Chapter

Alveolar Ridge Augmentation Techniques in Implant Dentistry

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Abstract

Implant supported restorations have become an ideal treatment alternative for the rehabilitation of edentulous sites. However alveolar bone defects due to resorption, trauma or oncologic diseases may considerably affect favorable implant positioning and prosthetic outcomes. Various alveolar ridge augmentation procedures are available to gain enough bone volume and apply the ideal treatment plan afterwards. Guided bone regeneration, ridge splitting, distraction osteogenesis, maxillary sinus augmentation and autogenous block bone grafting are main techniques which have successful outcomes in reconstruction of bone defects. It's difficult to demonstrate that one augmentation procedure offers better outcomes than another. Studies documenting augmentation techniques seem to be comparable and state favorable results for each procedure.

Keywords: biomaterials, alveolar ridge deficiency, distraction osteogenesis, ridge splitting, guided bone regeneration, onlay block bone graft

1. Introduction

Dental implant supported prosthetic rehabilitation has become a widely used treatment option in partial and completely edentulous patients as recent advances occur in materials and techniques. Hard and soft tissue defects are usually present in these edentulous patients due to a variety of traumatic events such as periodontal diseases, oncologic pathologies and tooth loss. Ridge augmentation procedures may be necessary before or during the implant surgery to overcome the challenges arising from bony defects and achieve ideal implant positioning with predictable treatment outcomes (**Figure 1**).

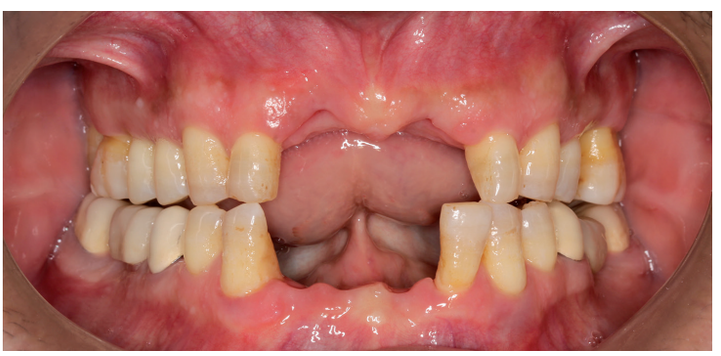

Figure 1.
Loss of anterior teeth resulting with severe loss of alveolar bone. Bone volume should be restored for the proper restoration of the lost teeth.

A large variety of bone augmentation techniques can be applied in the presence of bone defects. Guided bone regeneration, ridge splitting, distraction osteogenesis, maxillary sinus lifting and autogenous onlay block bone grafting are main techniques which have successful outcomes in reconstruction of bone defects. This chapter reviews alveolar ridge augmentation techniques in brief [1–4].

Defect morphology plays a critical role when choosing the type of augmentation procedure to perform. Number of surrounding bony walls are important when an augmentation is planned, because vascularization and healing properties are provided by these walls to the augmentation site. Therefore, defects with less amount of remaining bony walls are considered to be complex [5, 6].

1.1 Classification of defect morphology

Classification of the defect morphology is as follows [5]:

- *Thick five bony wall defect* is usually a tooth extraction socket. This type of defects have most of the important keys for a predictable bone regeneration process. Defect size is small, therefore regeneration by particulate bone grafts is possible. Surrounding five bony walls provide space maintenance and stabilize the blood clot along with the graft particulates. Torn blood vessels post-extraction accelerates the regeneration by releasing growth factors to the site. Augmentation of five bony wall defect is preservation of the residual alveolar ridge. Any resorbable graft material can be used in this type of bone defect depending on the desired healing period until the implant placement.

- Regeneration of *four to five bony wall defect* is impaired since vascularization from bony walls is reduced and partially replaced by soft tissue vascularization. When the buccal wall is missing post-extraction, space maintenance is no longer possible by the socket itself. Soft tissue tends to grow into the socket, therefore use of a barrier membrane along with particulate bone grafts is necessary to regain the ideal volume and contour of bone. Any resorbable bone graft material can be preferred in this case. When one of the lateral walls is missing following extraction, repair of this wall can be faciliated with socket preservation procedure at the time of extraction. Otherwise, during the healing period residual bone resorption may occur to an extend that requires further augmentation procedures.

- Treatment of *two to three bony wall defect* is similar to the treatment of four bony wall defect. Since the defect size is bigger in this type, use of autogenous bone grafts is required for their osteogenic properties. It's recommended to combine autografts with other resorbable graft materials to avoid rapid resorption and provide enough space while new bone regenerates. Resorbable barrier membranes can be supported with tenting screws or titanium reinforced non-resorbable membranes can be preferred in this type of defects as it requires more stability and space maintenance for longer periods.

- *One bony wall defect* is the most challenging defect type. Vascularization and regeneration potential of this defect is very low. Bone volume that needs to be regenerated is at high levels. For predictable outcomes, it's recommended to fixate onlay bone blocks to the host bone in this type of severe bone atrophies. There are studies reporting better outcomes with utilizing both onlay bone block grafting and guided bone regeneration at the same time [7] (**Figure 2**).

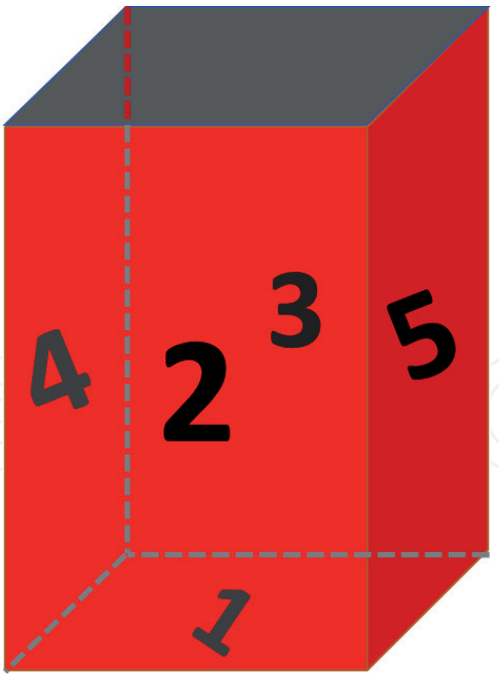

Figure 2.
Schematic representation of a five-walled bone defect. A reduce in the number of any walls renders corresponding wall-numbered bone defect. Translation of this wall-wall-number defect classification to the clinical scenario may not always be straight-forward.

