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Review Article

Autogenous Bone Grafting in Oral and Maxillofacial Surgery: Principles, Biology, and Clinical Applications

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Abstract

Background: No one bone graft material is best for every situation in oral and maxillofacial surgery. As such, selecting the appropriate bone graft should be determined on a case-by-case basis through evaluation of the cost, morbidity, and predicted success rate of each grafting material. **Objective:** This article reviews the biological basis of the process of autologous bone graft incorporation and survival, differentiates between autologous and other grafting materials, and explains the biological considerations behind choosing a particular grafting material and approach**. Methods:** Narrative review of the literature pertaining to the biology and physiology of autologous and non-autologous bone grafting materials**. Results**: While autologous bone is considered the gold standard of bone graft material because of its ability to incorporate and undergo osseointegration in host bone, it is limited by donor site morbidity, resorption, a limited supply, and time required for harvesting. Non-autologous grafting materials are unlimited in their supply and do not have donor-site morbidity but lack osteogenicity, have poorer incorporation and revascularization, and are more expensive. The factors affecting graft incorporation and survival include the vitality of osteocytes and osteoblasts, the microarchitecture of the graft material, and the osteogenicity of the recipient bone, with the cranial bone and inlay grafts on vascularized dura having the best volume retention.

Conclusion: An understanding of the biology behind autologous bone grafting allows clinicians to choose the best grafting material and techniques to optimize both biological properties of the graft and minimize donor-site morbidity, particularly in children.

Keywords: autogenous bone graft; craniomaxillofacial reconstruction; bone graft survival; osteocyte viability; cranial bone graft; graft revascularization.

1- Introduction

The management of bone defect reconstruction is a common problem in oral and maxillofacial surgery due to trauma, tumor surgery, congenital deformities, and bone degeneration due to aging. Many types of bone grafting materials are currently in use, such as autologous bone, allografts, xenografts, and synthetic materials, all with different biological performance [1]. Even after many years of significant development in the area of biomaterials, autologous bone still serves as the gold standard due to its excellent osteogenic, osteoinductive, and osteoconductive characteristics [2]. In this review article, we will revisit the basics of physiology associated with the integration, viability, and remodeling of autogenous bone grafts.

2- Principles of Bone Augmentation: Bone augmentation and replacement is among the most commonly done surgical procedures in craniomaxillofacial surgery. The choice of biomaterials depends on the specific situation,

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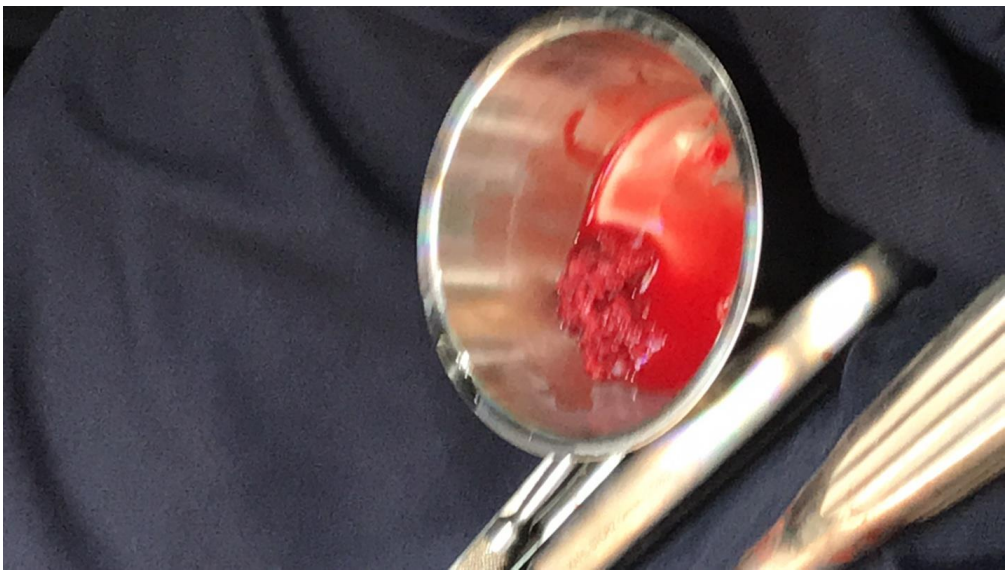
surgical preference, availability, and cost. Even though some biomaterials are claimed to be superior to others, the reality is that every biomaterial has its advantages and disadvantages. Hence, there should be a flexible and situation-specific choice of materials. For example, what is an ideal biomaterial for the repair of a cranial defect in a healthy two-year-old child does not equal what material would be best for a 71-year-old person with many comorbid conditions; similarly, materials for cheekbone augmentation in a state-of-the-art craniofacial center will be different from materials available in a less fortunate facility. Generally, bone augmentation and replacement materials are divided into three main categories:

