Facial Skeletal Augmentation Using Custom Facial Implants

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Facial skeletal augmentation is one of many techniques used to enhance facial aesthetics. It is especially useful in the malar, mandibular angle, and genial areas. For many years, correction of facial contour deformities posed challenges for reconstructive surgeons. Two-dimensional radiographic and photographic imaging modalities provided limited diagnostic and treatment planning information. An arduous procedure could be undertaken to take a facial impression and create a stone facial model of the facial soft tissues. This three-dimensional (3D) model simulated the patient’s face but provided no information on the underlying bony contours. The surgeon primarily used their artistic ability to diagnose and treat facial contour deformities. Treatment was limited to the use of stock implants that were placed as is or altered at the time of surgery. With the more widespread use of computed tomography (CT) in the 1980s, 3D representations of the patient’s facial skeletal anatomy became available. Computer technology has advanced to allow an accurate duplication of a patient’s facial skeletal and soft tissue anatomy. According to Winder and Bibb, medical rapid prototyping is defined as the manufacture of dimensionally accurate physical models of human anatomy derived from medical image data [1]. This technology was originally described by Mankowich and colleagues in 1990 [2]. With the use of this technology, the ability to manufacture or fabricate custom craniofacial implants has evolved.

Proprietary software programs allow computer-assisted design (CAD) and prototyping through computer-assisted manufacturing (CAM). These technologies allow the fabrication of custom implants to replace or augment the facial skeleton and enhance a surgeon’s ability to treat facial contour abnormalities [3,4].

The creation of custom implants with CAD/CAM technology provides the surgeon with several advantages over the use of stock implants. The 3D information and virtual software provide for better patient evaluation and treatment planning, especially in cases of facial asymmetry. If a surgeon wants to correct unilateral deformities, mirror imaging software can be used to fabricate an implant that duplicates the facial skeleton of the opposite side. Customized implants have a more precise fit because the undersurface of the implant is manufactured to fit precisely to the patient’s skeletal anatomy. These implants adapt to sharp curvatures and bony abnormalities that may be present [3]. This is particularly advantageous in posttraumatic facial contour abnormalities, in which the custom implants fit into irregular defects and the edges of the implants blend into the facial anatomy and are not visible or palpable. Custom implants require little if any surgical time to hand carve. It is not necessary to alter the bony anatomy as is often the case with stock implants, reducing surgical and anesthesia time. Disadvantages of 3D modeling for custom implants include the need for CT scans, increased preoperative time for planning, and increased expense to the patient for the CAD/CAM process.

The purpose of facial augmentation is cosmetic enhancement, not functional improvement. It is important to consider the patient’s concerns and expected outcome when planning treatment. The clinical examination allows the best evaluation of contour deformities. 3D imaging allows the best...
means of quantifying the deformity and planning treatment. The area of interest is evaluated for symmetry, height, width, depth, and its relationship to the entire face. In most cases, aesthetic criteria and the surgeon’s experience blend to provide the optimal treatment of an individual patient.

Surgeons have alternatives for facial implants. They may use stock implants, customized stock implants, or custom fabricated implants, all made from a variety of materials. Both stock implants and custom implants have been found to have a low complication rate and good long-term success [4,5]. The surgeon must evaluate the pros and cons of each technique in the context of each individual patient and their presenting problems to determine the most appropriate treatment.

Technology

The initial step in fabricating custom implants begins with a 3D image. Historically, medical CT scanners have been used. During the past 10 years, cone beam CT (CBCT) has become available as an office-based alternative. There are important differences between the 2 technologies. Currently, 64-slice and 128-slice medical CT scanners are commonly available. They can scan a patient’s maxillofacial region in little more than a second, thus reducing movement artifact [6]. CT scans are more accurate and of higher quality than CBCT scans [7]. CBCT scans have less metal artifact (scatter) and expose the patient to less than 10% of the radiation received from a CT scan [6,8]. Manufacturers have software that can improve the 3D reconstructions from CBCT scans, making them acceptable for custom facial implants (Andrew Christiansen, Medical Modeling Inc, Golden, CO, USA, personal communication, 2011). Because of the reduced radiation and convenience, the office-based CBCT scanner is a good choice for the surgeon.