2. Guided bone regeneration

Guided bone regeneration (GBR) is a procedure utilizing barrier membranes to create adequate space for new bone formation. Use of barrier membranes avoids soft tissue collapse and non-osteogenic cell migration into the bone defect [8]. It also facilitates an ideal environment for bone formation by providing space maintenance, stabilization of graft materials and prevention of soft tissue ingrowth (**Figure 3**) [9]. Guided bone regeneration can is indicated for the augmentation of [8]:

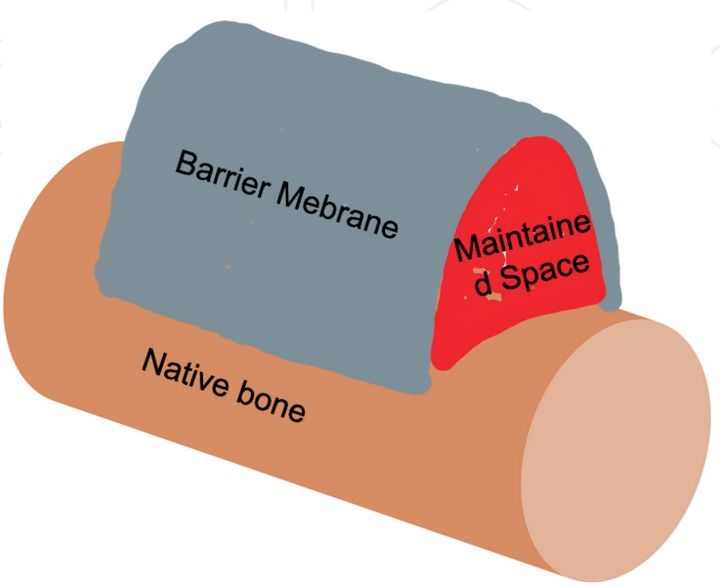

Figure 3.
Guided bone regeneration (GBR) procedure create and maintain a space via a semi-permiable barrier membrane which the blood cloth will occupy and allow the proliferation of the bone-producing cells.

- Vertical bone defects
- Horizontal bone defects
- Fenestration bone defects
- Dehiscence bone defects
- Combined vertical and horizontal defects
- Circumferential peri-implantitis defects
- Extraction sites

Over a decade, autogenous bone block grafting was the standard procedure in augmentation of bone defects. Due to its' invasive harvesting technique, morbidity at the donor site and limited availability, new techniques are developed. With rapid progress in biomaterials, GBR became one of the safest and most common techniques as it's less invasive and causes less discomfort post-operatively. Particulate grafts used in the procedure can easily be adapted into complex defect geometries [2, 5]. Urban et al. demonstrated a new bone formation of 5.45 mm vertically as a mean value when GBR protocol is performed utilizing xenograft and autogenous particulate graft mix with d-PTFE membranes [10]. Still, GBR has its own technique-sensitive challenges and is need to be practiced meticulously.

To achieve successful and repetitive outcomes, guided bone regeneration has 4 key principles: P-A-S-S [2, 8].

Primary wound closure is an important key factor for an optimal healing and success. In the augmentation sites, biomaterials and membranes increase the tissue volume so it becomes harder to close the wound without tension.

To provide a tension-free closure, incision design must be considered carefully.

- Incision should be kept within the keratinized tissue as much as possible.
- Vertical releasing incisions should be as far as possible from the augmentation site and help create a wide-base flap.
- Subperiosteal scoring incision and flap release should be performed.

Angiogenesis provide nutrients and oxygen to the augmentation site and enhances healing process in this way. To ensure an ideal angiogenesis, patients must be examined thoroughly in terms of systemic diseases which affect healing mechanisms such as diabetes mellitus and osteoporosis. In these cases, an internist or an endocrinologist may be consulted if necessary. Any uncontrolled systemic disease should be taken into consideration as a contraindication. Smoking habits also reduce vascularization and proper blood supply in the surgical site. Measures like using local anesthetics without vasoconstrictors or encouraging patients to regulate their smoking cycles can be taken.

Space creation and maintenance prevents soft tissue collapse to the surgical site thus osteogenic cells can proliferate and gradually form bone tissue. Biomaterials and particulate grafts along with barrier membranes can be used for this process. While barrier membranes prevent migration of soft tissue cells to the regeneration space, bone grafts and biomaterials provide structural strength. Depending on the type of barrier membrane in use, tenting poles can be used to provide additional strength.

Stability of wound clot is essential for optimal healing since the blood clot provides lots of growth factors to the surgical site. Primary wound closure and barrier membranes, acting as a roof to the regeneration site, contribute in stabilizing the blood clot. Recent studies show that barrier membranes need to be fixated with pins or screws to provide enough stability also to the graft materials, otherwise up to %40 of graft content is lost until the patient leaves the clinic [11, 12].

2.1 Barrier membranes

A barrier membrane is an essential component in guided bone regeneration procedures. Various membranes with different features are available on the market [12]. Barrier membranes should fulfill some basic requirements to be safely utilized in dental applications [3].

- *Biocompability:* Host tissue and membrane should be biologically compatible avoiding any foreign body reactions.
- *Space-maintenance:* Barrier membrane must avoid any collapse and maintain space during the regeneration period.
- *Barrier function:* Preventing soft tissue cells from migrating to regeneration site is an essential feature for membranes.
- *Stability:* Membranes must have mechanical strength and proper physical properties which protects the regeneration site during healing period.
- *Degradability:* Ideally a membrane should degrade at a time rate matching the regeneration period.

There are two main groups of membranes: resorbable and non-resorbable [7].

2.1.1 Resorbable membranes

Using resorbable membranes eliminates the second surgical intervention for membrane removal after healing and in this way decreases morbidity. Less complications occur with resorbable membranes compared to the non-resorbable ones. These membranes can easily be manipulated and adapted to the defect since they don't have any reinforcements with high elastic modulus. On the other hand, when compared to non-resorbable membranes they are more prone to collapse which lowers the maintained space. Bone graft substitutes and additional tools like tenting poles can be used along with resorbable membranes to increase stability. One major drawback of these membranes is varied and sometimes unpredictable resorption rates which directly affect new bone formation [13–15].

Resorbable membranes can be classified as natural and synthetic (**Figure 4**).

- *Non-cross-linking resorbable collagen membranes* are made of native collagen, have high levels of biocompability. They well-integrate into tissues and rapidly become vascularized. However, non-cross-linking resorbable membranes may resorp earlier than the required time for regeneration and lose their barrier functions. Cellular activity of host bone, membrane properties and possible exposures affect the biodegradation time. If any exposure occurs within the membrane, soft tissue spontaneously covers the exposed area in most cases. Bone grafts may resorp causing a decrease in the expected bone formation, though [3, 13].