- Organic materials, comprising autogenous (from the patient), allogeneic (from a different person), and xenogeneic (from other species) grafts;
- Synthetic organic materials, such as hydroxyapatite and osteoinductive biologics, for example, BMP;
- Inorganic materials, including methyl methacrylate, silicone, porous polyethylene, titanium mesh, and bioactive glass.

3- Autogenous Bone Grafting Material

The use of autogenous bone grafting continues to be favored when dealing with skeletal reconstruction. The skull, iliac crest, and ribs have been observed to be the commonest sites used [2]. Because of revascularization and integration of the graft with the neighboring bone tissue, the likelihood of infections and graft resorption is minimal compared to other types of non-vascularized grafts. However, autogenous bone grafting prolongs operation time and has donor site morbidity issues. Resorption is unpredictable and makes it difficult to achieve exact shaping of the bone to fit the cranium and facial bones.



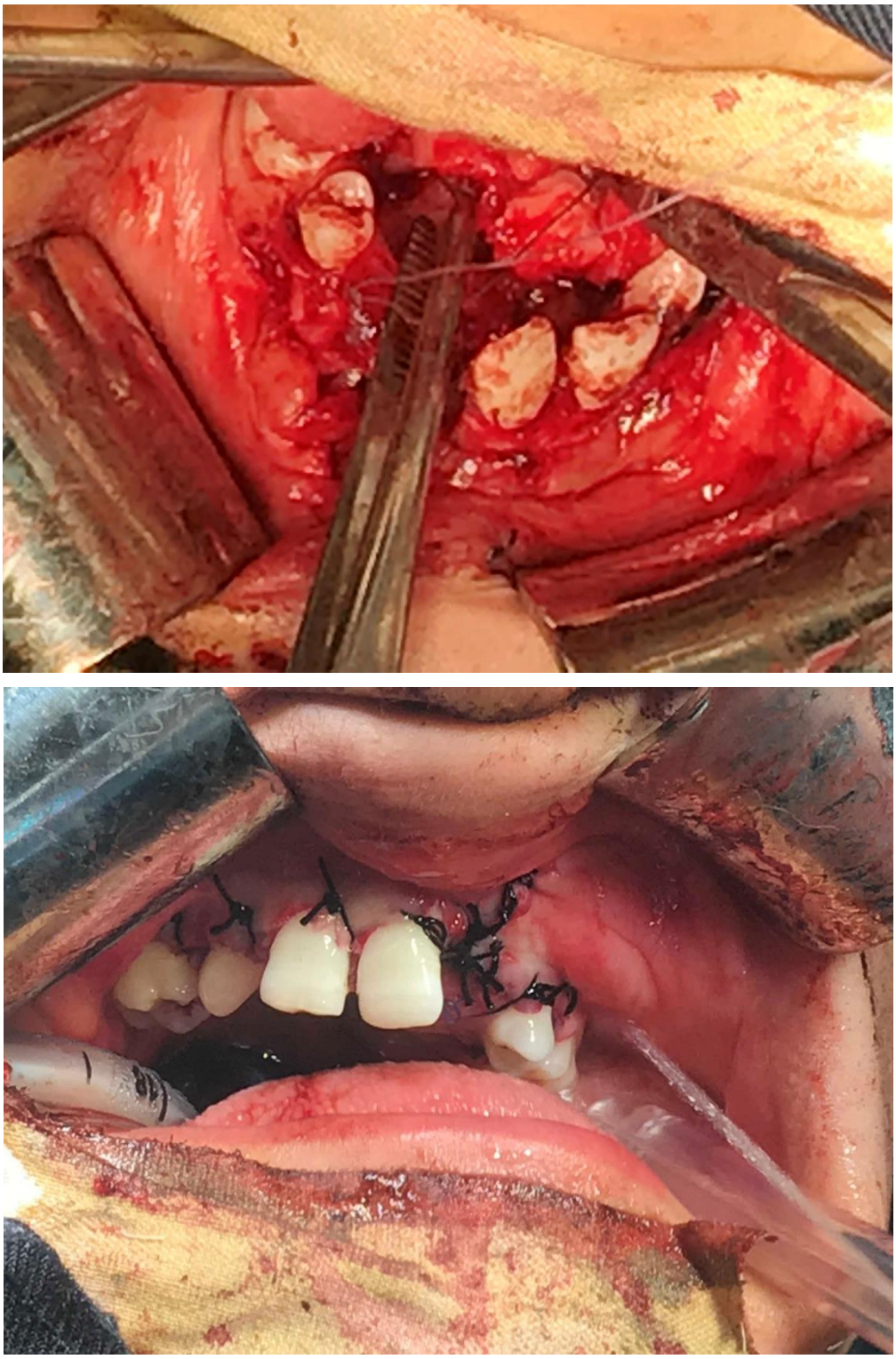
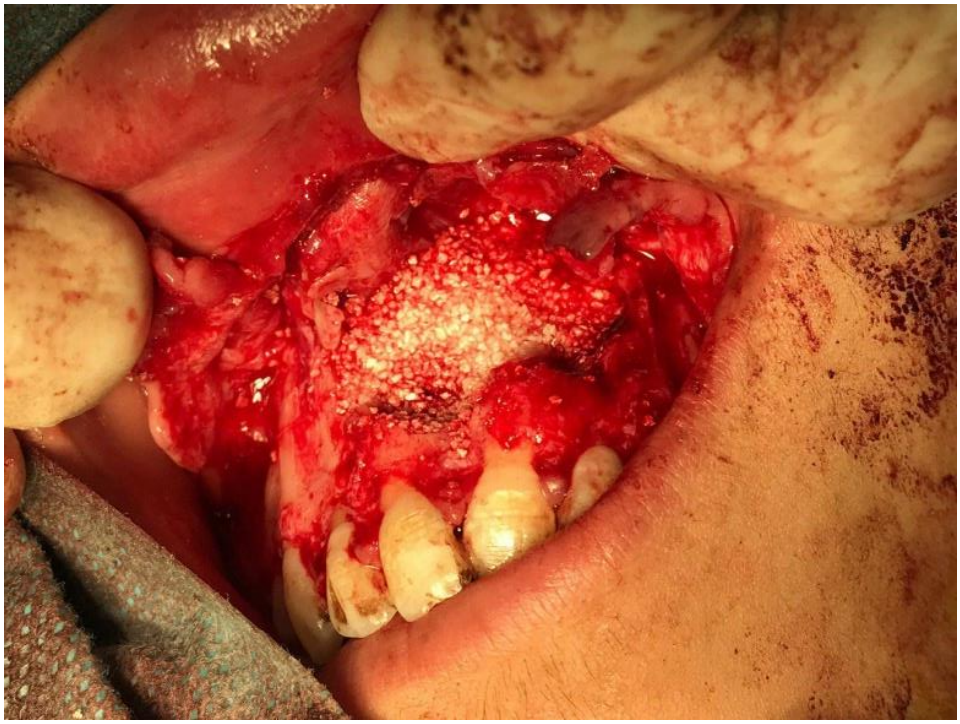


