Maxillofacial Bony Considerations in Facial Transplantation

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Abstract

Alloplastic facial transplantation has become a new rung on the proverbial reconstructive ladder for severe facial wounds in the past couple of decades. Since the first transfer including bony components in 2006, numerous facial allotransplantations across many countries have been successfully performed, many incorporating multiple bony elements of the face. There are many unique considerations to facial transplantation of bone, however, beyond the considerations of simple soft tissue transfer. Herein, we review the current literature and considerations specific to bony facial transplantation focusing on the pertinent surgical anatomy, preoperative planning needs, intraoperative harvest and inset considerations, and postoperative protocols.

Keywords

► facial transplantation
► graft
► tissue reconstruction

Defect Classification

There are multiple patterns of facial injuries among patients who are suitable candidates for facial transplantation. Every patient and every defect will be unique, and classification can aid in communication among physicians and help with preoperative planning. Multiple classification systems have been proposed in the past, however, to describe specific defects of the midface, though, often to gear toward oncological defects and free tissue reconstruction.2–4 First, Okay and colleagues separated palatomaxillary defects into three categories.2 In their system, type I defects involved only the hard palate but not the tooth-bearing maxilla, type II defects involved the tooth-bearing maxilla and less than half the total area of the hard palate, and type III defects involved the tooth-bearing maxilla and more than half the total area of the hard palate. Cordeiro and Chen, by contrast, related each half of the maxilla to a six-walled box and separated defects based on which wall, and how many, the defect involved.3 Last, Brown and colleagues applied a vertical and horizontal class, each I to IV, to defects based on their extent.4 The Brown classification is the most-commonly used system today, but all systems are applicable. While various classifications are useful in comparing unilateral defects across many patients, they do not guide the reconstructive plan, especially for facial transplantation.

Numerous classification systems also exist describing mandibular defects, but again, they are more applicable to oncological defects and free tissue transfer. In the setting of facial transplantation, the mandible is often harvested and transplanted angle to angle. Mohan and colleagues devised a classification system specific to facial transplant, with three categories for soft-tissue defects and three for bony defects...
which loosely follow LeFort I to III. Most often for full facial transplantation, bony defects are expanded to mimic a LeFort II or III (► Fig. 1). In the case of extensive bony destruction, however, the transferred bone can include the mandible (angle-angle), a LeFort III midface (zygoma-zygoma), and the superior orbital rim, frontal bone, and anterior and posterior tables of the frontal sinus.

Preoperative Considerations
Anatomy and Blood Supply
Adequate blood supply and nutritional input is necessary for tissue survival. Various cadaver studies have been performed in which latex was injected into the external carotid network of arteries to determine which vessels could sufficiently, independently, supply facial structures, and they have identified that the primary blood supply to the palate is via the internal maxillary artery, though there exists an extensive anastomotic network between the facial and maxillary artery systems. Previous composite facial transplants including only facial artery anastomosis have demonstrated that the palate can survive without anastomosis of the internal maxillary artery. However, if the transplant includes the muscles of mastication and the buccal fat pad, i.e., areas supplied primarily by terminal branches of the internal maxillary artery, then it is prudent for anastomosis to take place at the takeoff of the external carotid artery (ECA), so as to maximize arterial supply. Also, while it is possible for a composite midface transplant including bony components to survive off a single facial artery, the blood supply is more robust, the pedicle length longer, and the anastomotic vessel caliber greater from bilateral anastomosis at the takeoff of the ECA. Cadaver studies evaluating the transplant of multiple bony components, specifically a LeFort III transplant with overlying soft tissues, have been performed and suggest that the most at-risk areas due to marginal blood
supply include the posterior sphenoid and ethmoid bones plus the zygomatic arches. The relevant vascular supply for facial transplantation is depicted in Fig. 1.

Many patients would have undergone multiple facial surgeries including multiple free tissue transfers to the face before undergoing facial transplantation. As such, surgeons should be aware of potentially compromised native vasculature leading up to facial transplantation; damage to the branches of the ECA and its branches from previous surgery, trauma, or due to stenosis from atherosclerosis can compromise transplant viability. Thus, it is important to evaluate the available vasculature with a computed tomography arteriogram and digital subtraction angiography for vascular mapping prior to transplantation. This visual map of the patient's vessels can guide planning for arterial and venous anastomosis intraoperatively.