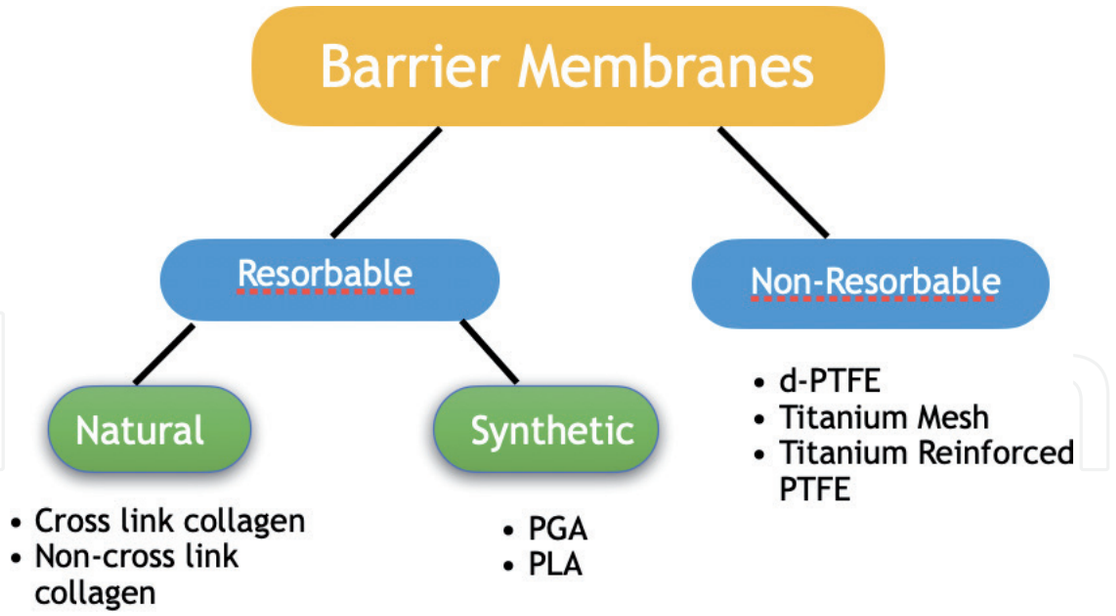

Figure 4.
Classification of barrier membranes used in guided bone regeneration procedures.

- *Cross-linked resorbable collagen membranes* are rich in cross-linking collagen fibrils so their degradation time is extended. Increased amount of collagen fibrils result in less biocompatibility and harder manipulation, still studies state good results in tissue integration and bone regeneration using these membranes [13–16].

- *Synthetic resorbable membranes*, mainly consisting of polyesters like polylactic acid or polyglycolic acid copolymers, are produced to achieve extended biodegradation period and increased biocompability. Derived from various origins, these membranes can offer various physical, chemical and mechanical properties. They also differ from natural resorbable membranes in terms of degradation pathways. Tatakis et al. demonstrated that synthetic resorbable membranes degrade via hydrolisis and alteration of degradation products through citric acid cycle causes an acidic enviroment. Therefore, using synthetic resorbable membranes result in higher inflammatory response and complications of soft tissue perforation [3, 13].

2.1.2 Non-resorbable membranes

When a bone defect lacks several supportive adjacent walls, utilized barrier membrane should provide additional strength to maintain space and stay stable during the regeneration process. To ensure stability and structural strength, different materials and compositions are used in production of non-resorbable membranes: titanium mesh, e-PTFE, d-PTFE and titanium reinforced PTFE membranes [3].

- **Expanded polytetrafluoroethylene (e-PTFE)** is the first generation of non-resorbable membranes used for guided bone regeneration. It's mostly preferred when a critical size defect is present and high amount of grafting is needed. Their stiff form makes them less compatible with soft tissues causing high rates of exposure. Once an exposure occurs with these membranes in use, infection develops and due to the porous structure, mechanical or chemical cleaning of infected site is almost impossible whether at early or late stage of healing. Recently, these membranes are rarely used in oral surgical interventions due to the high infection and irreversible complication rates [5, 7, 13].

- **Dense polytetrafluoroethylene (d-PTFE) membranes** are produced to overcome the disadvantages of e-PTFE membranes. These membranes have smaller pore size that they don't allow microorganism migration while oxygen diffusion is still possible in case of an exposure. With their low infection rates and additional mechanical strength, these micro-porous non-resorbable membranes are found to be effective in guided bone regeneration procedures [3, 13, 17]. Ronda et al. reported a mean defect fill of 5.49 mm in vertically augmented sites using d-PTFE membranes 6 months post-operatively [18].

- **Titanium mesh membranes** are porous titanium plates used in guided bone regeneration. The pores in these membranes are large and do not interfere with blood supply. Ti mesh is highly biocompatible to the surrounding tissues. Infection rates are very low with these membranes. They have a wide range of properties like rigidity, elasticity, stability and plasticity which exceptionally make these membranes adaptable but rigid at the same time. Titanium mesh membranes are commonly used in large bone defects and when a resistance to the pressure of soft tissue is needed to avoid collapse. Main disadvantage of Ti mesh membranes is high exposure rates due to their stiffness, several studies reported different exposure rates up to %50 [3, 17, 19].

- **Titanium reinforced PTFE membranes** are modifications of PTFE membranes. There are titanium frameworks embedded in these membranes for additional strength and rigidity therefore they successfully maintain space during the healing period and do not collapse. They are mostly used for vertical bone augmentation where additional resistance to soft tissue collapse is crucial. Added framework results in higher rates of exposure [3, 20].

2.2 Bone grafting materials

Various bone grafts and biomaterials can be used in guided bone regeneration. To choose the right material for predictable results in augmentation procedures, how these materials induce bone healing should be well-known. Healing properties of bone grafts and biomaterials are classified into three categories: osteogenesis, osteoinduction, osteoconduction [3, 5, 8].

2.2.1 Osteogenesis

Osteogenesis is defined as formation of new bone through viable osteoblast cells transferred to the site within grafting material. Autogenous bone grafts are transplanted from one site to another and the only type of grafting material with osteogenic features. Compared to cortical bone grafts, cancellous bone grafts contain higher amounts of osteoblast cells. To maintain the vitality of these cells and the dependent osteogenic process, angiogenesis is critically important. Therefore, once the autogenous bone graft is harvested it should be stored in sterile saline solution and placed in the recipient site as soon as possible. There are studies stating that autogenous bone grafts lose their osteogenic properties in 5 days without vascular support [5, 13].

2.2.2 Osteoinduction

Osteoinduction is a process where grafting material induces mesenchymal stem cells to migrate, proliferate and differentiate into osteoprogenitor cells. With osteoprogenitor cells occuring in the site, new bone forms [5, 13].

