Custom-Designed Facial Implants
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Accurate correction and estimation of facial contour defects have historically posed arduous challenges for reconstructive and aesthetic surgeons, but technological innovations in the design and manufacture of facial prostheses have significantly improved the precision, fit, and reliability of these reconstructive devices. In the mid-1980s, CT replaced standard radiographic analysis as the reference standard in the diagnosis and treatment planning of craniofacial abnormalities [1, 2]. Leveraging the imaging capabilities of CT, computer-aided design (CAD) and computer-aided manufacture (CAM) methods subsequently were developed to replicate the anatomic topography and to enhance fitting of the implant in more complex cases requiring prosthetic restoration. In 1994, Binder and Kaye [3] reported their early clinical experiences using a three-dimensional (3D) CAD/CAM process for customizing implants in the reconstruction of post-traumatic and congenital facial deformities. Patients in this series experienced favorable aesthetic and functional outcomes with low morbidity, characterizing 3D CAD/CAM custom-designed implants as an accurate, simple, and cost-effective method for facial contour restoration [3]. In the ensuing years, this technique was extended to the customization of implants for augmenting and compensating skeletal and soft tissue discrepancies in patients who had complex acquired and aesthetic contour deficiencies [4]. Today, 3D CAD/CAM technologies continue to be refined and used for a wide variety of reconstructive and aesthetic applications.

Overview and advantages of custom-designed implants using three-dimensional computer-aided design and computer-aided manufacturing technologies

The 3D CAD/CAM technique generates a life-like aesthetic model based on images configured from digitalized and reformed CT data [3]. The resulting model serves as the foundation on which a specific implant is fashioned. Using this method, the surgeon is able to examine and analyze anatomic subtleties not otherwise evident in a two-dimensional format. Produced by combined computer imaging and modeling, the posterior surface of the resulting implant forms an extremely precise fit to the underlying bone base. This interlocking implant–bone interface accurately guides exact placement of the implant and contributes to greater overall stability [4]. The degree of conformity between the custom implant and irregular bony surfaces is so precise that internal or external fixation typically is not required [5]. For well-defined bone...
defects, volumetric parameters can be estimated ef-
f ectively by applying surface molding techniques to predict the degree of augmentation necessary for the optimal change in external contour. Custom implants also can be used for aesthetic augmentation of the facial skeleton or to correct soft tissue def-icits. By configuring the implant with extended anterior dimensions that approximate the normal soft tissue contours, the implants also can replace def-icient tissue or simulate soft tissue volumizing 

[5].

In addition to the primary benefits of heightened accuracy in contouring the implant surface to the underlying bone, the technical advantages of 3D CAD/CAM custom-designed implants include en-
hanced stability, accuracy of placement and form, and greater refinement in facial contour restoration [5]. It also is generally easier to predict soft tissue dis-
placement following direct augmentation with grafts or implants than with orthognathic procedures, such as osteotomies and segmental bone reposition-
ning. Thus, in properly selected patients who do not have major facial deformities and who lack major occlusal or functional problems, custom-designed entire implants may be a more desirable option than more extensive reconstructive surgery [6,7].

When used for esthetic restoration of soft tissue, biocompatible alloplastic implants are more pre-
sic and durable than autogenous grafts. Bone or cartilage autografts undergo variable amounts of resorption, and preserving these materials carries the risk of donor-site morbidity [8,9]. Carving block of alloplastic material to fit irregular bony de- fects is cumbersome, impractical, time-consuming, and frequently yields suboptimal results. Simi-
larly, modified off-the-shelf implants lack the ability to adapt and conform to the underlying bone topography; often producing conspicuous or palpable rough edges [10]. Conventional molding techniques also compromise implant stability, be- cause these methods use the skin surface as the base contour of the implant, thereby preventing en-

[11–13]. Injection of the longer-lasting fillers (e.g., the acrylics or silicone) also may mask a contour defect; however, these fillers are not permanent, require repetitive use, and have lim-
itations in treating larger-volume defects or in creating structural changes in facial contouring. Fat transfer presents unpredictable results in resorp-
tion, may cause irregularity, and may require frequent in-
jections.

Given the shortcomings of these methods, 3D CAD/CAM custom-designed implants can reduce substantially the use of autografts and the need to carve and shape implants or grafts during surgery. These advantages, in turn, decrease surgical time-
Custom silicone implants manufactured using the 3D CAD/CAM technique comply fully with the requirements for approval by the United States Food and Drug Administration (FDA) [1]. Although various biomaterials may be used for augmentation, only a few are amenable to the 3D CAD/CAM process for fabricating custom prosthetic devices. Biomaterial for customized implants should be relative inert, noncancerogenic, flexible, and easily carved if further refinements are required at the time of surgery. Preferably, the implant also should be nonporous for greater resistance to infection [10]. At present, the author and colleagues have found silicone elastomers (rubber) to be the optimal FDA-approved biomaterial that meets most of the ideal implant requirements and satisfies the demands of the custom molding process. Silicone rubber can be compressed for insertion through small incisions without losing its shape and detail and retains flexibility to adapt to gross surface changes [3].