Imaging and Planning
A comprehensive understanding of the donor and recipient skeletal dimensions is important to preparing for and achieving a successful skeletal fit. The typical fixation points include the zygomatic arches or bodies, nasofrontal suture line, and the mandibular osteotomy sites. Patients can undergo bimaxillary transplant including parts of both the donor maxilla and mandible, or the patient can undergo a single jaw transfer. If only a single jaw is to be transferred, however, then the dimensions of the recipient and donor must be closely examined and compared. A patient receiving a near-total transplant in 2008 was noted postoperatively to have a class II skeletal profile with retrognathia and significant overjet as a result of a size mismatch between the donor maxilla and recipient mandible. Thus, if a bimaxillary transplantation is not part of the surgical plan, then orthognathic planning should be incorporated preoperatively to predict and manage the donor–recipient occlusal relationships.

An option to help avoid occlusal issues is to transplant both the maxilla and mandible, a bimaxillary transfer, making osteotomies in the recipient mandible, typically angle to angle, with subsequent plate reconstruction and connection to the new graft. Many facial transplant recipients have an intact temporomandibular joint (TMJ), which is why, historically, the joint has not been included in the graft. However, many patients have also developed persistent issues with trismus, arthralgia, scarring, and fibrosis of the TMJ over time, perhaps due to alterations in bony anatomy during the transplant process but also perhaps as a long-term result of their original trauma. Thus techniques have been developed for complete transplantation of the mandible that includes the condyles and TMJs as an alternative to making osteotomies in the mandible, in hopes that TMJ complications may be alleviated by the incorporation of TMJ into the transplanted components. One such transplantation has been performed of a unilateral jaw, angle-to-opposite condyle, with subsequent suture suspension of the condyle to the recipient’s glenoid fossa. In that isolated case, however, the patient regained 1 cm of mandibular excursion. Research is ongoing, and studies are currently evaluating different options for managing the TMJ, from transfer of the condyle and suture suspension to transfer of the entire joint capsule and part of the temporal bone.

Often, precontoured custom plates are not necessary, and short plates spanning each osteotomy site can be efficiently and effectively fashioned intraoperatively. That said, preoperative planning is an important part of successful facial transplantation, and there are numerous technologies available today that can improve the chances for a successful operation and successful long-term outcome.

Cephalometry
At a minimum, photos of donors and recipients should be taken and anthropometric proportions analyzed. CT scans with fine cuts are preferable, however, and allow more precise and efficient skeletal comparisons and virtual surgical planning (VSP). Objective cephalometric comparisons are important for long-term operative success. Specifically, the total facial height and width is important to note. As per the vertical facial relationships, distances among the trichion, glabella, nasion, subnasale, and menton should be measured, as should the mental canthal width, lateral canthal width, zygomatic width, and alar base distance for comparing horizontal facial relationships. While cephalometry is useful, it does have its limitations: cephalometry can only describe two dimensional (2D) movements. It is not adequate for ensuring correct alignment in osteomyocutaneous transplantation which relies on the three-dimensional (3D) rotational movements described by the pitch, roll, yaw, and translation.

Orthognathic Planning
In addition to cephalometric evaluation of facial proportions, a comparison of donor and recipient occlusion is also important for functional and aesthetic success. A patient who underwent near-total facial transplantation in 2008, for example, was subsequently noted to have an angle class II profile; there was significant retrognathism and significant maxillary overjet secondary to the donor’s longer maxilla relative to the recipient. This case highlights the need for orthognathic planning before transplantation. Gordon and colleagues have proposed the use of a “hybrid occlusion” model in which preoperative casts are made of the donor maxilla and recipient mandible. The casts can be used for simulated articulation between the maxilla and mandible and anticipation of bony discrepancies. Preoperative casts can be very time consuming, however, and may be hindered by the unexpected presence of dental caries, soft tissue bulk, and difficulty with intraoperative osteotomies.

Virtual Surgical Planning
Preoperative CT imaging of donor and recipient bony structures can allow for virtual manipulation, occlusal and other bony comparisons, and planning of osteotomies to maximize the skeletal match. Jacobs et al described a protocol for VSP to aid in appropriate bony match between a donor and recipient. Three-dimensional reconstructions of facial skeletons can be made, and the donor maxillary arch can be superimposed over the recipient mandibular arch. Following,
adjustments in the placement of osteotomies can be planned and cutting guides 3D printed to optimize the resultant occlusion and bony fit. The authors emphasized the importance of the interzygomatic and intermolar distances being within 5 mm between donors and recipients to achieve a suitable skeletal match.

