Osteocutaneous Maxillofacial Allotransplantation: Lessons Learned from a Novel Cadaver Study Applying Orthognathic Principles and Practice

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Background: Osteocutaneous maxillofacial allotransplantation is an encouraging technique for reconstruction of complex midfacial injuries (i.e., Gordon type III composite tissue allotransplantation). Although clinical results have been promising, there are no published guidelines, to date, on how to establish a functional occlusion and class I skeletal relation between the donor maxilla and recipient mandible. The purpose of this study was to use orthognathic principles and practice to improve occlusal and facial skeletal outcomes in osteocutaneous maxillofacial allotransplantation.

Methods: Three Le Fort III–based maxillofacial allotransplantations were performed, using six fresh cadavers. Each recipient was prepared bluntly simulating a massive, bilateral orbitozygomatic maxillofacial defect. The first transplant was completed according to published protocol. The second was planned using dental cast models, cephalometric analyses, model surgery, and occlusal splint fabrication. The third involved an edentulous scenario, with the donor alloflap fixated to the recipient's mandible using a mimic Gunning splint to establish the vertical dimension of occlusion.

Results: All three operations resulted in facial aesthetics comparable to those seen with autologous methods. Operative times ranged from 3.5 to 5.3 hours. The first allotransplant resulted in a class II malocclusion (overjet, 5 mm). The second recipient, with a preexisting class II skeleton, displayed a small anterior open bite of –1.7 mm, 1 mm of overjet, and a class I skeletal relationship (A-point–nasion–B-point angle, 2.3 degrees) following transplantation. The final transplant, consisting of an edentulous alloflap to an edentulous recipient, demonstrated an orthognathic profile.

Conclusion: Use of orthognathic principles and practice in osteocutaneous maxillofacial allotransplantation resulted in improved occlusion, skeletal projection, and facial harmony relative to standard technique. (*Plast. Reconstr. Surg.* 128: 465e, 2011.)

Osteocutaneous maxillofacial allotransplantation is a promising reconstructive technique for complex midfacial injuries not amenable to autologous reconstruction (i.e., Gordon type III composite tissue allotransplantation).[1,2] In light of recent success, many institutions are now developing maxillofacial transplant programs.[3] Although preliminary clinical results have been encouraging, there have been no published guidelines, to date, on how to establish a functional occlusion and class I skeletal relation between the donor maxilla and recipient mandible.[4] In fact, all reports of successful osteocutaneous maxillofacial allotransplantation thus far suggest some degree of malocclusion associated with suboptimal facial-skeletal harmony.[5–7]

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Received for publication January 20, 2011; accepted April 25, 2011.

DOI: 10.1097/PRS.0b013e31822b6949

Disclosure: *The authors have no financial interest to declare in relation to the content of this article. No outside funding was received.*

With this in mind, we chose to evaluate the potential benefits of applying orthognathic principles for the purpose of improving outcomes related to occlusion, function (i.e., mastication), *and* aesthetic facial harmony. This entailed (1) investigating the critical steps and time points required for preoperative planning including orthognathic model surgery and cephalometric analysis in the context of osteocutaneous maxillofacial allotransplantation; (2) detailing high-yield maneuvers for combinations of various dentate/edentulous donor/recipient scenarios; (3) evaluating orthognathic methods in relation to predicting and optimizing posttransplant occlusion between the donor maxilla and recipient mandible (or vice versa for face/mandible allotransplantation); (4) observing facial harmony improvement relative to skeletal arrangement; and (5) gathering insight as to the potential value of functional, occlusive rehabilitation following transplantation. This study is, to our knowledge, the first of its kind to explore the additional value of applying orthognathic principles and practice to osteocutaneous maxillofacial allotransplantation.

MATERIALS AND METHODS

Study Design and Cadaver Procurement

This was an experimental study, using six fresh cadaveric heads, each of which was obtained for the purpose of comparing three separate mock face transplant techniques. Each alloflap harvest was based on a consistent Le Fort III alloflap design. However, varying approaches were used for preoperative planning and alloflap inset.[1] Two cadavers were female and four were male, and four were dentate and two were edentulous. All cadavers were Caucasian. Gender-specific donor/recipient designation was random and based on the order of donation. Each cadaver was donated for the sole purpose of medical research and all specimens were obtained, dissected, and managed in accordance with the institutional review board guidelines for Harvard Medical School and the Massachusetts General Hospital.

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Recipient Preparation

Massive, central orbitozygomatic maxillofacial defects were created bilaterally in each of the recipient heads (n = 3) to simulate a clinical scenario where autologous techniques would be inadequate for reconstruction (Fig. 1, *left* and *above, right*).[8] This was done by removing the entire maxilla; zygomatic complexes; orbital floors; nasal bones; soft and hard palate; and the entire overlying soft-tissue component including the nose, upper lip, and bilateral cheeks with parotid glands. For the purpose of investigation, all massive defects were created in blunt fashion using a mallet and rongeur, to mimic an irregularly shaped defect (as opposed to an ideal Le Fort III-shaped defect).[9]