Indications

Reconstruction of posttraumatic and congenital facial deformities

The physical and emotional consequences of untreated facial deformity resulting from trauma or congenital causes make the accuracy and predictability of selected surgical modalities critically important [3]. The spectrum of facial deformities may range from small- to moderate-sized facial contour defects to large, traumatic injuries. Notwithstanding the severity of the defect, several factors may preclude satisfactory repair of traumatic facial deformities. Patients who have particularly thin skin, small surface irregularities, or deformities in prominent locations leave little latitude for error. In these circumstances, the contour defects may go untreated because of the reluctance to use osteotomies, onlay grafts, or implants that cannot provide the precision required to achieve accurate and successful long-term results [3]. Timely treatment of acute facial injury may not always be feasible because of the lack of appropriate trauma personnel. Other patients may require primary surgical intervention for life-threatening injuries, which precludes surgical intervention of the facial injury during the immediate posttraumatic period. Deferring appropriate management of traumatic facial injuries can lead to numerous and varied facial deformities. Consequently, a high percentage of patients who have moderate to severe maxillofacial trauma suffer from malalignment, displacement, postoperative asymmetry, and problems in facial contour [16]. Even patients receiving adequate and timely treatment may be susceptible to late-onset deformities caused by incomplete resolution of comminuted bone fragments, and resultant collapse of the remaining structure [10,15]. In correcting pyogenic and periodontal deformities, delayed osteotomies and bone repositioning may incur facial incisions, varying degrees of morbidity, and a relatively high rate of skeletal relapse and bone resorption [17]. In maxillofacial surgery, problems in predicting the final outcome may not occur with unequal movement and distribution of soft tissues that accompany the final positioning of facial bones. These inconsistencies of soft tissue change can diminish the outcome of an otherwise correctly planned and well-executed skeletal procedure [18,19].

Custom CAD implants have been used successfully to treat selected patients who had posttraumatic and congenital facial deformities. Not many patients, this method may prove to be an accurate and simple means to reconstruct difficult problems. In others, it may be the only treatment that can provide a reasonable degree of success [3]. In appropriate cases lacking major functional or occlusal abnormalities, adequate treatment of contour deficiencies may be achieved simply by using onlay alloplastic implants to mask the deformity [6,7]. This technique has demonstrated remarkable results in treating complex, finite posttraumatic facial contour deformities. Custom alloplastic prosthetics may be used to reconstruct bone defects over most areas of the face and skull without imposing postoperative irregularities of grafts or standard implants [3]. A significant advantage of this method is the ability to design the template before surgery and to overlay margins around the bone defects or to further edges, rendering the implant virtually undetectable. In some cases, defects also can be reconstructed with the advantages gained by using more than one biomaterial simultaneously.

The patient in Fig. 1A presented 2 years after a motor vehicle accident with a complex contour defect over the right anterior skull and temporal region resulting from bone loss incurred as a result of the primary injury and after two life-saving craniotomies. This case illustrates how the use of custom implants with 3D computer imaging and modeling can be used to optimal advantage in reconstructing a difficult contour defect completely and with good long-term results (Fig. 1A-E).

The patient in Fig. 2 (preoperative photographs 2A, C, and D) had been involved in a pedestrian-physical defect as a result of a sliding gienoplasty. Rather than revising the gienoplasty, a custom implant was used. The postoperative results (Fig. 2B, D, and F) illustrate how a smaller defect can be restored permanently, precisely, and predictably.
Fig. 1. A 28-year-old patient presented with a complex posttraumatic defect secondary to bone loss and muscle atrophy over the right frontal and anterior temporal region of the skull 2 years after two life-saving cranio-
craniotomies had been performed. (A) Preoperative photograph. (B) Frontal view of the model with the initial tem-
plate designed and molded on the anatomic model derived from 3D CT imaging. The template is formed to
fill the frontal and temporal bone defect and also is designed to compensate for the atrophy of temporals mus-
cle within the temporal fossa. (C) Intraoperative view of the reconstruction of the entire frontal and temporal
defects with the use of the custom implant. (D) Because of the absence of peristeenum within and around the
defect, two biomaterials (silicone rubber and expanded polytetrafluoroethylene) were used simultaneously to
bridge the area of bone and to fixate the large implant to the surrounding soft tissues. (E) One year postopera-
tively the area is restored to a completely smooth and symmetric contour. To date, the results have been un-
changed and without complication for over 14 years.

Fig. 2. A few years after the symphyseal region, (A, C, E)
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Patients who have con-
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Fig. 2. A few years after sliding genioplasty, this patient developed areas of residual contour defects in the parasympathetic region. A, C, D Preoperative photograph; B, D, F Postoperative photograph. One year after a custom mandibular implant and subnasal augmentation, the deficiency noted over the parasympathetic areas is reconstructed, and the entire contour of the chin and mandible is augmented. Overall aesthetics are improved with the use of one custom-designed implant.

The implant is important for overall contour changes of the mandible and chin esthetically.