Urist et al. performed the landmark study on osteoinductive grafting materials isolating bone morphogenetic protein (BMP), a growth factor from the transforming growth factor (TGF)-β family, and described it as the main inductive agent [5, 21, 22].

2.2.3 Osteoconduction

Osteoconduction refers to bone growth into a scaffold formed by the grafting material [5]. It's characterized by resorption of the grafting material and apposition of the new bone which is called "creeping substitution" process. Osteoconductive graft materials are biocompatible and contains osteoconductive surfaces such as pores, tubes and ducts so that the surronding bone can grow into these spaces. This type of grafting materials have no potential of bone growth by itself but take part in the regeneration process as a supporting structure [3, 5, 22, 23].

2.2.4 Types of grafting materials

Various types of grafting materials are available for use in bone augmentation procedures (**Figure 5**). With different action mechanisms and regeneration potentials, there is no definitive recommendation specific to any procedure. Results vary depending on the regenerative approaches in conjunction with grafting materials. The most common classification for bone graft materials is as follows [3]:

- Autografts (same individual)
- Allografts (human cadaver source)

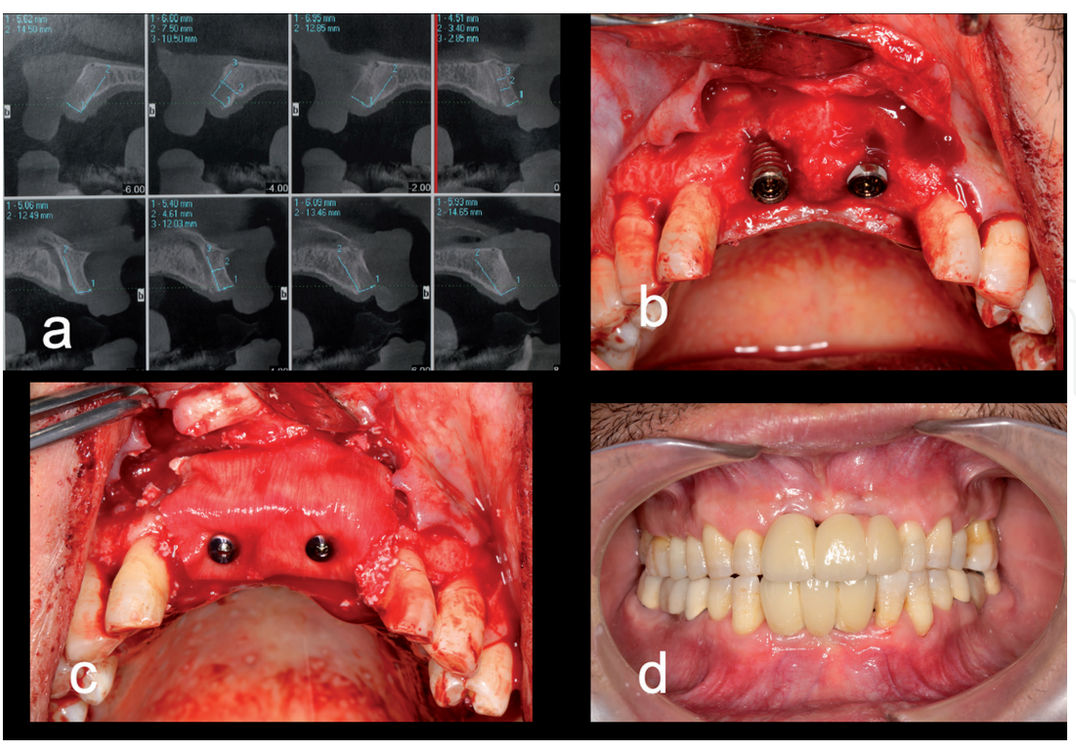

Figure 5.
Restoration of missing maxillary incisors (clinical view in **Figure 1***) via GBR and titanium dental implants. (a) tomogram reveal severe bone atrophy, (b) dental implants showing insufficient bone coverage, (c) GBR procedure covering the area of missing bone volume stabilized on to the dental implants, (d) final prosthetic restoration.*

- Xenografts (animal source)
- Alloplasts (synthetic source)

2.2.4.1 Autografts

Autogenous grafts, also known as autografts, are type of grafts transferred from one site to another within the same individual. These grafts are harvested in the form of bone blocks or particulates. Main intraoral donor sites are mandibular symphisis, ramus buccal shelf and maxillar tuberosity. They can either be harvested from iliac crest, calvaria, tibial plates and costae extraorally when larger volumes of autograft is required [2, 3].

Containing viable osteoblast cells, these materials are the only grafting materials with osteogenic properties. Therefore they have capacity of bone growth in the recipient site when vascularized. During incorporation growth factors, such as bone morphogenetic proteins, are released and induce bone growth through osteoinduction mechanism. Subsequently, a part of autograft becomes nonviable and acts as a scaffold with its calcium phosphate matrix. Surrounding bone is conducted by this matrix to regenerate. So autografts acts in all three mechanisms: osteogenesis, osteoinduction and osteoconduction [2, 24].

Main advantages of autografts are low cost, unique osteogenic properties and early vascularization. Although autografts are considered to be a golden standard for augmentation procedures, search and evaluation for new grafting materials continue due to secondary surgical site for harvesting, limited source, morbidity and infection risk at the donor site. In contrast, a number of comparative studies reported autografts to remain golden standard for augmentation procedures due to their rapid stimulation of new bone formation compared to other bone grafting materials [3, 5, 13].

2.2.4.2 Allografts

Allografts are transferred from an individual to another within the same species. Since there is no need for a secondary surgical site to obtain allografts, reduced morbidity is one of the advantages brought by use of this graft. Unlimited source is another advantage over autografts. Although allografts have no osteogenic properties, they stimulate bone growth via osteoconduction and incorporation of osteoinductive growth factors. There are strict sterilization and decontamination protocols regarding these materials due to the risk of disease transmission and host immune response. Donors are carefully evaluated and graft materials are gradually processed to avoid any risks. Some studies reported that certain allografts are less osteoinductive than others because of the sterilization protocols and the variability of their content. Schwartz et al. studied on different allografts taken from various tissue banks and stated wide range of variability related to donor's age, preparation method and sterilization protocols [2, 3].

There are four forms of allografts: fresh frozen bone, freeze-dried bone allograft, demineralized free-dried bone allograft and deproteinized bone allograft.