Donor Alloflap Harvest

For the donor heads (n = 3) , Le Fort III–based alloflaps were harvested using handheld osteotomes, a Lindeman side-cutting burr, and a fine vibrating reciprocating saw (Stryker, Kalamazoo, Mich.). (**See Video, Supplemental Digital Content 1,** which demonstrates key portions of (1) raising an osteocutaneous maxillofacial alloflap, (2) inset of a Le Fort III–based alloflap with rigid fixation to an edentulous recipient, and (3) novel modifications consistent with orthognathic principles and practice, ***http://links.lww.com/PRS/A391.***) All donor globes (n = 6) were protected during infraorbital dissections using a vibrating saw ultrasonic aspirator with Sonopet and Nakagawa Serrated Knife (Stryker) that strictly cuts bone (and not soft tissue), so that corneal donation following solid organ procurement would remain possible.[10] All three osteocutaneous alloflaps were harvested using a modified Le Fort III–based design (a craniofacial disjunction, with preservation of the pterygoid plates) incorporating all of the midfacial skeletal and soft-tissue components necessary for adequate reconstruction (Fig. 1, *below, right*).[11,12]

Transplantation Protocols

Three separate allotransplantations were performed. The first maxillofacial transplant used a dentate donor to reconstruct a dentate recipient using the standard Le Fort III technique previously published by the Cleveland team.[1] Of note, no additional orthognathic applications were used (maxillofacial transplant-1) (Fig. 2).

The second maxillofacial transplant (MFT-2) included a dentate donor and dentate recipient with orthognathic planning and execution for the

Fig. 1. Frontal (*left*) and lateral (*above, right*) photographs of cadaveric recipient with bilateral, extensive orbitozygomatic maxillary defects created in a blunt fashion and Le Fort III–based alloflap necessary for alloreconstruction (*below, right*). Irregular contours are intentionally placed during preparation, to avoid making an ideal Le Fort III defect.

Video. Supplemental Digital Content 1, which demonstrates key portions of (1) raising an osteocutaneous maxillofacial alloflap, (2) inset of a Le Fort III–based alloflap with rigid fixation to an edentulous recipient, and (3) novel modifications consistent with orthognathic principles and practice, is available at ***http://links.lww.com/PRS/A391***.

purpose of investigational comparison with maxillofacial transplant-1. Alginate impressions were obtained to evaluate skeletal and soft-tissue alterations (Fig. 3). The donor maxilla and recipient mandible stone models were placed on a Galetti articulator. Selective occlusal grinding was instituted to remove guiding and balancing interference to establish an ideal hybrid occlusion, which was defined as "the maximal intercuspal position accompanying bilateral posterior contacts with overbite and overjet of 0-2 mm" (Fig. 4). A "hybrid" occlusal splint made of acrylic (so named because of the hybrid occlusion resulting from a native mandible and transplanted maxilla) was then fabricated using a combination of donor maxilla and recipient mandible occlusal planes (Fig. 5). Intraoperatively, the splint was used to appose the jaws, maxillomandibular fixation was applied, and five-point rigid fixation was used to stabilize the upper facial segments.

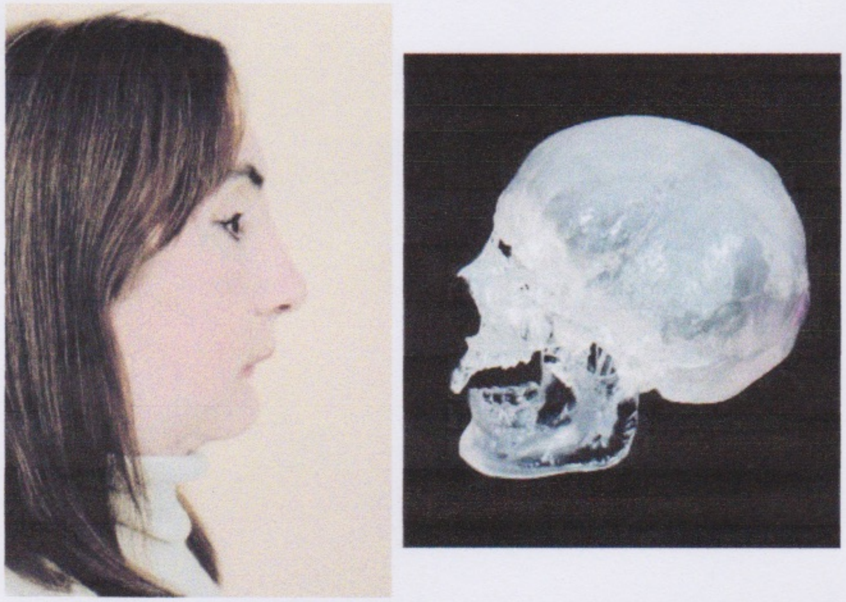

Fig. 2. Profile photograph (*left*) and stereolithographic model (*right*) of the world's first face and maxilla transplant displaying class II malocclusion with approximately 4- to 5-mm overjet. The recipient also displays a class II skeletal profile consistent with our study's maxillofacial transplant-1 result. (Reproduced from Siemionow M, Papay F, Alam D, et al. Near-total human face transplantation for a severely disfigured patient in the USA. *Lancet* 2009;374:203–209. Used with permission.)

