Bone grafting in maxillofacial trauma

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Purpose of review
The purpose of this article is to review the recent grafting strategies in maxillofacial trauma.

Recent findings
Recent technological advancements have applications in the management of maxillofacial trauma; advancements in imaging modalities such as 3D imaging can help surgeons in both the preoperative and intraoperative periods. These may be coupled with navigational systems to further facilitate complex reconstructions. 3D printing has been used in reconstruction and 3D, 4D, and 5D bioprinting technologies continue to improve and to find new uses, and stem cells and growth factors in maxillofacial trauma are also among the most studied topics. Maxillofacial traumas have decreased in number during the COVID-19 pandemic, as more conservative approaches have been preferred in COVID pandemic conditions.

Summary
Preoperative planning is the most important step in the reconstruction of maxillofacial trauma defects, and early bone and soft tissue reconstructions are recommended in severe maxillofacial traumas. Autogenous grafts are the gold standard in bone grafting. Nonvascularized grafts are planned according to the size, shape, and location of the defect, with vascularized bone flaps preferred in large defects, wide soft tissue defects, and contaminated defects. Alloplastic grafts or xenografts may be used if autogenous grafts are not available.

Keywords
autogenous graft, bone grafting, maxillofacial trauma

INTRODUCTION

Maxillofacial traumas include a wide range of injuries from simple soft tissue injury to severe head and neck injuries in poly-trauma patients. Reconstruction of such severe injuries may be challenging, and bone grafting in maxillofacial trauma repair is one tool in the reconstructive surgeon's armamentarium. The ultimate goal of these surgeries is the optimal aesthetic and functional reconstruction of the face.

In order for a bone graft to be successful, the graft must have a sufficient amount of viable osteogenic cells, maintain strong osseous bulk, and resist resorption, in order to maintain the facial skeleton and to allow for subsequent prosthetic rehabilitation. It must also act as a precursor for bone production and maturation by the bone induction principle.

There are many challenges in the reconstruction of the maxillofacial region, such as a limited amount of tissue, the need to reconstruct complex defects, the potential need for multiple or staged surgeries, and the limited vascular capability of traumatized maxillofacial tissues. Also, there can be unpredictable results of bone grafts owing to devitalization of the surrounding recipient bone stock, and a limited ability to contour grafts. A sufficient vascularized flap including bone and soft tissues may overcome these limitations [1].

TIMING of BONE GRAFTS

Autogenous bone grafts are the most viable treatment option in bony tissue losses or damage to the maxillofacial skeleton. It is preferable to perform a strong, load-bearing, bony reconstruction of the facial skeleton, as this inhibits contraction of the overlying facial soft tissues following injury and the initial surgery. This can be done using three different surgical approaches:

- Single-stage approach: appropriate bone grafting is performed with adequate soft-tissue coverage.

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KEY POINTS

- Contamination risk must be kept in mind for all maxillofacial interventions in the COVID era and other pandemic situations.
- Preoperative and intraoperative imaging technologies will help the surgeon to do more precise surgery.
- 3D, 4D and even 5D technologies will make the reconstruction process more aesthetic and functional.
- 3D bioprinting technologies which use stem cell and other growth factors will decrease complications related to alloplastic materials.
- Synthetic grafts which are similar to normal human bone or have different substance release properties such as antibiotics or different growth factors may increase the use of synthetic materials in grafting.

- Two-stage approach: If adequate soft tissue coverage is not available in the initial surgery, temporary bone grafting is performed during initial soft tissue reconstruction. Definitive bone grafting is performed later in a second-stage surgery.
- Delayed approach: Open fixation of defects is performed with or without temporary bone grafting, and definitive bony reconstruction is performed in staged surgeries as soon as possible. This is often in the form of a vascularized bony flap. This approach is used in cases of catastrophic tissue damage, and when the patient's survival from the inciting injury may be uncertain at the time of initial repair.