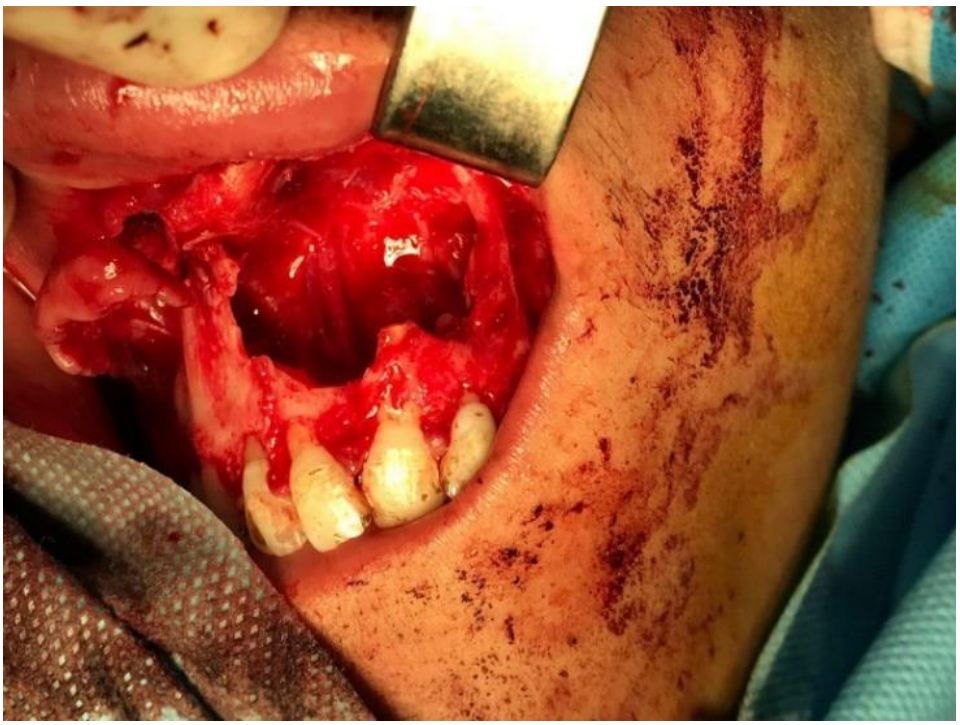
Figure 1-3. Intraoperative examples of autogenous bone graft harvesting and application.

4- Alternative (Non-Autogenous) Grafting Materials

Various substitutes have been produced to replace autogenous bone. Some of the main benefits of using such substitutes include the availability of an essentially unlimited source and absence of donor-site morbidity [3]. Most of the substitutes can also be preformed to fit the size of the defect. However, unlike autogenous bone, many of the non-autogenous materials used for bone grafts do not have any viable cellular component, and as a result, the osteogenic capability is significantly reduced. Bone morphogenetic protein and demineralized bone matrix may possess osteoinductive capabilities through differentiation of undifferentiated mesenchymal

cells to osteoblasts. Nonetheless, the use of such materials as grafting materials may be limited due to insufficient mechanical and structural properties. Other bone substitutes act mainly as osteoconductive scaffolds that aid in bone growth, which include allografts, hydroxyapatite, and other ceramics. On the other hand, materials like methyl methacrylate, titanium, and porous polyethylene are mostly biologically inert [4,5]. The process of biological integration and revascularization of the material varies with the type of material used, architectural structure, implantation, and clinical uses, and some of them may be associated with infections, foreign-body reactions, displacement, and even fractures [6]. Despite the fact that methyl methacrylate is relatively cheaper [7], many modern and sophisticated non-autogenous biomaterials may prove to be more expensive, thus making their use difficult in developing countries [8]. Consequently, despite the development of other biomaterials, autogenous bone remains significant in the reconstruction of craniofacial bones because of the osteogenic, osteoinductive, and osteoconductive nature of the bone, among other factors.