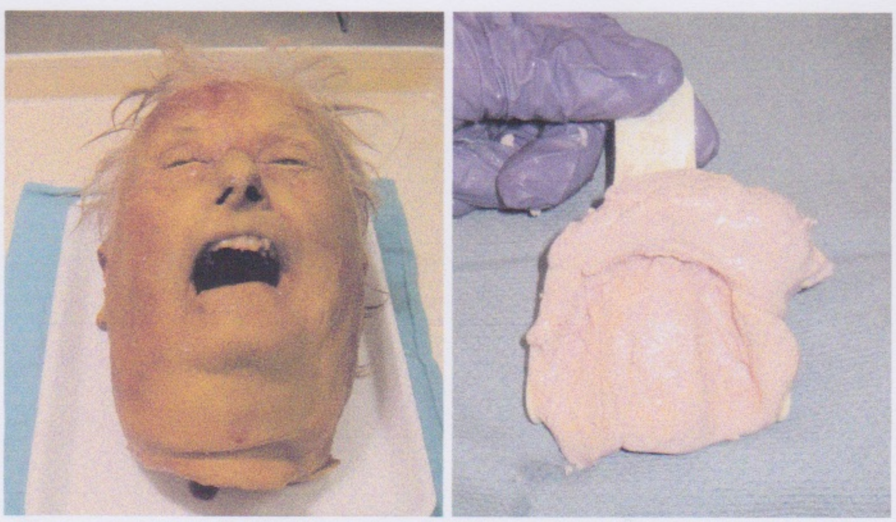

Fig. 3. Photograph of donor with corresponding alginate impression. Donor and recipient impressions are both used to create dental cast stone models for preoperative planning and for hybrid splint fabrication.

For preoperative planning and postoperative assessment of maxillofacial transplant-2 procedures, three-dimensional computed tomographic reconstructions were generated from two-dimensional imaging data (Fig. 6). Cadaveric heads were scanned preoperatively and postoperatively using a 64-slice helical computed tomography scanner (GE Lightspeed; General Electric Corp., Waukesha,

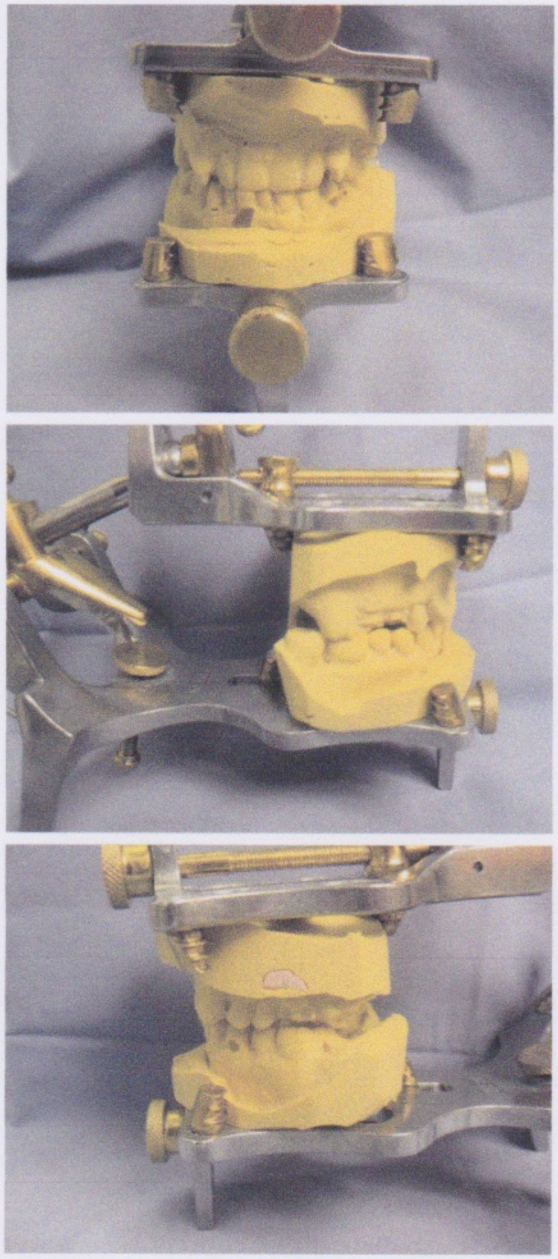

Fig. 4. Donor maxilla and recipient mandible dental cast models mounted on a Galetti articulator, demonstrating adequate occlusion. Selective occlusal grinding was then undertaken to establish an adequate occlusion which, at a minimum, was defined as the presence of bilateral posterior contacts with overbite and overjet of 0 to 2 mm.

Wis.). Scout films from the computed tomographic scan protocols were imported into an orthognathic treatment planning program (Dolphin v.9.0; Dolphin Imaging and Management Solutions, Chatsworth, Calif.). Cephalometric tracings were completed for the donor and recipient before (preextirpation and postextirpation) and after transplantation to evaluate skeletal and occlusal relation.

The third transplant (maxillofacial transplant-3) was performed in an edentulous scenario for which we used maxillomandibular intermaxillary fixation screws. An impression tray was used for vertical spacing, which in essence mimicked the effect of a Gunning splint. This was necessary to establish the proper vertical dimension of occlusion and to assist in the immediate stabilization of the upper facial segments, thereby allowing for potential future prosthetic rehabilitation following transplantation (i.e., denture fabrication). For all three mock transplants, maxillomandibular fixation was accomplished by using Erich arch bars for the dentate donor/recipient and intermaxillary fixation screws for the edentulous donor/recipient. Rigid fixation was applied at the bilateral zygomaticofrontal, nasofrontal, and bilateral temporozygomatic connections using 2.0-mm titanium plates (Stryker) for all three scenarios (**see Video, Supplemental Digital Content 1, *http://links.lww.com/PRS/A391***).[13]

For the dentate transplantations (maxillofacial transplant-1 and maxillofacial transplant-2), adequate posttransplant occlusion was defined as the presence of bilateral posterior contacts with 0 to 2 mm of overbite and overjet, rather than the classic "first molar mesiobuccal cusp-to-mesial groove" relation described by Angle in 1899.[14] The important distinction here is that, unlike Angle's classification, which describes one's native mandible-to-maxilla relation based on first molar intercuspation, osteocutaneous maxillofacial allotransplantation requires a new classification of occlusion, because the most important relation in osteocutaneous maxillofacial allotransplantation is the "donor maxilla molar-to-recipient mandible molar" relation (or vice versa in the setting of mandible allotransplantation). In addition, the donor's facial anthropometrics are inherently different from the recipient's.[15]