VSP has been tested in cadaveric studies and found to aid in adequate bony positioning across multiple axes. In a study by Dorafshar and colleagues, five cadaveric heads underwent LeFort III facial harvest with bilateral sagittal split osteotomies (BSSO) to the mandible and subsequent transfer. VSP was employed to plan the donor and recipient osteotomies and compare the cranial bases of the two heads. Following, intraoperative navigation and cutting guides aided in harvest and recipient site preparation. Post-transplant positioning was later evaluated with CT scans and was found to be satisfactory in all axes except lateral translation. The authors emphasized the need for surgeon discretion during intraoperative positioning to maximize the bony fit. A separate cadaveric study also noted that faster dissection of both donor and recipient tissues was possible with VSP and 3D-printed cutting guides and that the virtually-planned hybrid skeletons were similar to the actual operative results. VSP and custom cutting guides can be particularly important for guiding nasofrontal osteotomies which, if performed incorrectly, can cause disruption of the medial canthal tendon, disruption of the skull base, or damage to the donor lacrimal system. VSP and 3D custom cutting guides were employed in the first face transplant in Helsinki, involving transplant of a Le Fort II maxilla and central mandible with teeth. In this case, the patient demonstrated appropriate occlusion postoperatively but did note some TMJ arthralgia due to a mismatch of the donor mandibular width with the recipient’s facial width.

Stereolithographic Models
In addition to VSP, the creation of stereolithographic models can also be useful in the preoperative period. Models created from CT scans can be used during mock cadaver dissections leading up to facial transplantation to further illuminate the placement of osteotomies and intraoperative positioning. Stereolithographic models can be particularly useful in cases in which the maxilla and mandible are transplanted, as the lack of recipient bony landmarks is challenging. Further, models can be sterilized and used intraoperatively. Cadaveric studies have demonstrated utility with checking a donor graft by fitting it in a model prior to ligating its vascular pedicles. In this way, bony discrepancies can be identified and corrected and hardware can be customized for inset before ischemia time is entered.

Advantages and Disadvantages
VSP, use of cutting guides, and stereolithographic models can lead to faster dissection, minimal required alterations to the donor graft and recipient site after the initial dissection, and improved functional and aesthetic outcomes. Appropriately-placed osteotomies can enhance the bony match between the donor and recipient, but it can also avoid disruption of the medial canthal tendon, damage to the lacrimal system, and disruption of the skull base. Technology-enhanced surgical planning has been used in multiple facial transplants over the past decade. In 2011, for example, the first successful transplant was performed in Belgium incorporating 3D modeling as well as digital planning and creation of cutting guides. Also, VSP and 3D printed cutting guides were used in the first face transplant in Helsinki. In this case, a LeFort II maxilla, central mandible, and teeth were transplanted, and appropriate dental occlusion was confirmed postoperatively.

Advantages of preoperative planning must be weighed against their shortcomings, however. Cephalometry is useful for 2D comparisons but often does not adequately account for 3D alignment including rotational movement that can occur in facial transplantation. Creation of preoperative impressions, for example, requires immediate on-call availability of a dental specialist. Also, facial transplantation is often highly time-sensitive, and there may not be sufficient time for preferred preoperative planning or imaging. Further, while preoperative models and casts theoretically predict the bony fit intraoperatively, they fail to account for the effects of soft-tissue components, dental caries, and success of osteotomies.

Intraoperative Considerations

Intraoperative Navigation and Imaging
The computer-assisted planning and execution (CAPE) system advocates intraoperative navigation facilitating trackable cutting guides for on-table, real-time feedback; it combines VSP and premade patient-specific cutting guides with intraoperative navigation to optimize patient results. The CAPE system uses reference guides that are mounted to the donor and recipient skulls during surgery and confirms that the premade cutting guides are appropriately placed prior to performing osteotomies. Upon transfer of the donor fragment to the recipient, the system then provides feedback, both quantitative and qualitative information, about the bony fit, including such comparisons as new orbit volumes, airway patency, and facial projection. After confirming these parameters, the surgeon can then fixate the donor flap with more confidence of the positioning.

Intraoperative navigation on its own has also been demonstrated facilitating more accurate osteotomies in terms of distance, roll, and pitch compared with unnavigated osteotomies. Intraoperative CT scanning has been employed in the setting of trauma reconstructions, but it has not played a significant role in facial allotransplantation to date.