Whether using CT or CBCT, it is important to follow the specific protocol required by the manufacturer that is providing the technical support and implant fabrication. The area of interest and any surrounding area necessary to aid in treatment should be scanned. For instance, to augment the mandibular angle or malar area it is usually necessary to scan the entire face and orbits. Among other things, this strategy enables the surgeon and software designer to create a facial midline and to compare matched anatomic parts. Once the scan is completed, the imaging data or DICOM (Digital Imaging and Communications in Medicine) information is transferred to the commercial manufacturer, where the design process begins.

The commercial manufacturer uses proprietary software to reformat the DICOM images into 3D skeletal and soft tissue images. The images allow the surgeon to quantify and further evaluate the patient’s contour deformity. The software can be used to create an anatomic resin stereolithographic model that illustrates the position of vital structures such as the mandibular canal and any teeth that are present (Figs. 1 and 8A).

The surgeon has a few alternatives, varying from a handmade approach to the complete virtual creation of the custom implants. Both techniques create implants that adapt well to the patient’s bony anatomy (see Fig. 8C).

Techniques

Handmade Approach

A 3D resin stereolithographic model is obtained from the manufacturer. The model allows direct measurements of the deformed area and its relationship to other areas of the face. The surgeon uses a modeling material to custom sculpt the shape of the implant. The soft material can be carved, trimmed, or shaped as desired. A needle can act as a depth gauge and be passed through the material to check its thickness. When the surgeon is satisfied with the shape, the modeling material is allowed to dry and harden. It is then sent to the manufacturer, where it is duplicated in the implant material of choice (see Fig. 1).

Virtual Technique

This technique is completely digital, thus alleviating the need for a resin stereolithographic model. The surgeon works with a software designer at the manufacturing company to create the optimal
shape and size of the implant. The surgeon can start with a block of digital modeling compound or with the typical shape of a stock implant, modifying it as needed (Fig. 2). One benefit of computer planning is the ability for mirroring. Mirroring allows the comparison of the affected side with that of its normal counterpart. The surgeon can accurately determine the size and shape of the implant needed to match the shape of the normal counterpart (Fig. 3). An amount of asymmetry is always
present in human paired and unpaired parts. Regarding the facial skeleton, the more asymmetry that is present the harder it is to determine a midsagittal plane and the less reliable mirroring is [9].

**Implant materials**

Alloplastic implants offer many advantages over autogenous grafting, including predictable long-term results, reduced patient morbidity, and reduced surgical time. Over the years many different alloplastic materials have been used for maxillofacial augmentation. Although various biomaterials may be used for augmentation, only a few can be used for custom implant fabrication with the CAD/CAM process.

The ideal implant should be biocompatible and resistant to infection. It should be easy to customize, allow for easy removal, and be resistant to migration [10]. Each material offers advantages and disadvantages, but the decision on the material selection is usually based on a surgeon’s experience and preference. The following implant materials are currently available in the United States for use as a custom implant.

**Hard Tissue Replacement (HTR)**

Hard tissue replacement (HTR) (Biomet Microfixation, Jacksonville, FL, USA) is a nonresorbable, porous, polymeric composite consisting of a polymethylmethacrylate substrate sintered with a polyhydroxyethylmethacrylate and calcium hydroxide coating. The external surface aids in imparting hydrophilic properties with extensive porosity. The interbead porosity ranges from 150 to 350 μm with a 200 μm intrabead pore size. Despite the porous nature of the material, it has significant compressive
strength (5000 psi in moldable form) [11]. As a result, it is relatively stiff and is the most rigid of the materials discussed in this article. The easiest way to alter the material is with trimming burs. One significant benefit of this material is that there is no bony erosion over time around the implant. Karras and Wolford showed no bony erosion in HTR chin implants over an average length of follow-up ranging from 12 to 44 months [10].