RESULTS

All three operations were successful at restoring facial aesthetics comparable with those seen with autologous methods.[16] Operative times ranged from 3.5 to 5.3 hours. The addition of orthognathic practice, as described here, necessitated significant labor and personnel, resulting in an additional 2 hours of preparation time for the edentulous scenario (1.5 hours for cephalometric analyses and 0.5 hour for maxillomandibular fixation/screw in-

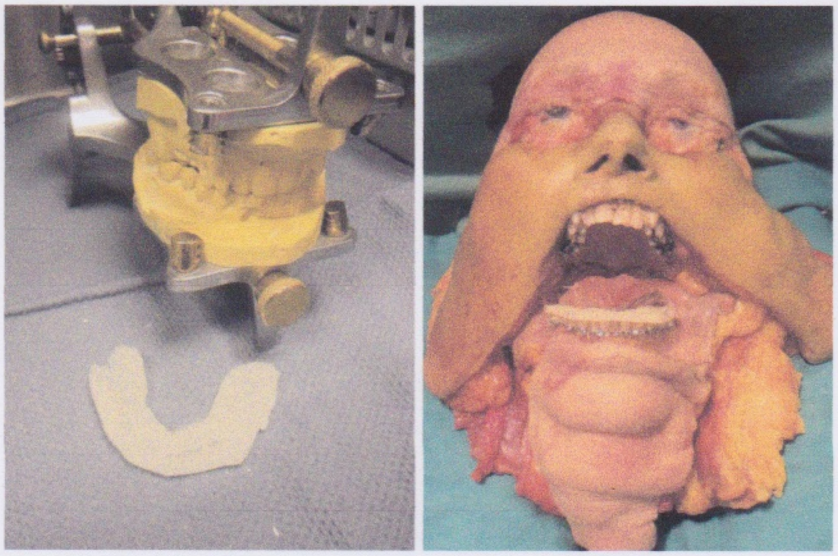

Fig. 5. Photographs of the hybrid acrylic splint used for maxillofacial transplant-2 procedures (*left*) and in situ during rigid fixation (*right*).

sertion) and 4.5 hours for the dentate scenario (1.5 hours for model generation, 1.5 hours for model surgery/splint fabrication, and 1.5 hours for cephalometric analyses). The first mock transplant resulted in similar class II malocclusion with positive overjet (4 to 5 mm), consistent with the world's first recipient (Fig. 2).[5]

For the second transplant (Figs. 6 through 8), preoperative cephalometric planning demonstrated that the donor cadaver head had a class III skeletal relationship before transplantation (sella-nasion–A-point angle, 84 degrees; sella-nasion–B-point angle, 85.5 degrees; A-point–nasion–B-point angle, –1.5 degrees), with –2 mm of overjet, 1.8 mm of overbite, a maxillary length (condylion to anterior nasal spine) of 45.8 mm, a mandibular length (condylion to gnathion) of 105.2 mm, and a posterior vertical maxillary height (sella to posterior nasal spine distance) of 45 mm. The recipient head, before bilateral orbitozygomatic maxillofacial defect creation, had a preexisting class II skeletal relationship with bimaxillary retrognathism (sella-nasion–A-point angle, 77.0 degrees; sella-nasion–A-point angle, 72.3 degrees; A-point–nasion–B-point angle, 4.7 degrees), with 6 mm of overjet, −0.5 mm of overbite, a maxillary length of 55.4 mm, a mandibular length of 116.6 mm, and a posterior vertical maxillary length of 41 mm.

Dental cast model analysis of the second transplant demonstrated that an ideal hybrid occlusion (bilateral posterior contacts with overbite/overjet of 0 to 2 mm) could be obtained after selective occlusal grinding. However, after performing the upper horizontal osteotomies (i.e., zygomaticofrontal and nasofrontal), it was apparent that the loss of approximately 2 mm of bone at these points resulted in a more superiorly positioned anterior maxilla when the upper facial segments (zygomaticofrontal, nasofrontal) were rigidly fixed with bone-to-bone contact. Following transplantation, the composite head (donor midface and maxilla on recipient mandible) had an improved class I skeletal profile (sella-nasion–A-point angle, 80.1 degrees; sella-nasion–B-point angle, 77.8 degrees; A-point–nasion–B-point angle, 2.3 degrees), with a posterior vertical maxillary length of 48 mm, a maxillary length of 50.6 mm, a mandibular length of 117.1 mm, an overjet of 1 mm, and a small anterior open bite of –1.7 mm. Cephalometric tracing sequence and orthognathic measurements, before and after transplantation, demonstrate improved anthropometrics and facial-skeletal relation for the maxillofacial transplant-2 scenario (Fig. 9 and Table 1).