GRAFTS

Different classifications are used for defining types of bone grafts. Classifications can be made according to source, donor site, histologic architecture, embryologic origin, and blood supply. Due to their osteogenic, osteoinductive, and osteoconductive properties, autogenous bone grafts are the gold standard for bony reconstruction in the maxillofacial region. Autografts are harvested from the same individual. Isografts are harvested from genetically identical twins if possible, and are rarely employed or available. Grafts harvested from the same species are called allografts, whereas those harvested from different species (e.g. bovine-derived, porcine-derived, coralline calcium carbonate) are called Xenografts. An allogeneic bone graft that can be harvested either by a live donor or a cadaver is the best option when there is not an available autologous bone graft. Alloplasts (e.g. Hydroxyapatite, calcium phosphate cement (CPC), beta-tricalcium phosphate (TCP), biphasic alloplastic materials, bioactive glasses, synthetic polymers) are synthetic materials [2]. Synthetic bone grafts have osteoconductive properties, and some of them have osteointegrative properties also [3■■]. TCP ceramics are considered to have the most similar chemical properties to native bone amongst the synthetic grafts. Calcium phosphate ceramics, biphasic calcium phosphate, hydroxyapatite, CPC, calcium sulfate, bioactive glass, and polymethylmethacrylate are other synthetic bone grafts [4].

Cancellous, cortical, and corticocancellous grafts are three types of autogenous bone grafts. Cancellous bone grafts consist predominantly of trabecular bone tissues. Cancellous bone has higher osteogenic and osteoinductive properties than cortical bone, and a larger number of progenitor cells and osteoblasts. This allows for rapid revascularization of the graft within two days of implantation, provided good bone-bone contact is established in the recipient site. A reduced number of cells undergo necrosis which enhances neoangiogenesis, which in turn results in early integration of the graft. Overall greater resorption due to lower density structure and lower mechanical support are disadvantages of cancellous bone grafts [4,5]. Cortical autografts have poor osteogenesis potential, and mainly have osteoconductive potential due to reduced osteoblast content. However, cortical bone grafts have much more mechanical strength, the resorption process is much longer and may be permanently substituted by new bone growth if adequate blood supply is available at the recipient site [6■].

Autogenous grafts can be harvested from both intraoral or extraoral structures [7]. Autogenous graft donor sites are listed in Table 1.

RECONSTRUCTION

Mandible

The site of the graft for mandibular defects is planned according to comorbidities such as soft tissue loss, intraoral exposure as well as mandibular defect size. Bone grafts provide a rapid, dependable reconstruction even in the contaminated areas. A fresh bone edge that is generally 5–10 mm distant from the bone edge must be prepared before grafting to allow for plating and rigid fixation of the graft. Maximal surface contact must be obtained between the graft and the recipient bone, and should ideally encompass the complete cross-section of the osteotomy [8■■].

For mandibular reconstruction of large (>60 mm in length) defects, generally the fibula osteofascial cutaneous flap is preferred, though

Table 1. Autogenous donor sites.

Intraoral donor sites	The Chin: Block grafts up to 40 mm can be harvested from the symphysis area of the mandible. These grafts have 65% cortical bone and 36% cancellous bone.
	Lateral Ramus: Corticocancellous block graft up to 35 mm can be harvested from the mandibular symphysis area intraorally. These grafts have 100% cortical bone composition.
	Maxillary Tuberosity: Provides a small amount of cancellous bone.
	Anterior Palate: Provides a small amount of corticocancellous bone.
	Other Parts: Maxilla buttress, Zygomatic process of maxilla, anterior nasal spine.
Extraoral donor sites	Iliac Crest: One of the most common site of bone grafts. It may be designed as vascularized or nonvascularized and cortical or cancellous in various lengths and forms. It has minor complications such as gait disturbances, hypesthesia, scar formation, or delayed wound healing in the donor. (Postoperative morbidity)
	Calvarial Graft: Because of mechanical features, slow resorption rate, and proximity to the maxillofacial region calvarial grafts are good candidates for maxillofacial graft reconstruction.
	Tibial Grafts: The anterior part of the tibial plateau can be used as a graft.
	Rib Graft: Osseous or osteochondral grafts can be harvested from the fifth to seventh ribs.

the scapula is also routinely employed. Fibula can provide a vascularized bone graft up to 26 cm. It has the advantages of good osseointegration quality and has skin coverage, especially for oral cavity reconstruction. Containing live osteocytes and osteoprogenitor cells is another advantage of vascularized cortical bone grafts. The peroneal artery pedicle is reliable and the length of the pedicle is sufficient. With good vascular anastomosis and stability, 90% of the osteocytes in the graft can be viable after transfer. The bone also tolerates segmental osteotomies for reshaping, and the large segment of bicortical bone provided by this flap has sufficient thickness for osseointegrated implants [8▪▪,9].