Freeze-dried bone allografts (FDBA) and demineralized freeze-dried bone allografts (DFDBA) are more frequently in use. DFDBA is demineralized with hydrochloric acid to provide easier access to growth factors such as BMP thus increase osteoinductive potential. Due to the lack of mineralized content, disadvantage of rapid resorption arises with DFDBA use. For this reason, FDBA is utilized more routinely in bone augmentation procedures. Compared to DFDBA, it's easier

to track FDBA on radiographs with it's mineralized and radiopaque characteristics. Therefore, it's easier document this material's follow-up and resorption rates [5, 24].

2.2.4.3 Xenografts

Grafts obtained from different species like bovine animals are called xenografts. This type of grafts are deproteinized to avoid the risk of disease transmission and they are present in spongeous form. Deproteinized bovine bone mineral (DBBM) is the most utilized and well-documented type of xenograft. Since it's highly purified, anorganic and protein-free, it has no osteogenic potential nor osteoinductive properties. DBBM contains natural calcium phosphate which facilitates osteoconduction. Mineral content of this graft material provides low rates of resorption over time. Due to their long-term low resorption features, there is a widespread use of xenografts in augmentation procedures where the healing period is long and space maintenance is needed during this time. Sinus augmentations, contour augmentations, augmentation of horizontal and vertical defects are among the procedures xenografts can be preferred. Several studies demonstrated that DBBM particulates are present in the regeneration site up to 10 years after the placement [7, 13, 25]. In a study conducted by Mendoza-Azpur et al., GBR cases utilizing xenografts alone and along with autogenous block bones are evaluated. Results demonstrated statistically no significant difference between two groups in terms of implant survival rates. Higher rate of complications and post-operative discomfort is reported in the group receiving autogenous block bones, though [26].

2.2.4.4 Alloplasts

Alloplastic biomaterials are produced in the laboratories synthetically to avoid the disadvantages of allografts and xenografts. Providing space maintenance and acting as a scaffold, they stimulate osteoconduction. Biocompatibility, zero risk for disease transmission and availability are important advantages of these biomaterials. There are resorbable and non-resorbable forms of alloplasts. For resorbable alloplasts, porosity of the material is the main factor that affects resorption rate; increased micro-porosity leads to faster turnover. Although non-resorbable alloplasts are seldomly used alone as the grafting material in augmentation procedures, resorbable alloplasts show good results used either alone or in combination with other grafting materials since they act as a scaffold and provide stability to the regeneration site. These materials are derived from the combinations of hydroxyapatite (HA), β-TCP, polymers and/or bioactive glasses [5, 24].

Synthetic hydroxyapatites are biomaterials similar to the human bone in terms of chemical composition. Therefore they cause minimal inflammation and foreign body reactions. With their high levels of chemical stability and biocompatibility, they can be used in many clinical applications such as ridge preservation following extraction or ridge augmentation to reconstruct bone defects. One of the important advantages of this material is the possibility of altering the microstructure and new bone formation accordingly [3, 5, 13].

Calcium phosphate ceramics are promising biomaterials considering their high level of biocompatibility, low risk of foreign body reactions and possibility of combination with bioactive molecules and therapeutic agents. Hydroxyapatite layer forms after the placement of calcium phosphate ceramics faciliating osteoinduction in addition to osteoconduction mechanism. Although alloplastic materials have many advantages, these materials demonstrate lower regenerative potential in comparison with other grafting materials [3]. Further studies are required to document these biomaterials [3, 27].

2.3 Growth factors

Bone augmentation procedures are advanced and complex surgical interventions. Since there are multiple factors affecting the treatment outcomes, growth factors which promote healing and regeneration are mostly used along with the grafting materials and membranes. These agents are widely utilized especially when bone healing mechanisms are affected by the patient's medical conditions such as diabetes mellitus or osteoporosis. Growth factors used in dentistry are divided in two categories: platelet concentrates and recombinant growth factors [3, 5, 28].

2.3.1 Platelet concentrates

Platelet concentrates are obtained by centrifuging autologous blood to concentrate platelets, cells taking part in the active secretion of growth factors. These concentrates have two forms as platelet-rich plasma (PRP) and platelet-rich fibrin (PRF) [3].

PRP is the first generation of platelet concentrates consisting %95 platelets, %4 red blood cells and %1 white blood cells. Although PRP has been widely used for it's healing enhancing properties for a long time, it's observed to have some major drawbacks. Several studies reported that incorporation of bovine thrombin or calcium chloride as anticoagulants decelerates the healing process and poses a risk for infection transmission or host immune response. It's preparation method is demanding and technique-sensitive. Furthermore, there are studies showing rapid release of growth factors from PRP whereas the desired release process is extended and gradual to cover the regenerative phase. PRF is developed to overcome these limitations [28].

PRF is obtained without any anticoagulant use, therefore it's a fibrin matrix containing the full set of growth factors in it's matrix. Fibrin form of this platelet concentrate facilitates a slow release of growth factors over time as desired. PRF, later called as L-PRF, is rich in leukocytes and platelets. High levels of leukocytes contribute in wound healing and vascular formation along with their contribution in host defense to pathogens at the regeneration site as they are anti-infectious and immune modulating cells [29].

L-PRF is easily prepared compared to PRP. Once the blood sample is collected, it's put in glass tubes and centrifuged at 750 g for 12 minutes. It's important to centrifuge the collection quickly, since the sample's contact with glass tube walls starts the coagulation process rapidly. When the centrifugation is complete, there are three layers in the tube: red blood cells in the bottom, cells plasma at the top and L-PRF in the middle [13, 30].

With it's fibrin matrix structure acting as a scaffold for tissue ingrowth, rich content in cells recruiting future regenerative cells to the site and gradual delivery of growth factors make L-PRF attractive for use in regeneration procedures (**Figure 6**) [31, 32].

2.3.2 Recombinant growth factors

Bone morphogenetic protein (BMP) is a well-documented recombinant growth factor with it's recruiting, proliferating and differentiating effect on mesenchymal progenitor cells. Studies show osteoinductive properties of BMP activates osteoblast differentiation pathway MAPK/ERK. It's capacity of osteoinduction is at higher levels compared to other known growth factors therefore BMP can be utilized to promote bone regeneration especially in complex augmentation procedures like vertical augmentation [13, 33].