**Medpor**

Medpor (Stryker Corporation, Newman, GA, USA) is a solid porous polyethylene implant with a pore size ranging from 125 μm to 250 μm, which allows for tissue ingrowth [12]. It produces a minimal foreign body reaction, resulting in a thin fibrous capsule. The material is available in stock implants of various shapes and sizes for facial augmentation. Because of the tissue ingrowth

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**Fig. 3.** The mirror imaging technique for virtual custom implant fabrication with computer reconstruction of facial soft tissue from the patient’s 3D imaging. Lateral (A) and oblique (B) views of right malar area indicate deficient contour with normal contour of the left side shown in lateral (C) and oblique view (D). Anatomic reconstruction of the facial skeleton showing deficient size of the right malar bone compared with the left in frontal view (E). Mirror imaging around facial midline to determine shape and thickness of the custom implant to create skeletal symmetry (F). Oblique view to show the overlay of mirror imaging that is represented by the translucent area. The translucent area indicates the amount of deficiency of the right side compared with the left (G). Oblique view of the completed virtual implant (H). (Computer illustrations courtesy of Medical Modeling Inc, Golden, CO, USA; with permission.)
and limited potential for movement after tissue healing, some surgeons place these implants without screw fixation. However, Yaremchuk comments that screw fixation is critical for the successful use of these implants. In addition, he reports that by fixating these implants, potential movement that may lead to hematomas or seromas is minimized [13].

**Silicone**

Silicone facial implants were first placed in 1953. Because of its molecular makeup, silicone is highly resistant to degradation. It is highly biocompatible, with minimal to no clinical toxicity or allergic reactivity. Most commonly, this material is used in a vulcanized form that can be trimmed with the ease of a scalpel blade. These implants retain their strength and flexibility throughout a wide range of temperatures, allowing for easy sterilization. Because of the chemical inertness of the material, a fibrous capsule forms around the implant, with no tissue ingrowth [14]. The implant and its capsule are not attached to the bone, and movement can be detected when palpated. This property allows for easier removal of the implant if necessary. One frequently reported disadvantage of this material is that these implants cause variable amounts of bone resorption, especially in areas of muscle function such as the chin area. This characteristic results in implant settling, making long-term stability and aesthetic outcomes less predictable [10].

**PEEK Optima-LT (polyetheretherketone)**

PEEK Optima-LT (Synthes, West Chester, PA, USA) has been engineered for strength, stability, and biocompatibility. Its stiffness and strength closely resembles those of cortical bone [15]. Standard plates and screws may be used to stabilize these implants. However, according to the manufacturer, the screw holes must be predrilled away from the surgical site. This material is being used more frequently for craniofacial applications [16].

All of the above materials are radiolucent. Many surgeons soak the porous materials in an antibiotic solution before placing them. It has been shown that the most effective way of infiltrating antibiotics into porous materials is to place them in a large syringe with an antibiotic solution. Negative pressure is created in the syringe by a repeated pumping action while tapping the syringe to knock off the bubbles that form. The result is to replace the air in the pores on the surface with the antibiotic solution. There are no available studies to show the effectiveness of this technique in reducing the perioperative risk of infection [17].

**Mandibular angle augmentation**

Contour abnormalities occur from congenital deformities, traumatic injuries, disease, or previous surgery. Patients usually do not have aesthetic concerns about the mandibular angle area, even when they have mild to moderate congenital deformities of this area. It may become an aesthetic concern when there is a notable asymmetry (such as in hemifacial microsomia) or because of acquired factors such as an injury, previous surgery, or disease that cause a change in the patient’s normal appearance (see Fig. 1). A reduced ramal height tends to cause a softer, more ovoid facial appearance which is more aesthetic for the female face. Increased ramal height tends to create a more square face and a more masculine appearance.

3D imaging creates a 3D facial soft tissue and skeletal model that is especially useful in the diagnosis and treatment planning for mandibular angle deformities. It enables the surgeon to directly measure the extent of the deformity on computer images and anatomic models. For acquired problems, the surgeon may be able to compare the patient’s current status to that of before an injury. The surgeon’s past experience and artistic license are more important in treating these deformities than the use of any radiographic norms. Augmenting the facial skeleton usually does not result in an exact 1:1 change of the facial soft tissue. This ratio varies with the nature of an individual’s soft tissue. In the case of traumatic injuries, after time has passed, scarring and soft tissue atrophy may have occurred. This situation may prevent achieving an ideal soft tissue change even if an implant accurately replaces the missing facial skeleton [3].

Two techniques are available for creating custom implants for these deformities. CAD/CAM technology can be used to virtually create implants, or the surgeon can use a modeling material to
custom sculpt an implant on an anatomic model of the patient’s facial skeleton. The manufacturer then creates an implant out of various materials that are identical to the sculpted implant. We have found custom implants to provide the best outcomes for abnormalities of the mandibular angle and ramus area.