Maxillary arch

The fibula osteofascial cutaneous flap is also a good alternative for maxillary arch reconstruction because of the ability to reconstruct zygomaticomaxillary buttresses and a neomaxillary arch as well as the aforementioned advantages. Maxillary reconstruction with the fibula does have the disadvantage of requiring multiple osteotomies to accurately reconstruct the complex architecture of the midface.

Scapular flaps and deep circumflex iliac flaps can be used to reconstruct the maxillary arch. The deep circumflex iliac flap can be designed as an osseous, osteocutaneous, osteomyocutaneous flap. In contrast to fibula osteocutaneous flaps, the deep circumflex iliac flap has significant donor site morbidity. Violation of abdominal oblique muscles is the major disadvantage of this graft [10]. If there is a relatively small bone loss instead of segmental loss in the mandible and small defects as a premaxillary segment in the maxillary arch, vascularized radial bone flap may be used. The osteocutaneous radial forearm free flap is reliable with a long pedicle but has various donor site morbidities as the risk of radius fracture, impaired wrist function [11]. The bone stock is also miniscule, and may resorb to a degree that ultimately yields an inferior structural result.

The scapula osteocutaneous flap is harvested from the lateral border or the tip of the scapula with (or without) skin paddle can be used for maxillofacial defects. It has the lowest donor-site morbidity among these options. The lateral border of the scapula is harvested with additional vascular supply available to the scapular tip; the natural shape of the scapula lends itself well to reconstruct the maxillary arch and the hard palate [12▪].

Reconstruction of midfacial detects involving maxilla, orbits, palate, nasal and paranasal tissues require complex procedures. The reconstruction involves separating the oral and nasal cavities, suspending the orbit and separating it from paranasal tissues, as well as decreasing dead spaces from the resected maxillary sinus. Restoring vertical and horizontal facial buttresses are important for facial height, width, and proportions, and to maintain the structural integrity of the midface [13]. When there is a severe bone defect of the maxillary arch, including significant defects in the nasomaxillary and zygomaticomaxillary bony buttresses with facial tissue loss in the midface, a vascularized bone flap is required. The treatment strategy in this area is planned according to defect size and depth as well as residual dentition which provides support in the construction of a prosthesis.

Upper face

Upper face reconstruction may require frontal bone and nasoorbitoethmoid recontouring. The overlying soft tissues in the periorbital region, forehead and nasal dorsum are relatively thin; therefore, contours of bony tissues are extremely noticeable in these areas. However, the bones in these areas do not have as complex physiological functions and are subjected to lower mechanical stresses than the mandible and maxillary arch. Free bone grafts such as membranous cortical bone from the calvarium (with inner and outer table cranial bone) grafts have good survival rates, and do not yield any additional donor-site morbidity as graft harvesting can be done in the same surgical field via a bicoronal approach [1]. The facilitation of rigid fixation due to thickness helps harvesting and survival of cortical bone grafts. Also, these grafts are not vulnerable to upper aerodigestive tract contamination, provided the frontal sinus is addressed adequately. Rib grafts are another option in this field, but have lower-volume retention compared to cortical calvarial bone grafts, and harvesting site morbidity.

BONE GRAFT SUBSTITUTES

Bone graft substitutes consist of the combination of bone marrow aspirate or platelet-rich plasma and autologous bone. Many synthetic materials are used in place of autologous bone, and all are well described and safe when employed appropriately. Demineralized bone matrix and demineralized freeze-dried bone allograft are processed allograft bone. They contain collagen, proteins, and growth factors in various forms as powder, putty, chips, or gel form. Graft composites consist of other bone graft materials and growth factors. Bone morphometric proteins are proteins that promote and regulate bone processing and the healing period, and may be applied independently, or may come preapplied to various allograft or synthetic products [3▪▪].

COMPLICATIONS

All bone grafts should have viable tissues fully surrounding them to restore blood supply to the graft. Bone grafts must be fixated rigidly to healthy bone to prevent resorption, and must be separated from the contaminated areas of the nasal cavity and oral cavity or they will become infected. Avascular bone grafts may be used successfully in noncontaminated defects with the adequate soft tissue on all sides; if there is a question of contamination, a staged procedure should be planned or a vascularized flap should be employed.

RECENT RESEARCH

After the outbreak of COVID-19, the number of maxillofacial trauma patients tended to decrease [14▪]. Fractures of the maxillofacial region were considered ‘high risk’ for COVID transmission, and conservative management strategies were often employed. If the COVID status of the patient is unknown or positive during surgery, only surgical, anesthetic, and nursing staff team should be allowed into the operating room, and the surgical team must use proper protective equipment such as an FFP 3 mask with visors or goggles if powered air purifying respirator is not available [15▪▪].