Platelet-derived growth factor (PDGF) is the second most utilized growth factor in augmentation procedures. It's responsible for cell migration and proliferation to

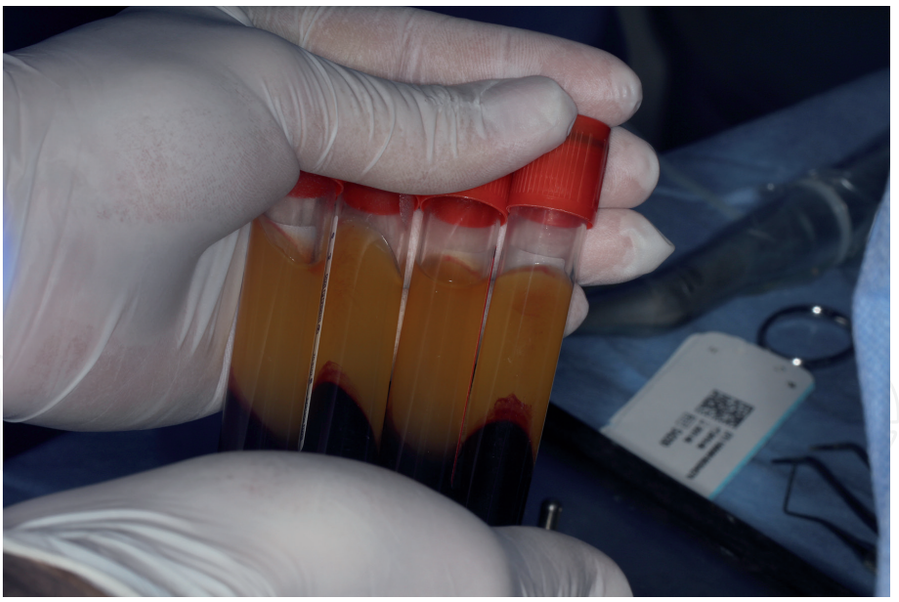

Figure 6.
Prepared human blood-derived PRF in the centrifuge tubes.

the defect site. Several studies reported PDGF to be highly effective on regeneration in advanced periodontal osseous defects [3].

3. Autogenous onlay block bone grafting

In many bone defects, guided bone regeneration procedures result in successful outcomes. It has several superiorities over block bone grafting like eliminating the secondary surgical site for bone harvesting and post-operative discomfort at the donor site. However, GBR is well-documented in regeneration of new bone up to 4.5–5 mm width and height. When the defect size gets larger, it's harder to achieve predictable results with this protocol. Although extending the healing period is recommended in large size defects, new bone quality is still observed to be less than ideal. Also GBR covering full arches, especially mandible, is not predictable. Therefore autogenous block bone grafting is utilized in large size defects [11, 34].

Significant amount (>5 mm) of new bone formation in vertical or horizontal dimensions can be achieved utilizing autogenous bone block grafting. It is indicated in augmentation of severely atrophic crests. In a review by Aloy-Prosper et al., autogenous block bone grafting procedures and their results are evaluated. In horizontally augmented sites utilizing block bones, implant survival rates are found to be ranging from %96.9 and %100. In vertically augmented sites through same procedures, implant survival rates are slightly lower ranging from %89.5 and %100 [35].

Autografts to be used in the procedure are obtained from various donor sites intra- and extraorally. Less complications are reported when intraoral donor sites are preferred for harvesting. When deciding for the donor site, amount of needed bone volume and defect size should be carefully evaluated. Autogenous bone graft shows high resorption rates, therefore it's important to harvest larger volumes considering the possible resorption [5]. Despite high resorption rates, osteogenic potential of autogenous bone makes this procedure feasible. Comparing GBR with autogenous block bone grafting, Jensen et al. reported that reaugmentation is needed in %11.1 of GBR cases and %2.8 of block bone grafting cases due to insufficient new bone formation [36]. Recently, there are studies recommending

combination of autogenous block bone grafting and GBR. Chappuis et al. clinically and radiographically evaluated GBR in combination with autogenous block bone grafting. %98.1 success rate and a minimal block graft resorption rate of %7.7 is reported in 10 years post-operatively [37].

3.1 Intraoral donor sites

Mandibular symphisis, buccal ramus shelf, maxillary tuberosity and torus are the main intraoral sources for bone block harvesting. Membranous grafts such as grafts obtained from mandibula are reported to have less resorption rates than the endochondrial grafts obtained from extraoral sites. Dimensional stability of the new bone and incorporation of grafts to the host site is also shown to be better when membranous grafts are utilized. Main advantages of intraoral bone blocks are less occuring complications, no need for patients to go under general anesthesia, no cutaneous scarring, easy surgical access, less morbidity in the donor site and more content of bone growth factors [38–41].

3.1.1 Intraoral harvest from ramus

Block bone grafts harvested from ramus are cortical type. Around 10–15 mm thick and 4 cm long blocks can be harvested from ramus. Maximum thickness of the bone block is defined by the distance between external oblique line and inferior alveolar nerve. Harvesting from mandibular ramus is more utilized than harvesting from symphisis since complications like significant change in the facial contours and post-operative sensory changes may occur in symphisis harvesting. Risk of neurovascular damage and difficult surgical access remain as disadvantages of harvesting from ramus, though [2, 41, 42].

3.1.2 Intraoral harvest from symphisis

Grafts harvested from mandibular symphisis is corticocancellous type. Due to anatomic limitations, blocks harvested from this site is shorter in length when compared to the blocks harvested from ramus. Maximal block dimensions are within the limits of mental foramina, apex of the anterior teeth and lower edge of the mandible. When harvesting from symphisis, osteotomies should be done 5 mm further from the apex of anterior teeth, mandibular lower edge and mental foramina. Easy surgical access and high amounts of osteoblasts make symphisis a preferable donor site. On the other hand, complications such as changes in the jaw contour, devitality of teeth and mental nerve damage may occur [34, 42].

3.2 Extraoral donor sites

Amount of bone volume harvested from intraoral donor sites is limited. Significantly greater graft volumes can be harvested from extraoral donor sites to reconstruct large size defects. Possible extraoral donor sites are calvaria, tibia, costae and iliac crest. Bone blocks obtained from extraoral donor sites tend to resorp faster than the blocks harvested intraorally. Therefore, greater volumes of bone should be harvested when reconstruction is planned with extraorally harvested bone blocks. Harvesting from extraoral donor sites have some major drawbacks such as increased morbidity at the donor site and requirement for patients to go under general anesthesia along with hospitalization afterwards [2, 5, 34].