Surgical placement of the implant can be from an intraoral or extraoral approach. If approached intraorally, the incision is made in the mandibular vestibule distal to the mental foramen. The peristium is reflected superiorly to the midportion of the mandibular ramus and inferiorly to the lingual surface of the inferior border of the mandible. It is important to achieve sufficient soft tissue relaxation to allow placement of the implant and prevent it from being displaced. This goal is achieved by creating a releasing incision through the peristium below the inferior border and using finger pressure to dissect and expand the tissue, creating a pocket for passive placement of the implant. Once the implant can be placed passively as planned, 1 or 2 screws are placed transcutaneously to secure the implant. This is to maintain the implant in its planned position and to prevent displacement of the implant during function or from soft tissue tension. If approached extraorally, care should be taken to make the incision low enough below the inferior border of the ramus so that after the implant is placed, the incision is still positioned below the mandible in the neck region. No attempt is made to close the pterygomasseteric sling. The platysma muscle and skin are closed, providing a 2-layer closure over the implant.

Fig. 2 illustrates a case in which a patient had normal height to his mandibular ramus but wanted to increase his facial width to create a more square facial appearance. The patient’s 3D imaging was sent to a manufacturer. Working with a software designer, virtual planning for the size and shape of implants to augment the mandibular ramus was completed. The implants were symmetric in size and shape.

The patient in Fig. 1 is a 60-year-old man who wanted cosmetic enhancement of his mandibular right ramus area. At 40 years old, he had orthognathic surgery at another facility. At that time bilateral sagittal ramus osteotomies were completed to advance his mandible. A malunion resulted in bilateral loss of contour of the mandibular angle area. There was a greater loss on the right side than the left. As a result, the patient wanted to improve the contour of the right side. A custom implant was created using the hand-made technique. The 3D imaging and stereolithographic resin model were invaluable for quantifying and establishing the correct size and shape of the implant. The sequence for this technique is illustrated.

The patient in Fig. 4 is a 40-year-old man who had orthognathic surgery at another facility. This surgery included an intraoral vertical ramus osteotomy, LeFort I maxillary osteotomy, and genioplasty. Healing of the ramal segments resulted in bilateral loss of contour of his mandibular angle area and a more ovoid facial appearance. The patient wanted a “fuller stronger” appearance to his face. Treatment included orthodontic treatment and revision surgery to advance his maxilla and mandible. Secondary surgery included the placement of virtual custom implants to widen and lengthen his mandibular angle and a genioplasty with an interpositional allograft to lengthen his chin area. Because of the extent of vertical augmentation, the implants were placed using an extraoral approach. When planning implants like these, the surgeon should try to have enough overlap of the implant on the lateral surface of the mandibular ramus for easy placement and stability of the implant. In this patient, less than optimal overlap was present and a few wires were used to secure and suspend the implants in their planned position.

**Malar augmentation**

Contour abnormalities occur from congenital deformities, traumatic injuries, disease, previous surgery, and aging. During the aging process, repositioning and loss of subcutaneous fat can cause the loss of malar contour [18]. A flat malar area can give the face an aged appearance. Strong cheekbones tend to give the face a fresh youthful look [19]. The malar region should be round and full. Maxillary retrusion occurs often in combination with a congenitally deficient malar area (Fig. 5C).

The evaluation and aesthetic criteria for the malar area have been discussed in several articles [19–23]. In the frontal view, there should be a gentle convexity from the infratemporal area to an area below the ear, with its widest point in the area of the zygomatic arch. Hinderer used a system of 2 lines, 1 from the lateral canthus to the commissure of the lips, and another from the tragus to the inferior aspect of the nasal ala [21]. He stated that the height of contour occurred in the area superior to their intersection (see Fig. 5A). In the profile view, an aesthetic malar contour is represented by an anteriorly facing curve or convexity starting anterior to the ear and extending forward to an area.
Fig. 4. Patient’s facial skeleton and soft tissue (A). Treatment included a bilateral augmentation of the mandibular angle with virtual custom implants and a genioplasty with an interpositional allograft (B). Preoperative photographs: right lateral view (C), frontal view (D), and left lateral view (E). Postoperative photographs (right lateral view [F], frontal view [G], and left lateral view [H]) indicate increased length of the chin and bilateral increased contour and length of the mandibular angle area. Preoperative (I), immediate postoperative (J), and 18-month postoperative (K) panoramic radiographs.
inferior to the eye [23]. This contour extends to or slightly forward of a line extending from the eye perpendicular to the postural horizontal (see Fig. 5B).