For the edentulous scenario, as seen in the supplemental video, the use of an impression tray helped to maintain proper vertical orientation during alloflap fixation, with a final result consistent with an orthognathic profile and superior facial-skeletal harmony (Fig. 10) (**see Video, Supplemental Digital Content 1, *http://links.lww.com/PRS/A391***).[17]

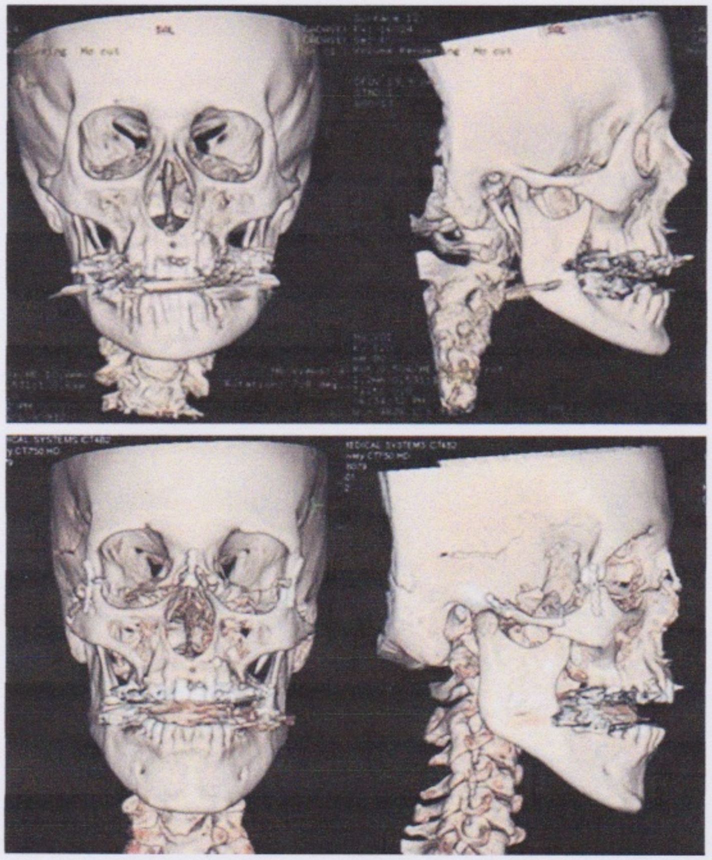

Fig. 6. Three-dimensional computed tomographic scans (frontal and right lateral) of recipient for the maxillofacial transplant-2 scenario are shown before (*above*) and after (*below*) transplantation.

DISCUSSION

Osteocutaneous maxillofacial allotransplantation is a rare subset of complex facial composite tissue allotransplantation known as a type III Gordon composite tissue allotransplantation.[2] This type of face and maxilla transplantation was first performed at the Cleveland Clinic in December of 2008.[1] Since then, a total of three maxillofacial transplants have been reported (Table 2).[18] Although there have been numerous cadaveric studies evaluating osteocutaneous Le Fort design, pedicle length, identity transfer, and maxillary perfusion,[19–25] none has addressed orthognathic applications with respect to occlusal planning, splint fabrication, cephalometrics, and facial-skeletal harmony (Table 3).[26]

In fact, all reports of successful osteocutaneous maxillofacial allotransplantation thus far suggest some degree of malocclusion and suboptimal facial-skeletal relation.[5–7] We therefore hypothesized that by using orthognathic planning and key principles, we could improve our results based on (1) optimization of occlusion between donor maxilla and recipient mandible, (2) surgical guidance for achieving aesthetic facial-skeletal harmony during flap inset and rigid fixation, and (3) enhancement of our team's ability to predict and plan intraoperative and posttransplant occlusal modifications based on the recipient's pretransplant occlusion and the donor's midface dimensions. Although all three maxillofacial transplants were successful in reconstructing each recipient's complex midface defects, functional occlusion and facial-skeletal relation were generally improved when orthognathic principles were applied.[27] In the second transplant, although an adequate occlusal relationship was established using hand-articulated cast models, such occlusion could not be achieved intraoperatively with ideal positioning of the flap.

Fig. 7. Photographs from the maxillofacial transplant-2 scenario showing donor (*left*), recipient pretransplant (*center*), and hybrid posttransplant result (*right*). For this dentate maxillofacial transplant-2 scenario, orthognathic practice and principles were applied.

Fig. 8. Photographs from the maxillofacial transplant-2 scenario shown in Figure 7. The final result demonstrates an improved class I skeletal profile with 1 mm of overjet and −1.7 mm of open bite.

After placing the donor maxilla and recipient mandible in an adequate occlusion, guided by our hybrid occlusal splint, we had significant difficulty performing rigid fixation of the orbital segments, as it appeared the orbital volume was excessive, and there was a large gap at the nasofrontal junction, with an underrotated, retrognathic mandible with a steep mandibular plane angle. Therefore,

Fig. 9. Cephalometric tracing sequence for the maxillofacial transplant-2 scenario demonstrating the donor facial profile (*left*), recipient facial form (*center*, before defect creation), and the posttransplant result (*right*).

Table 1. Cephalometric Measurements Showing Improved Facial-Skeletal Relation following Osteocutaneous Face Transplantation with Orthognathic Applications

Cadaver	SNA (degrees)	SNB (degrees)	ANB (degrees)	Skeletal Class	S-PNS (mm)	Co-ANS (mm)	Co-Gn (mm)	Overbite (mm)*	Overjet (mm)†
Donor	84	85.5	–1.5	III	45	45.8	105.2	1.8	–2
Recipient									
Preablation	77	72.3	4.7	II	41	55.4	116.6	–0.5	6
Posttransplant	80.1	77.8	2.3	I	48	50.6	117.1	–1.7	1

SNA, sella-nasion–A-point angle (measure of maxillary sagittal position); SNB, sella-nasion–B-point angle (measure of mandibular sagittal position); ANB, A-point–nasion–B-point angle (measure of maxillomandibular relationship); S-PNS, sella to posterior nasal spine distance (measure of posterior vertical maxillary length); Co-ANS, condylion to anterior nasal spine (measure of maxillary length); Co-Gn, condylion to gnathion (measure of mandibular length).
*Measure of vertical relationship between incisors.
†Measure of sagittal relationship between incisors.

we rotated our flap slightly in the counterclockwise direction (as viewed from the right) to allow for close bone-to-bone distance at the nasofrontal junction, with some disimpaction of the flap from the recipient bone posterolaterally at the zygomaticofrontal regions, to improve the sagittal projection of the midface and the mandible. With these movements, we were able to improve overall facial-skeletal form (the recipient had a class II skeleton at baseline) and preserve ideal orbital volume at the expense of compromising our planned occlusion.

