sealing materials [50].

CONCLUSION(S)

Alveolar ridge atrophy presents significant challenges in tooth replacement therapies, particularly in implant dentistry. To minimise post-extraction bone loss, numerous surgical techniques have been developed. The future of oral reconstruction is likely to involve greater application of biological principles, including growth factors and bioengineered tissues. Recent advances in stem cell research focus on regenerating tooth structures using tooth buds within extraction sockets or placing cellular scaffolds to maintain alveolar bone volume. However, further well-designed randomised controlled trials are necessary to establish evidence based guidelines for selecting the most effective techniques and materials for ridge augmentation.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Apr 14, 2025
- Manual Googling: Dec 10, 2025
- iThenticate Software: Dec 12, 2025 (9%)

ETYMOLOGY: Author Origin

EMENDATIONS: 8

AUTHOR DECLARATION:
- Financial or Other Competing Interests: None
- Was informed consent obtained from the subjects involved in the study? NA
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: **Apr 13, 2025**
Date of Peer Review: **Jul 05, 2025**
Date of Acceptance: **Dec 14, 2025**
Date of Publishing: **May 01, 2026**