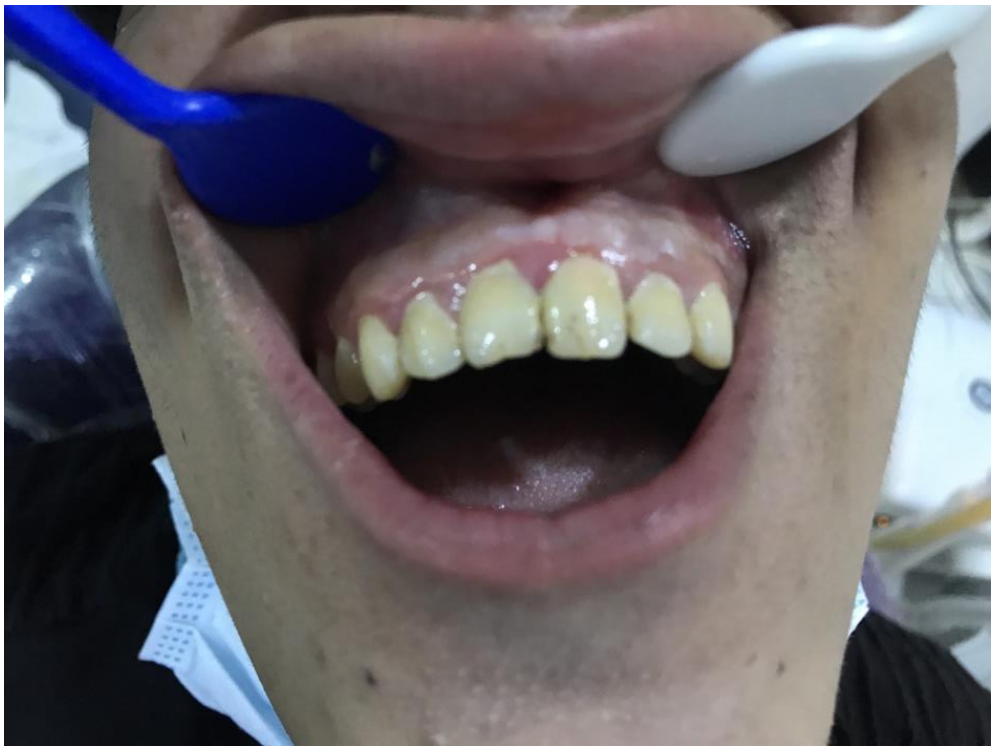


Figure 4-6. Examples of alternative grafting materials and clinical outcomes.

5- Factors Affecting Graft Volume Retention and Clinical Outcome

The two clinical outcomes that define the success of the autogenous bone graft are the ability of the graft to retain its volume and biological response after transplantation. Volume retention is achieved by the interaction between the rate of osteolysis due to revascularization and remodeling and osteogenesis within the bone graft and surrounding tissues. In cases where osteolysis exceeds osteogenesis, there is shrinkage of the graft, while the opposite yields increased volume. The biological response is determined by the viability of osteoblastic cells.

5.1- Osteocyte and Osteoblast Survival

Live bones have cells that include osteocytes and osteoblasts. While osteocytes have limited capacity for generating new bone formation, they play an important regulatory role in guiding osteoblasts and bone remodeling [9,10]. The main benefit of using autogenous grafts is that they stimulate bone formation; therefore, maintaining the cells which is crucial. The death of osteocytes promotes osteolysis due to increased osteoclastic activity [11]. Cell viability is an important factor determining whether a graft will be successful.

The initial viability of cells in a non-vascularized bone graft is based on diffusion of nutrients from the recipient bed. The process of angiogenesis, which occurs at the recipient site, restores the nutrient supply, but it takes time and does not prevent cell death because osteocytes and osteoblasts die in 25 hours if there is no vascularization. Diffusion of oxygen and nutrients ensures that the outer layer of cells will survive; thus, thick and large grafts have more non-viable inner cells than thinner ones. Only viable cells will actively contribute to the formation of new bone, while non-viable inner bone acts as a scaffolding that is gradually substituted through creeping substitution. At this stage, the necrotic center of a graft is more vulnerable to infections and mechanical failures.

While surface osteocytes seem to be the least susceptible to die after transplantation, even their viability is threatened by harvesting and preservation procedures. Thermal damage caused by power tools during harvesting and contouring, as well as osmotic

or dehydration damage during ex vivo preservation, are all avoidable risks; suggested protective measures are limited use of high-speed tools, irrigation with cold saline solution, and preservation of the graft in a blood-soaked sponge [12]. The recipient bed cell viability can be compromised by infection, hematomas, irradiation, or scars, all of which obstruct nutrient supply and neovascularization.

Vascularized bone grafts become an ideal choice when large defects or poor recipient beds are encountered, because of rapid and reliable revascularization and consequently higher osteocyte survival rate [13]. As a living tissue, the grafted bone maintains all of its biological abilities to rapidly heal, integrate with surrounding tissue, resist infections, and adapt to mechanical loads [14].

6- Microarchitecture of the Bone Graft

There are multiple autogenous sources of bone, not all of which can be safely harvested without any functional and aesthetic consequences. Among the most frequently used sources of bone grafts, one may mention the cranium, ribs, and the iliac crest. Rib harvesting carries risks of contour deformities, pleuritic pain, and pneumothorax, while harvesting from the iliac crest is accompanied by post-operative pain and risk of injury to the lateral femoral cutaneous nerve. Overharvesting of the iliac crest may lead to damage to the anterior growth apophysis in children [15]. Unlike the iliac or rib bones, which require a separate incision, the cranial bone can be harvested together with craniomaxillofacial surgery without additional discomfort and with an insignificant, well-disguised scar. The bone from the cranium may be harvested as full-thickness, split-thickness, or particulate corticocancellous bone.