We find that most cases require symmetric cosmetic enhancement. Although the custom implants may vary on the surface contoured to the existing bone, the size and shape of the implants for the right and left sides are symmetric.

Surgically, malar implants are almost always placed by an intraoral approach. An incision is made in the posterior maxillary vestibule extending from the area of the first bicuspid to the first molar. A subperiosteal dissection is completed to expose the area of implant placement. Custom implants usually fit well in their planned position, requiring no alteration of their surface adjacent to the bone. Once the implants are in their proper position, the surgeon judges whether he has obtained his

Fig. 4. (continued)

Fig. 5. Frontal view indicates Hinderer’s system of 2 lines, one from the lateral canthus to the commissure of the lips and the other from the tragus to the inferior aspect of the nasal ala (blue). The malar height of contour occurs in the superior area of their intersection (blue ellipse). The face should have a gentle convexity from the infratemporal fossa to the area below the ear with the widest part at the zygomatic arch (A). Profile view: an aesthetic malar contour is represented by an anteriorly facing curve starting anterior to the ear and extending forward to an area beneath the eye. This contour extends to or forward of a line extending from the eye, perpendicular to the postural horizontal (B). Patient with congenital malar and maxillary hypoplasia showing a concavity instead of a convexity in the cheek area (C).
planned result and may or may not decide to make small alterations in the contour of the implant. The implant is then secured in place with a fixation screw.

The patient in Fig. 6 is a 55-year-old woman who wanted cosmetic enhancement of her malar area. After her clinical evaluation, a CBCT scan was taken and sent to a manufacturer. Working with a software designer, custom malar implants were created. They were shaped to increase the malar width and augment the anterior projection of her malar area. The implants were placed through an intraoral incision. The implants were well adapted to the patient’s bony contour but required some reduction in the area of the malar eminence. They were each secured with a fixation screw. The patient in Fig. 7 is a 45-year-old man who had a similar procedure.

Genial augmentation

Although many of these patients have congenital deformities related to mandibular retrognathia, contour deformities can also occur from previous surgery, traumatic injuries, or disease. The morphology of the genial area is highly variable in all 3 planes of space: anteroposterior, vertical, and
A few articles present aesthetic criteria for the lower lip and chin based on studies of normal and aesthetic populations [24–26].

The most important aesthetic criteria are the anteroposterior relationship of the chin to the lower lip and the vertical ratio of the lower lip to the upper lip with the lips in repose. The chin should be positioned 3-4 mm behind the lower lip in repose. A measurement is made from the anterior most point of the soft tissue chin to a line that is perpendicular to Frankfort horizontal and extends from the anterior most point of the vermilion of the lower lip (Fig. 9E). The vertical relation of the upper lip to the lower lip is about 1:2, with men having a slightly larger lower lip in comparison to the upper lip than women (men: 1:2.1–2.3). A custom implant allows the surgeon to vary the shape of the implant three-dimensionally depending on the aesthetic goals. The surgeon can vary the thickness of the implant in its anterior dimension to create more forward chin projection and vary the lateral thickness and posterior extension of the implant to widen the chin. For instance, if the surgeon wants to create more chin projection without changing the width of the chin, they place an implant that has a posterior extension that is thin and ends anterior to the mental foramen. If they want to create more width in the chin area, the lateral extension of the implant should be almost as thick as the anterior projection. The width is then gradually reduced as the implant reaches the mental foramen area and extends...
posteriorly to it. We use a 2-piece implant, as shown in Fig. 8B, which is customized depending on the aesthetic goals for the individual patient. The 2-piece implant is easier to fit and can be placed through a smaller incision. We find Medpor (Stryker Corporation, Newman, GA, USA) or HTR (Bio- met Microfixation, Jacksonville, FL, USA) to have better properties for mandibular augmentation than silicone.