Overall, a combination of preoperative and intraoperative planning and guidance methods is likely to optimize patient results. Ramly et al proposed using a streamlined computerized surgical planning protocol which incorporates all of the abovementioned tools utilized for the craniofacial planning and execution of osteocutaneous allotransplantation. In their protocol, a preoperative 3D CT is obtained for the recipient and donor. Of note, preoperative intermaxillary fixation screws are placed in the donor to aid with intraoperative surgical navigation. Scans are uploaded to the
software system to allow for the donor skeleton to be superimposed onto the recipient skeleton. Osteotomies are then planned, and cutting guides are made. The surgery is then executed with navigated osteotomies of the donor. The donor maxilla and mandible are placed in occlusal splints and intermaxillary fixation. The donor maxilla and mandible are inset into the stereolithographic model for tailoring while recipient osteotomies are performed also using cutting guides. The allograft is then inset and fixed. Finally, an intraoperative CT scan may or may not be utilized to help confirm appropriate positioning of the skeletal segments.29

Postoperative Considerations and Complications

Patients are monitored in the hospital for a week or more after surgery, often with similar monitoring protocols after other kinds of free tissue transfer.33 The flap itself is monitored, immunosuppressive medications are taken, pain is controlled, and mobility is gradually increased.

Acutely, transplantations are at risk of vascular compromise which could then lead to partial or complete flap failure. Given the relatively low number of facial transplants performed to date, the true risk of vascular complications is unknown. Drawing from literature surrounding free tissue transfer in the head and neck, however, surgeons can assume that there is a risk of vascular compromise, it is greatest in the first 72 hours after tissue transfer, it can occur up to several weeks after surgery, however, and it is most common due to venous obstruction.33 Often, the bony components of the transplanted tissue cannot be monitored directly; the overlying soft tissue can be examined and used as a surrogate marker for bony health. Postoperative CT scans can also be obtained and 3D reconstructions or models made to begin assessing the bony result.

The best way to assess the bony result is in the long-term, however, both through examination and patient reports of function. Malocclusion is common after facial transplantation, especially when a bimaxillary transplantation was not performed, and this can lead to suboptimal mastication, palatal defects, and a dentofacial mismatch.34 Even in cases in which patient-specific 3D models and cutting guides are utilized, patients have still been observed to have malocclusion.34 In some cases the malocclusion is cosmetic, such as when there is maxillary overjet, and it does not impair function.34 Still, a multidisciplinary approach from the start with early involvement of the oral surgery and dental teams can minimize postoperative malocclusion incidence and its sequelae, both cosmetic and functional.35 Conservative orthodontic treatment may help some cases of malocclusion. Others, however, may require revision surgery with bony osteotomies to correct the bite.34,37 In the case of edentulous patients, dental rehabilitation may be pursued via dental implants.38 Similar to implants in edentulous nontransplant patients, dental implant posts can be safely placed and have been demonstrated to effectively osseointegrate even in transplant patients taking immunosuppressive medications.38

Another complication that can develop is a palatal fistula, which can occur due to multiple factors. As described above, the palate can have a tenuous blood supply, so tissue loss could occur secondary to inadequate arterial flow. Also, differences in the midface height between the donor and recipient can create tension contributing to poor healing.26,34,39,40

Next, trismus and TMJ arthralgia can occur secondary to a mismatch in facial width with transfer of a mandible that is wider than the recipient’s face.26 Also, just as a unimaxillary transplant is more likely to lead to malocclusion, it can also have poor articulation between the donor and recipient maxilla and mandible, often leading to restriction in jaw opening and joint arthralgia. In some cases, symptoms can be improved with conservative measures including a modified diet, jaw physical therapy, and time. Others may require operative revision.

Summary and Conclusion

Facial allotransplantation offers a life-changing therapy for patients with significant facial injury that cannot otherwise be acceptably repaired. The mandible, maxilla, zygoma, and other bony structures in the face can be safely transplanted to enhance the overall reconstruction. Careful and thorough preoperative planning with a multidisciplinary team and often aided with patient-specific images, models, and cutting guides can improve the intraoperative efficiency and accuracy and the overall aesthetic and functional patient outcome. On the horizon for preoperative planning and surgical execution in facial transplantation is holographic VSP and 3D biomodels.41 As more and more facial transplants are performed the medical community as a whole is able to learn more about the procedure and its outcomes.

Note
This work does not necessarily represent the views of the U.S. Army or Department of Defense.

Conflict of Interest
None declared.

References

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