Because of possible contamination of the maxillofacial region, interventions in this area should be started with a scalpel or ultrasonic scalpel to reduce surgical smoke. Also, mucosal incisions should be done in the same manner. If hemostasis is needed, bipolar electrocautery should be used at lower power settings to minimize smoke generation. Self-drilling screws should be used, but if drilling is required, battery-powered low-speed drills should be used with limited irrigation [16▪▪].

Several technological devices and developments have facilitated the bony reconstruction of maxillofacial defects. This facilitation can be divided into three parts as preoperative, operative, and postoperative periods. Preoperative 3D CT scans help to evaluate defects better. Besides measuring defects, many stimulations such as stereolithographic models can be used for surgical planning and prosthesis adjustment. 3D printing techniques have various methods such as stereolithography, selective laser printing, fused deposition modeling, and others. 3D scanning technology has widely been used in maxillofacial reconstruction, and newer 4D printing technology uses the same technology as 3D printing but the final 3D print can be manipulated into custom and patient-specific (and sometimes adjustable) forms using the same software [17▪]. 5D printing is a promising technology of additive manufacturing. 5D printing has 3 printing axes and 2 additional axes as the movement of the printing head and movement of the print bed at specific angles. The main advantage of this technology is to produce a curved layer to the construct with improved tensile strength [18▪].

Prefabricated custom-made polyetheretherketone (PEEK) implants are good options in case of unavailable or insufficient autologous tissue or in cases that require unacceptable donor-site morbidity. However, PEEK has the same risks as alloplastic materials like infection and extrusion [19]. Intraoperative CT is a powerful tool for evaluating bony anatomy and is becoming increasingly accessible. Intraoperative CT use has been described for orbital, pan-facial, and complex zygomaticomaxillary complex, LeFort, and naso-orbital-ethmoidal fractures [20].

Real-time navigational surgery is a technology that allows the surgeon to see instrument position in real-time on a reference CT or MRI scan. New imaging modalities have a precision of less than 2 mm. Because of the complexity of maxillofacial defects in some cases, this technology has been investigated for reconstructive operations on the orbit, paranasal sinuses, and zygomaticomaxillary complex, though it is well established in the rhinology and neurosurgical communities [21].

Bone tissue engineering includes stem cell transplantation, patient-specific bioimplants, and biomaterial engineering to produce a patient-specific desired material. 3D biomaterials are defined as biologic materials, biochemicals, and living cells placed on 3D structures. There is ongoing research related to stem cell-based treatments in maxillofacial defects and trauma, though none are yet commercially available [22▪▪]. A synthetic graft that has autologous bone graft properties is the ultimate synthetic bone graft goal. There are studies utilizing hydrogels that have both angiogenic and osteogenic properties that are ongoing. For this purpose, hydrogels are combined with growth factors and peptides [23]. In addition, there is ongoing research on antibiotic-eluting implants as well as stem cell/tissue-engineered therapies.

CONCLUSION

Reconstruction of severe maxillofacial traumas remains challenging, and technical and technological advancements continue to evolve and provide new frontiers for the reconstructive surgeon. Both imaging and navigational technologies can help the surgeon reconstructing these complex defects, but the facial reconstructive surgeon must possess a thorough understanding of the relevant anatomy and function. Advancement in 3D biomaterials shows promise in decreasing complications related to both alloplastic materials and donor site morbidity, and stem cell and various growth factor-based therapies are promising in maxillofacial defect reconstruction.

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Conflicts of interest

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REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
▪ of special interest
▪▪ of outstanding interest