Sbordone et al. evaluated resorption rates following iliac crest block bone grafting via CT images. In 6 years follow-up, %87 mean resorption rate is

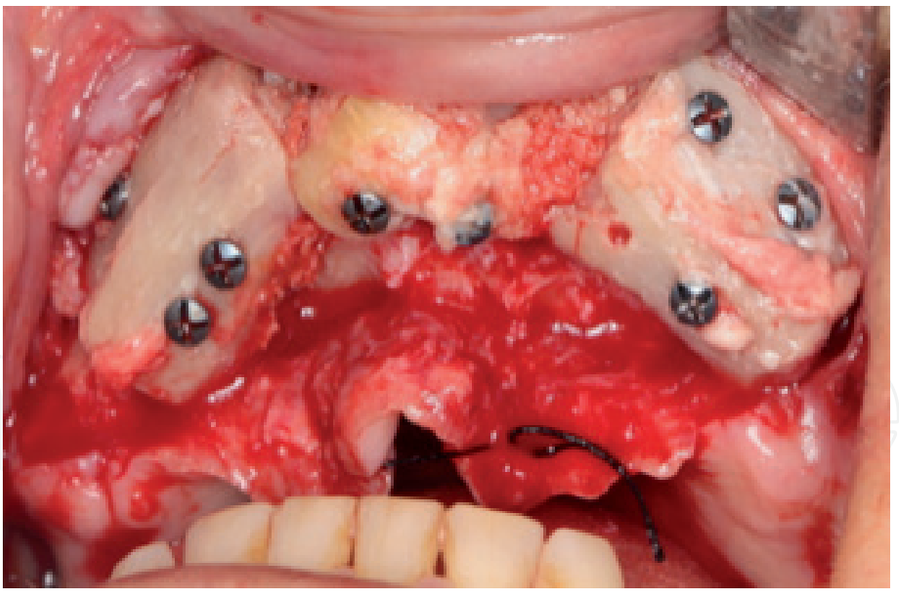

Figure 7.
Iliac block grafts fixated on the atrophic maxilla.

demonstrated at maxillary reconstruciton sites [43]. In a similar study conducted by Vermeeren et al., panoramic x-rays are evaluated for 5 years and resorption rates ranging between %44–50 are observed at sites grafted with block bones. Several studies report variety of resorption rates from %42 to %87 when autogenous block bone grafting is performed. Utilizing a collagen membrane along with autogenous block bone grafting is demonstrated to reduce resorption rates up to %25 (**Figure 7**) [44].

4. Alveolar ridge splitting

Alveolar ridge split is a common technique used in the presence of horizontally deficient alveolar ridges. Surgical procedure for this technique is initiated by one horizontal crestal osteotomy [45]. Piezosurgery, oscillating saws or diamond burs and chisels can be used for the initial osteotomy [2]. Different chisels of increasing width progressively create a gap between the buccal and palatinal/lingual plates afterwards. Interpositional grafting and/or immediate implant placement is oftenly applied to the created gap. This concept is based on the osseous plasticity of trabecular bone. Therefore, a 3- to 5 mm residual crest width is required for the procedure. Fractures may occur in ridges with lower width due to less presence of trabecular bone and less plasticity [46]. To gain greater amounts of new bone, vertical osteotomies may be added to the initial horizontal osteotomy. Another surgical concept of ridge splitting is the displacement of buccal plate by adding a second horizontal osteotomy apically to the initial horizontal osteotomy. In this concept, greenstick outfracture from the basal bone is created on purpose. If full-thickness flap is elevated, the plate should be fixed with screws to the palatinal/lingual plate. Partial-thickness flap is also preferred to keep periosteal vascularization when greenstick fracture is created [47, 48].

This procedure is indicated in cases presenting 3 to 5 mm bone width, with sufficient trabecular bone under the cortical layer. Two-stage ridge split is found to have high success rates up to %97 in terms of implant survival. Studies report 3 to 3.5 mm mean horizontal bone gain with this procedure [48]. Still, there are some drawbacks of this procedure: unpredictable results in severely atrophic crest where

trabecular bone is not present, high risk of uncontrolled fractures when applied to narrow ridges (<3 mm), bone gain only in horizontal dimension [46].

5. Maxillary sinus augmentation

Maxillary sinus is one of the paranasal sinuses, located adjacent to posterior maxilla. It's an air-filled anatomical cavity, lined with a membrane called "Schneiderian Membrane". Bone resorption following tooth loss, in conjunction with maxillary sinus pneumatization, causes crestal atrophy in the maxillary posterior region. Maxillary sinus floor elevation provides enough bone height for implant placement in atrophic posterior maxilla. To elevate the Schneiderian Membrane, various techniques are developed. These techniques are classified in two main categories: lateral window approach and transalveolar approach.

5.1 Lateral window approach

This technique consists of preparing a window on buccal bone (also lateral wall of maxillary sinus) and elevating sinus membrane through the window. The superoinferior and anteroposterior borders of lateral window is determined depending on the location of maxillary sinus. Inferior border is usually 2 to 5 mm above the sinus floor to prevent any challenges during the infracturing. Once the lateral window is prepared and Schneiderian Membrane is elevated, various grafting materials can be added to the created space [49]. Barrier membranes are oftenly used to cover the bony window afterwards (**Figure 8**). Use of barrier membranes is reported to be more efficient than no membrane use in terms of implant survival rates [50]. In a clinical trial conducted by Garcia-Denche et al., no significant difference was found in lateral window approach with and without the use of membranes, though [51].

Lateral window approach is indicated when residual bone height is below 6 mm. Simultaneous implant placement may be applied when residual height is ≥4 mm. In cases presenting less than 4 mm of bone vertically, delayed implant placement is found to be safer [52]. Before proceeding to the surgery, a thorough medical examination is crucial to avoid possible complications. One of the most common complications in lateral window approach is bleeding during the flap elevation or preparation of lateral window. To avoid bleeding, inferior alveolar artery and posterior superior alveolar artery should be well examined, via radiographic images, in terms of location and possible anastomosis. Presence of septa should also be examined for a well-designed window preparation and for avoiding any membrane

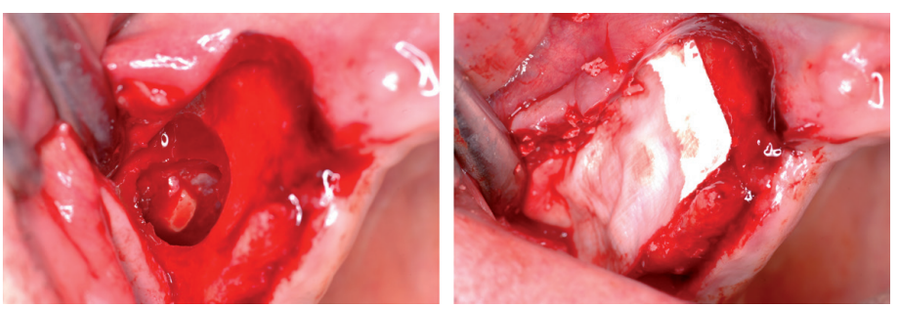

Figure 8.
Prepared lateral sinus access window (left) is closed by a resorbable barrier membrane (right) termed as the "open sinus lifting" or the "lateral window sinus lifting" technique.

perforations. Separate windows can be prepared, if necessary. Healthy Schneiderian Membrane is usually 1 mm thick. Thickness of the sinus membrane should be examined and pathological conditions must be treated before the surgery if present. In the presence of active sinus infection, neoplasmic lesions, uncontrolled diabetes, recurrent chronic sinusitis this technique is contraindicated [5, 49].