While full-thickness bone has the best biomechanical properties, it leaves the donor defect requiring closure; for that reason, the majority of surgeons prefer to use split cranial bone harvested through the diploic space, producing two parts – one part can be used for reconstruction, while the other is needed for closing the defect. Limitations of split cranial bone grafting include possible insufficiency of long-term thickness both at donor and recipient sites and the development of the well-developed diploic space, which usually does not develop before five years of age [16].

The bone taken from the cranium retains better long-term volume than other autogenous sources after onlay grafting [17]. This characteristic was historically attributed to the embryologic nature of the bone (membranous and endochondral), but recent research has shown that volume retention depends mostly on the ratio of the cortical to cancellous components of the graft [18,19]. Predominantly cortical grafts (cranium bone) show better volume retention compared to predominantly cancellous ones (rib or iliac crest) due to differences in the rate of revascularization [20]. While revascularization ensures osteocyte survival, it proceeds through osteolysis, when the cutting cones form to allow vascular ingrowth, and then the new bone fills the gap [21]. The rate of revascularization depends on the ratio of surface area to volume of the bone, which is much bigger in the case of cancellous bone [22]; this explains faster revascularization and resorption of the cancellous graft [23,24]. Thus, revascularization seems to depend not only on the type of bone, but on its microarchitecture [25]. It should be noted that particulate bone grafts taken from the cranium (mostly cortical) may be resorbed in the same way as cancellous grafts [26]; morselization of the bone graft leads to its impaction and increased cortical density, which in turn prevents revascularization and remodeling [27]. A high ratio of surface area to volume, which allows fast revascularization and resorption of the cancellous bone, also allows better osteoinductive and osteogenic effects due to greater surface area supporting osteocytes and osteoblast survival, as well as faster local production of the bone

morphogenetic proteins, which stimulates osteoprogenitors' differentiation. Besides the microarchitecture of the graft, its relationship with recipient tissue becomes another important factor in the behavior of autogenous bone [28].

7- Influence of the Recipient Bed

The interaction of the graft with the recipient bed leads to the appearance of various interesting biological effects [29]. Thus, the direct onlay placement of the cancellous autograft over the dura is associated with volume augmentation rather than resorption, while both cortical and cancellous inlays grow in volume, while onlay grafts decrease in size – even particulate cranial onlay grafts have the same pattern of change in volume [30]. Mechanical explanations for such behavior seem insufficient. As was mentioned above, isolation of the graft from the pericranium with a double-layered collagen membrane dramatically increases graft survival, exceeding the mechanical protection effects [31].

The main difference between the inlay and onlay cranial grafts is their relationship with the dura, because the pericranium covers both kinds of grafts [32]. However, even though the pericranium is considered the most important part of the cranial graft for its healing, the role of the pericranium is apparently much less prominent than that of the dura [33]. In the case of the inlay graft, the pericranium plays a significant role only in terms of the surface healing of the graft, while osteogenesis driven by the dura occurs throughout the graft. The isolation of an inlay graft from the pericranium does not affect the survival and volume of the graft significantly, but when the graft is isolated from the dura, its volume decreases considerably [34]. As for the role of the periosteum in the survival of onlay grafts, the results of research articles are conflicting – sometimes, the survival of grafts is increased due to rigid fixation of the graft together with the periosteum; sometimes – vice versa [35,36].

Summarizing all information provided above, one may say that dura-induced osteogenesis is more important than revascularization-related osteolysis in the inlay graft and leads to a volume increase, while in the onlay graft, pericranial osteogenesis is much weaker in comparison with revascularization-related resorption and leads to a volume decrease [37]. This decrease is especially significant for cancellous onlay grafts because of rapid revascularization of cancellous bone compared with the cortical one. Indeed, the abrasion of the cortical bone beneath the onlay grafts accelerates the process of resorption via increasing the rate of revascularization and osteoclastic activity [38]. Thus, the osteogenic potential of the recipient site explains the different behavior of identical grafts depending on their localization [39].

8- Clinical Applications

These biological concepts lead to the following recommendations regarding the use of autogenous bone grafts:

- Viability should be preserved at all stages of bone grafting. Nonviable bone possesses minimal osteoinductive properties and heals through creeping substitution, which slows down the process of healing and increases the risk of bone resorption and infection. Viability of nonvascular bone is contingent upon the size and thickness of the bone graft, as well as the ability of the recipient site to become vascularized and osteogenic; vascular bone should be used when viability is important, such as in load-bearing reconstruction procedures or in cases where there is an impaired recipient site.