This came at the cost of creating a few millimeters of posterior vertical maxillary excess, and interbone gaps between the upper bony segments. The posterior vertical maxillary excess manifested clinically as an anterior open bite of 1.7 mm. This potential problem was considered and anticipated during the preoperative planning, and the decision was made to proceed as follows: a small, anterior open bite with the condyles in centric relation would be accepted in the face transplant recipient, if necessary to maintain ideal facial-skeletal projection (to optimize midfacial convexity)[28,29] *and* orbital volume.[30] The rationale for this decision was that changes in midfacial skeletal projection would require future osteotomies of the alloflap or alloplastic augmentation, whereas an open bite could be corrected in the posttransplant phase without resorting to osteotomies of the alloflap or alloplastic augmentation (both of which are challenging techniques in the setting of impaired wound healing, questionable vascularity for maxillary osteotomies, and mandated immunosuppression).[31–33]

For posttransplant open bite correction, there are two potential options. First, for small anterior open bites such as that seen here, correction could be accomplished with nonsurgical methods, including additional occlusal grinding of posterior teeth, molar intrusion, or the assistance of miniature anchorage devices.[31] Second, a delayed bilateral sagittal split osteotomy may be used to treat the open bite and can be combined with second-

Fig. 10. Open-mouth (*left*) and right oblique views (*right*) of the maxillofacial transplant-3 scenario demonstrating a much improved orthognathic profile. (**See Video 1, *http://links.lww.com/PRS/A391*.**)

Table 2. Recent Timeline of All Reported Maxillofacial Allotransplants

Date	Location	Team	Skeleton Included
December of 2008	Cleveland, Ohio	Siemionow et al.	Vascularized Le Fort III: total infraorbital floor, bilateral zygomas, anterior maxilla with central maxillary incisors, total alveolus, anterior hard palate
April of 2009	Boston, Mass.	Pomahac et al.	Vascularized maxilla
March of 2010	Spain	Barrett et al.	Vascularized maxilla/mandible

Table 3. Summary of Pertinent Le Fort–Based Maxillofacial Cadaver Studies

Reference	Total No.	LeFort Type Studied	Summarized Findings	Key Recommendations
Baccarani et al., 2006[20]	1	III	Subperiosteal plane used for harvest of osteocutaneous flap by means of Le Fort III–based osteotomies	Technically feasible to include vascularized maxilla with facial alloflap
Yazici et al., 2008[19]	6	II	Key vascular structures for maxilla allograft harvest are within the masticatory space and its anterior pterygomaxillary extension	Vascular territories for maxilla allograft harvest are those in and around the infratemporal fossa, within the course of the internal maxillary artery
Pomahac et al., 2010*	4	III	Facial and angular blood vessels are connected to the maxillary vessels by means of an anastomotic framework centered about the microarchitecture (bony canals, periosteum) of the midface skeleton	The critical elements of a functional face transplant include appropriate donor selection and recipient vessel selection, meticulous graft harvest, complete graft revascularization, and restoration of motor and neurosensory function
Banks et al., 2009[22]	5	III	A single external carotid artery supplies the nasal dorsum and tip; bilateral perfusion is seen in the maxilla; ipsilateral perfusion is seen in the zygomaticomaxillary complex without notable contralateral contributions	Inclusion of the midfacial skeletal elements (i.e., maxilla) in the design of facial allotransplants requires bilateral vascular pedicles based on the internal maxillary arteries

*Pomahac B, Lengele B, Ridgway EB, et al. Vascular considerations in composite midfacial allotransplantation. *Plast Reconstr Surg.* 2010;125: 517–522.

ary aesthetic procedures at a later date, once the patient has been rehabilitated effectively.[35] This option is less ideal, as it is subject to the same challenges of wound healing and immunosuppression mentioned above; however, vascularity of the virgin mandible may not be as concerning. For example, a patient with a class II skeletal pattern and excessive overjet could be treated at 6 to 12 months postoperatively, with bilateral sagittal split osteotomies and mandibular advancement or setback, as indicated, in combination with bilateral donor parotidectomies and skin tailoring (i.e., face and neck lifting).

Of note, there are a few limitations to our study. First, cadaver models are unable to estimate and evaluate the difficulties associated with scar formation, which is a common scenario in patients presenting for maxillofacial transplantation.[18] One can hypothesize that the presence of scarring would be of minimal impact on orthognathic planning from the standpoint that our model surgery and cephalometric planning is based primarily on skeletal landmarks, rather than soft-tissue landmarks. In addition, the use of releasing incisions and scar excision is a standard ancillary technique used during recipient preparation. Second, this model does not account for pertinent variables such as nerve repair and vascular anastomoses of the alloflap. Fortunately, however, the donor supplies an abundant source of tissue grafts (i.e., nerve, vein) and therefore optimal facial-skeletal reconstruction should remain unhindered.