Surgically, chin implants may be placed intraorally or extraorally. We find that the intraoral approach is used in almost all cases. An incision is made through mucosa and the orbicularis oris muscle in the labial aspect of the anterior mandibular vestibule from the right to left mandibular cuspid. The incision is then continued tangentially toward the mandible, maintaining a flap with mucosa and muscle. This strategy allows a 2-layer closure to be completed. Depending on the length of the implant, the incision can be extended bilaterally, with care taken to identify and retract branches of the mental neurovascular bundle. The mucoperiostium is reflected, exposing an area of bone larger than that of implant placement. Anteriorly, this area extends from a place around the apices of the anterior teeth, inferior and posterior to the mental foramen down and around the inferior border of the mandible. In some cases in which a large implant of 9 to 10 mm or more is placed, releasing incisions may be required in the periostium under the inferior border of the mandible. This relaxes the tissue and helps maintain the lip height and position. Care is taken not to place pressure on or stretch the mental neurovascular bundle during the surgical exposure or implant placement. The intraoral approach enables the surgeon to determine the dental and skeletal midline, to more easily fit the implant as planned, and to adjust the implant if necessary to prevent pressure on the mental neurovascular bundle.

The patient in Fig. 9 is a 22-year-old woman who complained that her teeth did not meet normally and that her chin was “small.” She had a skeletal class II malocclusion and mandibular retrognathia. Her chin was narrow and well behind her lower lip. Her treatment included orthodontic treatment in preparation for a LeFort I maxillary osteotomy, bilateral sagittal ramus osteotomies, and the placement of a custom chin implant. The orthognathic surgery and custom chin implant were planned virtually (see Fig. 9C, D). The size and shape of the chin implant were designed to create more chin projection and width. The implant was designed as 2 symmetric pieces. They were placed through an intraoral incision and each piece was secured with a fixation screw.

The patient in Fig. 10 is a 21-year-old man who wanted cosmetic enhancement of his chin area. He had completed 3 years of orthodontic treatment at age 17 years. He did not want to undergo any orthodontic treatment or orthognathic surgery, but agreed to chin surgery. The patient had a long ovoid facial
appearance, with maxillary vertical hyperplasia and a maxillary and mandibular asymmetry. His lower lip was increased in height in proportion to his upper lip and his chin was narrow and posteriorly positioned to his lower lip. Treatment was planned to perform an inferior border osteotomy and place a custom implant to correct his 3D chin deformity. Treatment planning was completed on the images from a CBCT scan and an anatomic stereolithographic resin model. The 3D resin model was created to simulate the planned skeletal surgery and to be used for the handmade technique to create a custom chin implant. The skeletal osteotomy was planned to vertically reduce and augment the chin as well as to

Fig. 9. Preoperative photographs: lateral view (A) and frontal view (B). Fourteen-month postoperative photographs: lateral view (C) and frontal view (D). The 14-month postoperative lateral cephalograph (E) shows that the soft tissue pogonion (Po’) is 3 mm behind a line that is perpendicular to the Frankfort horizontal, extending from the most anterior point of the lower lip. The virtual treatment planning with a software designer for a LeFort I osteotomy, bilateral sagittal ramus osteotomy, and custom chin implant is illustrated in profile view (F) and frontal view (G). (Computer illustrations courtesy of Medical Modeling Inc, Golden, CO, USA; with permission.)
align the chin with the facial midline (see Fig. 10E, F). The handmade technique was used to fashion an implant to further improve the symmetry of the chin area as well as to widen and augment it (see Fig. 10G, H). Measurements and reference lines made on the resin model were transferred to the patient to duplicate the skeletal surgery so that the custom implant would fit as planned.
Summary

The use of 3D imaging and CAD/CAM technology aids in the diagnosis and treatment of facial contour deformities and provides the surgeon with several advantages over the use of stock implants. If a surgeon wants to correct unilateral deformities, mirror imaging software can be used to fabricate an implant to duplicate the facial skeleton of the opposite side. CAD/CAM technology allows the surgeon to expand their horizon and better treat more complex deformities. Customized implants have a more precise fit and require little if any surgical time to hand carve or to alter the bony anatomy, as is often necessary with stock implants. These benefits make them the treatment of choice for many cases of facial contour deformities.

References