- Autogenous bone, regardless of its type (cortical and cancellous), maintains its volume or even gains volume when used as an inlay graft on intact dura, as a result of an osteogenesis/resorption balance. Since the dura participates actively in the process of osteogenesis, viability is reduced in the case of

scarred dura. It is easier for cancellous bone to maintain volume when used as an inlay graft compared to cortical bone.

- Onlay grafting on healthy bone is associated with bone resorption, because of an osteogenesis/resorption balance that favors resorption. As cortical bone becomes vascularized more slowly than cancellous bone, it maintains volume better as an onlay graft; surface abrading of the recipient site promotes revascularization and, hence, bone resorption.

9- Cranial Bone as the Preferred Autogenous Graft Material

First of all, compared with rib and iliac grafts, the most important advantage of the cranial bone is that no distant donor site is required. Secondly, there is no donor morbidity with the cranial bone. Thirdly, it has better volume retention. It is widely accepted that the amount of cranial bone is insufficient in young patients. This misconception makes it possible for doctors to use the endochondral bone or alloplastic substitutes in craniofacial reconstruction. New techniques for harvesting particulate cranial bone have expanded the donor potential considerably, and inlay defects in most cases can be restored with the autogenous cranial bone regardless of the age of the patient.

Since the cranial donor site is within the field of operation, there is no operative morbidity of additional type. Bone can be harvested either from the outer table of the calvarium or from the inner table of a free bone fragment using the hand-held brace and craniotomy bit. In this way, thermal damage is excluded, and the viability of the graft is preserved. The size and pitch of the cutting instrument affect particle survival because small particles will be resorbed by macrophages, while big particles reduce osteogenic and osteoinductive activity. Bone dust obtained by high-speed drilling resorbs after inlay grafting due to osteonecrosis and the small size of the particles. Since the donor defect in the case of particulate harvesting is a partial-thickness and subcritical defect, it heals spontaneously, restoring the donor site thickness and allowing repeated harvesting, which is impossible in the case of split cranial bone. Harvesting from the ectocortical surface does not require neurosurgical help because the inner table remains intact, and particulate bone can be harvested from the parts of the skull inappropriate for splitting (temporal bone, greater wing of the sphenoid, occiput) and even from children without diploic space [40]. Remaining between the donor defects in the full-thickness bone, the trabecular lattice is stronger than split bone. Particulate grafts are especially convenient in the case of inlay reconstruction. As with any other cancellous graft, the bone mass after healing equals or even exceeds the original one [41,42]. With time, the graft becomes indistinguishable from the bone and can even initiate the development of the new diploic space. It is reparative osteogenesis, which resembles fracture healing and distraction osteogenesis. Taking into account the importance of dura in this case, particulate grafting on the scarred dura is usually replaced by exchange cranioplasty [43].

Any part of the skull can be harvested and reconstructed by the particulate graft from the endocortical surface. If there is a need to reconstitute the donor defect, it can be done by means of obtaining the necessary amount of additional particulate from the surrounding ectocortex. Since the healed particulate bone is similar to the native bone both in thickness and integrity, the donor site can be re-harvested again as particulate, split, or full-thickness bone. By means of repeating cycles of harvesting and healing, the craniofacial surgeon can obtain a practically unlimited renewable source of autogenous cranial bone.

10- Conclusion

Autogenous bone still remains the gold standard of care in oral and maxillofacial surgery owing to its biological characteristics that include its ability to form bone, induce and incorporate bone, and facilitate the formation of new bone as well as reperfusion and osseointegration with host bone. Grafting relies on the viability of osteoblastic and osteoclastic activity, graft microarchitecture (configuration of cortex-spongiosa), and host bed's potential for new bone formation. Augmentation grafts are more successful with the use of dura mater and craniotomy. Non-autogenous grafts remain valuable in cases of limited size and donor morbidity. However, these types of bone grafts fail to develop bone tissue and possess less reperfusion properties, which do not allow these grafts to be considered substitutes for autologous bone. An understanding of these biological concepts helps a maxillofacial surgeon to choose a type of graft, donor site, and method of implantation that will suit the specific needs of particular patients. More prospective studies are needed to determine indications for autogenous and non-autogenous grafting in various patient populations and health care settings.

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