Orthognathic surgery envelops many important characteristics pertaining to optimal outcomes related to osteocutaneous maxillofacial allotransplantation. The results of clinical studies to date highlight the underappreciated role of maxillofacial surgical expertise in Le Fort–based face transplantation. After the identification of a donor match, the maxillofacial transplant team will most often have approximately 24 to 36 hours before the actual transplant begins.[4] Therefore, once the brain-dead, beating-heart patient arrives to the hospital as a direct admission (to facilitate the use of neighboring rooms for surgery), the maxillofacial specialist on the face transplant team should obtain donor impressions and immediately begin making the stone models. These are placed on a Galetti articulator for best-fitting occlusion, with selective occlusal grinding as indicated for maximum intercuspation. The "hybrid" splint is then fabricated for the maxillofacial allotransplant. Computed tomographic scans and lateral plain films of the skull can then be completed and analyzed for cephalometric discrepancies that may increase the complexity of obtaining both an ideal facial-skeletal and occlusal result. Presurgical planning will help to identify potential challenges for obtaining adequate occlusion, in the setting of alloflap survival and bone healing. Furthermore, the team can, a priori, develop an algorithm for prioritizing facial-skeletal and occlusal outcomes in the setting of airway or bone-to-bone contact discrepancies.

At the expense of the dentate recipient's anterior dental contact (maxillofacial transplant-2 scenario), we decided preoperatively that the most important priorities, during alloflap inset, were to be as follows (in order of decreasing priority): (1) establish optimal sagittal/parasagittal relation of the new midface skeleton, providing aesthetic harmony, identity retention, and airway patency[36]; (2) preserve ideal orbital volume with neoinfraorbital floor reconstruction (i.e., avoiding enophthalmos); (3) minimize bony gaps between the donor and recipient bony segments (using donor bone grafts as needed) while in centric relation; and (4) maintain proper vertical alignment of the neomaxilla in relation to the upper facial skeleton, thereby allowing optimal occlusion. Also, for the purpose of function (i.e., mastication), three contact points (one anterior and two posterior) need to be established, with the posterior points being most valuable.[37] As such, for the maxillofacial transplant-2 scenario, we accepted the bilateral posterior contact in exchange for an anterior open bite of 1.7 mm (Table 1).[34]

Essentially, placing the condyles in centric relation and allowing for maximal bone-to-bone approximation at the superior skeletal segment junction resulted in an open bite. Had the condyles been distracted out of centric relation, the bite could have been "closed" with counterclockwise rotation of the mandibular complex. For the edentulous model, the condylar position was assessed clinically as described above, with the condyles situated in the most posterosuperior position within the glenoid fossa. The Gunning splint ensured adequate interocclusal distance and freeway space. This is a valid technique used during orthognathic surgery to ensure that the condyles are seated in centric relation during rigid fixation.

As such, the primary author's (C.R.G.) technique has now been modified because of multiple lessons learned from this study. Pretransplant cephalometric analysis revealed that the planned recipient, before defect creation, had a class I molar occlusion along with a class II skeletal relationship. As a result, his skeletal relation and orthognathic profile were greatly improved fol-