1. Futran ND. Maxillofacial trauma reconstruction. Facial Plast Surg Clin N Am 2009; 17:239–251.
2. Moussa NT, Dym H. Maxillofacial bone grafting materials. Dent Clin N Am 2020; 64:473–490.
3. ▪▪ Gillman CE, Jayasuriya AC. FDA-approved bone grafts and bone graft substitute devices in bone regeneration. Mater Sci Eng C Mater Biol Appl 2021; 130:112466.
This study describes current FDA-approved bone grafts and bone graft substitute devices.
4. Sohn HS, Oh JK. Review of bone graft and bone substitutes with an emphasis on fracture surgeries. Biomater Res 2019; 23:9.
5. Roberts TT, Rosenbaum AJ. Bone grafts, bone substitutes and orthobiologics: the bridge between basic science and clinical advancements in fracture healing. Organogenesis 2012; 8:114–124.
6. ▪ Chun YS, Lee DH, Won TG, *et al.* Current modalities for fracture healing enhancement. Tissue Eng Regener Med 2022; 19:11–17.
This study describes the healing period of bone fractures and modalities enhancing this process. This article discuss the importance of cellular inflammation and transformation process for different grafting techniques.
7. Khojasteh A, Esmaeelinejad M, Aghdashi F. Regenerative techniques in oral and maxillofacial bone grafting. In: Kalantar MH. A textbook of advanced oral and maxillofacial surgery volume 2 [Internet]. London: Intechopen; 2015. 862 p. Available from: https://www.intechopen.com/books/4553 doi: 10.5772/58687.
8. ▪▪ Zeiderman MR, Pu LLQ. Contemporary reconstruction after complex facial trauma. Burns Trauma 2020; 8:tkaa003.
This article describes the current management of complex facial trauma.
9. Shokri T, Stahl LE, Kanekar SG, *et al.* Osseous changes over time in free fibular flap reconstruction. Laryngoscope 2019; 129:1113–1116.
10. Likhterov I, Roche AM, Urken ML. Contemporary osseous reconstruction of the mandible and maxilla. Oral Maxillofac Surg Clin N Am 2019; 31:101–116.
11. Kearns M, Ermogenous P, Myers S, *et al.* Osteocutaneous flaps for head and neck reconstruction: a focused evaluation of donor site morbidity and patients reported outcome measures in different reconstruction options. Arch Plast Surg 2018; 45:495–503.
12. ▪ Harada H, Shimamato H, Oikawa Y, *et al.* Mandibular reconstruction with scapular systems: a single-center case series involving 208 flaps. Plast Reconstruct Surg 2021; 148:625–634.
This article describes the types and harvesting techniques of scapular grafts for mandibular grafting.
13. Badhey AK, Khan MN. Palatomaxillary reconstruction: fibula or scapula. Semin Plast Surg 2020; 34:86–91.
14. ▪ Pagotto LEC, Santos TS, Pastore GP. Impact of COVID-19 on maxillofacial surgery practice: a systematic review. Braz J Otorhinolaryngol 2021; S1808-8694:00173–177.
This article discusses the impact of the COVID-19 pandemic on maxillofacial trauma and surgery.
15. ▪▪ Ghai S. Facial trauma management during the COVID-19 era: a primer for surgeons. Curr Med Res Pract 2020; 10:169–173.
This study describes the management of maxillofacial trauma in patients with positive COVID status.
16. ▪▪ Grant M, Buchbinder D, Dodson TB, *et al.* AO CMF International task force recommendations on best practices for maxillofacial procedures during COVID-19 pandemic. Craniomaxillofac Trauma Reconstr 2020; 13:151–156.
This international task force describes the transmission ways of virüs and protection strategies during surgery.
17. ▪ Habib AAI, Sheikh NA. 3D printing review in numerous applications for dentistry. J Inst Eng India Ser C 2022.
This article reviews the use of 3D printing technology in dentistry.
18. ▪ Haleem A, Javaid M. 5D printing and its expected applications in Orthopaedics. J Clin Orthop Trauma 2019; 10:809–810.
This study describes the future aspects of 5D printing technology in bone fracture management.
19. Sharma N, Aghlmandi S, Cao S, *et al.* Quality characteristics and clinical relevance of in-house 3D-Printed customized polyetheretherketone (PEEK) implants for craniofacial reconstruction. J Clin Med 2020; 9:2818.
20. Cuddy K, Khatib B, Bell RB, *et al.* Use of intraoperative computed tomography in craniomaxillofacial trauma surgery. J Oral Maxillofac Surg 2018; 76:1016–1025.
21. Aman HH, Alenezi A, Ducic Y, *et al.* Secondary reconstruction of the complex zygomaticomaxillary complex. Semin Plast Surg 2020; 34:254–259.
22. ▪▪ Pourlak T, Pourlak T, Ghodrati M, *et al.* Usage of stem cells in oral and maxillofacial region. J Stomatol Oral Maxillofac Surg 2021; 122:441–452.
This study describes the usage of stem cell-based treatments in maxillofacial defects.
23. Qiao Y, Liu X, Zhou X, *et al.* Gelatin templated polypeptide co-cross-linked hydrogel for bone regeneration. Adv Healthc Mater 2020; 9:e1901239.