The augmented site is very well vascularized through surrounding sinus walls and Schneiderian Membrane, therefore it shows high success rates in terms of bone volume gain. Grafting is possible with various bone graft types. Graftless approach and grafting the site with highly degradable materials like collagen sponges or PRF is also possible but pneumatization of maxillary sinus and the required period for bone regeneration should be considered well enough before these approaches, since it's possible for membrane to collapse and decrease the bone gain [2, 49, 53].

5.2 Transalveolar approach

Comparing to lateral window approach, this technique is considered to be less invasive. It's indicated in cases with ≥6 mm residual bone height. In a retrospective clinical study by Rosen et al., implant survival rates were found to be higher where residual bone height is greater than 4 mm. This rate, which is 96% when the residual bone height is over 4 mm, decreases to 85.7% in the presence of bone height less than 4 mm [54]. In this approach, a pilot implant slot is created with a drill narrower than the final diameter of the implant. The pilot implant slot is prepared to a depth 1–2 mm from the sinus floor. Different osteotomes of increasing diameters and lengths are used to prepare the slot. It's recommended that the final osteotome has a diameter 0.5 mm less than the planned implant diameter. After the final osteotomy, dental implant is placed in the slot [49]. A group of researchers modified the technique by introducing bone grafts to osteotomy site before implant placement. This modification aims to increase bone amount between the implant and the sinus floor. However, Si et al. reported similar implant survival rates and no significant difference between grafted sites and nongrafted sites [55].

There are various modifications of membrane elevation in transalveolar approach: antral membrane baloon elevation, hydraulic sinus lift, hydrodynamic ultrasonic cavitation sinus lift, trephine core sinus lift and osseodensification.

Transalveolar approach is minimal invasive. Graft and membrane use is not compulsory with this technique and simultaneous implant placement is possible in eligible cases. On the contrary, full visualization of the surgical site is not possible

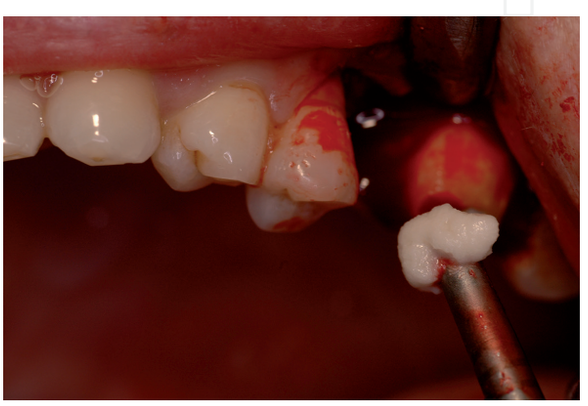

Figure 9.
Transcreastal osteotome technique used for the "closed sinus lifting" procedure. A bone graft was placed at the tip of the osteotome instrument for the prevention of the sinus membrane.

therefore possible complications, such as membrane perforations, may not be maintained well enough and intra-operatively (**Figure 9**), [46].

6. Distraction osteogenesis

Distraction osteogenesis is based on creating two bone segments by controlled osteotomies and gradually separating the segments to induce bone regeneration mechanism in between. In the surgical procedure, after full-thickness flap elevation and proper visualization of the site, fixation plates are temporarily adapted to the cortical bone. In this way, borders of osteotomy is determined. Following osteotomies, the distractor is fixed in the final position. Mobility of the transport segment is checked, then the device is put to initial passive position. Post-operative activation period is divided into three phases: latency, distraction, consolidation [2, 46, 56].

Latency: This protocol takes 5 to 7 days for a proper soft tissue healing. Distractor is not activated during this period to reduce the risk of wound dehiscence.

Distraction: Following latency, the distraction is activated by turning activation key at a rate of 0.5–1 mm per day. Transport segment is distracted from native bone vertically. Duration of distraction period depends on amount of bone needed.

Consolidation: Once the distraction is finalized, maturation of newly formed bone between the segments is expected for 8–12 weeks. Then the device is removed and implants are placed [2, 46].

Distraction osteogenesis can provide a bone gain of 5–15 mm vertically. Therefore it's safely indicated in vertical bone atrophies up to 15 mm [46]. In two clinical studies comparing autogenous bone block grafting and alveolar distraction osteogenesis (ADO), Bianchi et al. reported more bone gain in ADO group where Chiapasco et al. controversially reported no significant differences between the outcomes [56]. The procedure's contraindicated in cases presenting a thin knife-edge crest and insufficient bone amount to allow adequate anchorage. Patient co-operation during the distraction period is critical, treatment procedure should be thoroughly discussed with the patient before the initiation [46]. It is also a technique-sensitive procedure, therefore it is recommended for experienced surgeons to practice [57].

There is no need for additional bone grafts and membranes with this technique. Gradual distraction helps soft tissue increase along with bone regeneration. There is minimal infection risk and resorption levels are low in the newly formed bone. In sites regenerated with distraction osteogenesis, implant survival rates are comparable with other techniques. Alveolar ridge is regenerated by it's own osteogenic and regenerative potential, therefore autogenous bone transplant is not needed in distraction osteogenesis. Functional and esthetic discomfort of distraction device in oral cavity remains as one of the disadvantages, though. A wide range of complications with a high incidence up to %76 is reported with distraction osteogenesis [2, 46, 58]. Chiapasco et al. stated 'change of distraction vector' as the most frequent complication. Premature consolidation, insufficient distraction, resorption of transport segment and fractures of native bone, the transport segment or the device is among the possible complications [59].

7. Conclusions

This chapter reviewed various alveolar ridge augmentation techniques in implant dentistry in general aspect. Alveolar ridge augmentation procedures are advanced surgical interventions. Success of these interventions depend on many

factors such as the surgeon's experience, preferred technique, materials in use, patient's medical condition, defect topography and patient co-operation. With variety of factors affecting the outcome, it's hard to choose one technique over other. Guided bone regeneration and autogenous block bone grafting are two of the well-documented and safely applicable augmentation techniques. Both these techniques have challenging learning curves and require advanced skills in practice therefore following the evidence-based principles is critical for achieving successful outcomes.

Conflict of interest

The author declares no conflict of interest.

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