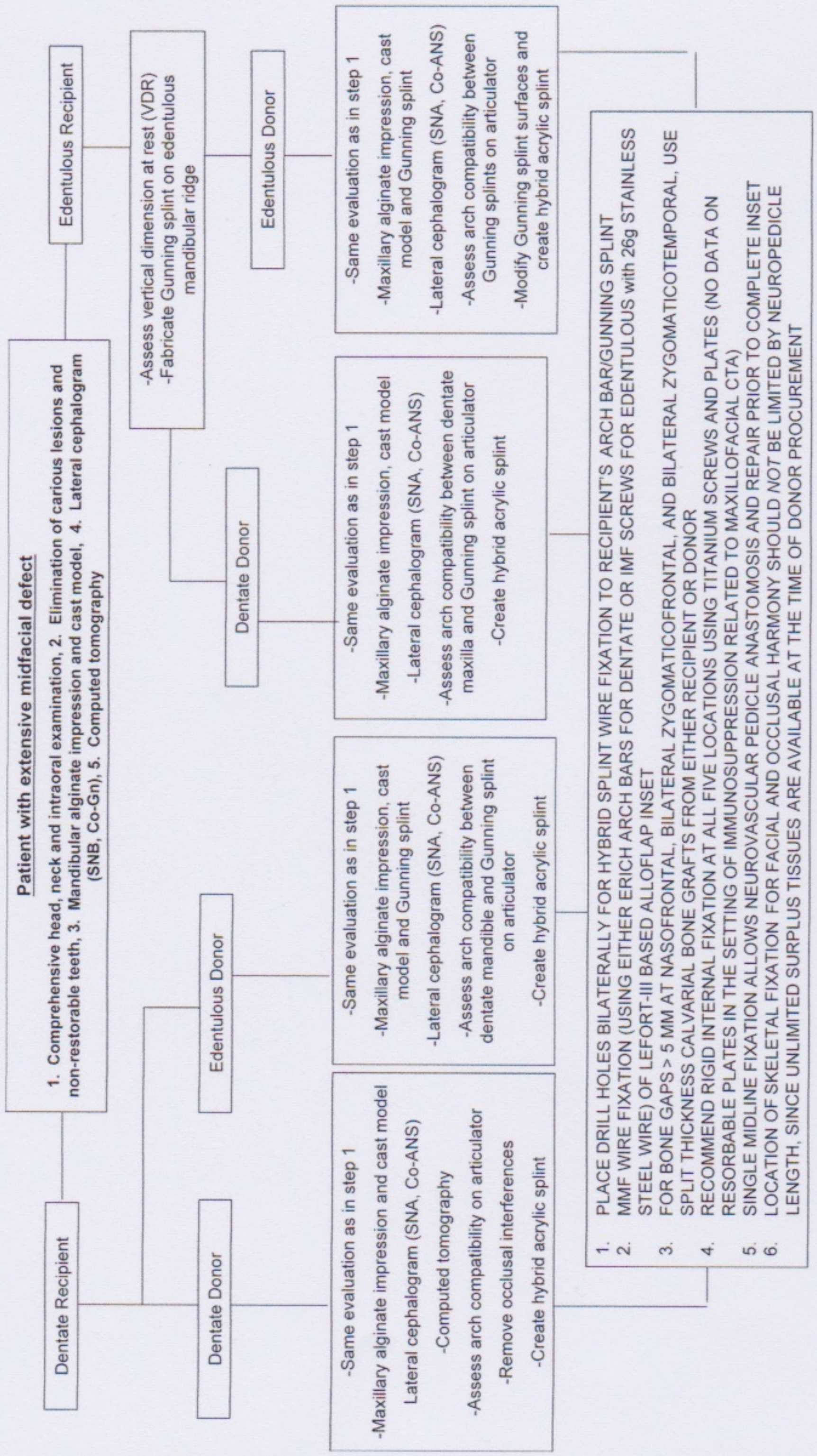

Fig. 11. Proposed algorithm for optimizing occlusal and facial-skeletal planning in patients undergoing osteocutaneous maxillofacial allotransplantation.

lowing transplantation, as demonstrated on posttransplant cephalometric and three-dimensional computed tomographic images. The valuable role of pretransplant orthodontia in this setting has now been confirmed, because some patients may need their mandibular incisor dentition to be decompensated (such as the recipient in this study) while they are kept on the transplant list awaiting suitable donor identification.[38] Removing abnormal labial or palatal inclination from the recipient's maxilla and/or mandible before transplantation will greatly enhance skeletal arrangement and evaluation intraoperatively. This greatly supports our recommendation that, analogous to their roles on established craniofacial teams, maxillofacial and orthodontic specialists should be involved with all osteocutaneous maxillofacial allotransplantation pretransplant assessments.[39]

CONCLUSIONS

Given that osteocutaneous maxillofacial allotransplantation, compared with other available techniques, has the new-found ability to restore superior function and aesthetics in the properly selected candidate,[40] the application and utility of orthognathic principles, as described here for the first time, cannot be overemphasized. To our knowledge, this is the first study and article to describe the role and utility of orthognathic principles and practice in osteocutaneous maxillofacial allotransplantation. The true value of our findings not only lies in improving functional rehabilitation of the recipient but also assists craniomaxillofacial surgeons in predicting the need for *intraoperative* (i.e., occlusal equilibration to eliminate interferences) and *posttransplant* occlusal modifications (e.g., orthognathic surgery, orthodontics, maxillofacial or alveolar distraction osteogenesis).[41]

As expected, an excessive overjet malocclusion was obtained using the control technique versus a much-improved occlusal result following orthognathic applications. Although a malocclusion may be considered an acceptable compromise to allow minimal bone gaps of the upper facial segments and preservation of orbital volume,[29] all teams must understand that an occlusion such as this may require future surgery in the challenged setting of immunotherapy. For mild to moderate anterior open bites, additional occlusal equilibration or posttransplant orthodontia can be considered for occlusal correction, thus avoiding the risks of additional surgery in the setting of mandated immunosuppression and delayed wound healing.[31]

In summary, our findings suggest that this approach could significantly improve overall facial-skeletal form and occlusion following transplantation (Fig. 11 and Table 4).[42] The total estimated cost for this type of workup ranges between $2000 and $3000 which, in the context of maxillofacial transplantation, will represent less than 1 percent of the estimated budget.[43] Furthermore, by combining pretransplant model surgery, donor/recipient cephalometrics, and the use of a hybrid occlusive splint during fixation, maxillofacial transplant teams are now capable of obtaining minimal occlusal discrepancies under the leadership of a craniomaxillofacial surgeon.

Table 4. Components of Orthognathic Workup for Optimizing Occlusal and Facial-Skeletal Planning in Patients Undergoing Osteocutaneous Maxillofacial Allotransplantation

Clinical Examination
Extraoral examination
Symmetry
Facial proportions (vertical thirds, horizontal fifths)
Nasal contour and projection
Malar projection
Periorbital contour
Profile (straight, convex, concave)
Vertical position of the mandible (need to correct if overclosed)
Chin-to-throat distance
Intraoral examination
State of the dentition
Presence of crowding
Angle classification (canine and molar)
Dental midline to midsagittal plane and facial midline
Overbite and overjet
Centric occlusion vs. maximal intercuspal position (if applicable)
Photographs
Frontal repose
Frontal smiling
Right and left lateral (right lateral is the conventional view for planning purposes)
Right and left three-quarters views
Superior (i.e., bird's eye) and inferior (i.e., worm's eye) views
Preinjury photographs
Radiographs
Panoramic radiograph
Lateral and anteroposterior cephalograms
Maxillofacial computed tomographic scan with axial, sagittal, and coronal reformations and three-dimensional reconstructions
Occlusal and skeletal analyses
Cast dental models (to assess maximal intercuspation and transverse relation)
Comparison of donor to recipient on cephalometric analyses (Steiner and Harvold)
Overlay tracings of donor maxilla and recipient mandible for maxillofacial allotransplantation (vice versa for mandibular transplantation)

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