Patients who have congenital facial contour defects may require primary treatment of their deformity or, in many cases, for final resolution of contour deficiencies following prior, unsuccessful procedures [3]. In patients who have unilateral defects, the external contour of each implant may be designed to match the contralateral normal bony prominence, thereby restoring symmetry [3]. The patient in Fig. 3, preserved with microglossa and mandibular asymmetry that he desired to have improved (Fig. 3A). The anatomic model, however, revealed that the asymmetry was caused by congenital dysplasia of the left condyle and ramus. Although the patient was advised that the procedure of choice would be to lengthen the left mandibular ramus, he did not wish to have orthognathic surgery. Instead, a custom implant was designed on the anatomic model to compensate for the asymmetry (Fig. 3A-E). The model proved invaluable for demonstrating the correct diagnosis and degree of dysplasia and for establishing the correct size and shape of the implant (see Fig. 3B). Postoperatively,
the implants remained stable and have continued to provide satisfactory long-term aesthetic results (see Fig. 3A, C, D-E).

The patient in Fig. 4 presented preoperatively with left-sided hypoplasia of the mandibular body and angle (Fig. 4A and C). Using a model, a unilateral extended mandibular body and angle implant was designed to provide a significant improvement in facial symmetry (Fig. 4B and D). Other cases of congenital facial deformities, including maxillofacial hypoplasia, premaxillary deficiency, Treacher-Collins syndrome (midface hypoplasia), and micrognathia, also have been treated with CAD/CAM implants with adequate to excellent improvement in facial contour and stable outcomes reported over follow-up periods of up to 15 years (Fig. 5A-D).

Aesthetic enhancement or correction of complex facial contour defects

Although this technique offers significant benefits, most routine cases of aesthetic facial contouring do not require the use of 3D CAD/CAM modeling. For these patients, current computer-designed off-the-shelf implants generally satisfy the needs of most procedures performed for aesthetic enhancement and facial rejuvenation [2,20-22]. Custom implants, however, may be an indispensable tool for achieving the desired contour changes in patients to whom previous attempts with off-the-shelf implants, or other recontouring modalities have been unsuccessful or in cases in which the contour defect is in an unusual location. In many cases, severe overlying soft tissue discrepancy is a common problem contributing to poor aesthetic outcomes [4]. This condition may arise as a consequence of injury to the overlying soft tissue, poor contour restoration or instability related to prior reconstructive efforts, or the normal aging process [24,25]. Use of the 3D image-modeling process may spare patients who require revision facial augmentation surgery from undergoing multiple surgical procedures. In Fig. 6, a patient presented with malpositioned malar...
Fig. 4. Unilateral extended mandibular angle and body implant. (A) Frontal preoperative view demonstrating hypoplasia of the left mandibular body and angle. (B) Frontal view 18 months postoperative: a unilateral extended mandibular angle and body implant was used on the left side to improve overall facial symmetry. (C) Preoperative profile view (D) 18 months postoperative profile view.
Fig. 6. Bilateral custom mandibular body and angle implants. Preoperative (A) frontal and (C) lateral views of hypoplasia of the mandibular body and angle. Postoperative (B) frontal and (D) lateral views showing results after bilateral custom mandibular body and angle implants.
Fig. 6: Removal of the existing malar implants and insertion of the custom midfacial implants changed the abrupt, artificial topographic changes present preoperatively (A, C) to a smoother, more natural aesthetic outcome seen 8 months postoperatively (B, D). (From Blinder W, Kaye A. Three-dimensional computer modeling. Facial Plast Surg Clin North Am 1994;2(3):368; with permission.)
implants which consolldage a major degree of the underlying skeletal asymmetry [4]. After the preliminary CT scan was obtained, a 3D rendering of the images showed that the existing implants were positioned over the orbital rim and encroached on the orbit (Fig. 7). After the model was generated, templates were designed conforming to the underlying skeletal deficiencies and a montage. The thickness of the custom implants over the nasal region was estimated using the computer-imaging measurements obtained from the existing implants which were subtracted out from the model image. This process facilitated removal of the old implants and insertion of the custom implants in a one-stage procedure with improved accuracy (Fig. 6A-D) [4].

Acute disease-induced changes in facial surface contour may require extreme precision in implant design. In restoring facial deformities, surgeons may customize alloplastic implants to fill large voids in the facial contour caused by substantial soft tissue loss [4]. In these cases, anatomic models are generated and, in conjunction with a montage, are used to estimate implant thickness and volume. This estimation is important in patients who have thin skin and abrupt changes in underlying skeletal anatomy. Custom order implants also have been used to replace soft tissue in the periorbital area, with excellent results [4]. In this situation, the implants are designed to modify the configuration of the underlying periorbital skeletal structure so that the lower eyelid and infraorbital skin drapes in a more horizontal and lateral orientation, thereby reducing the vertical extent of the deformity and supporting the lower eyelid.

**Treatment of facial wasting syndrome**

Facial wasting syndrome (FWS) is a complication of highly active antiretroviral therapy (HAART). The loss of subcutaneous fat in the cheeks and temples manifests as a hollow-eyed, bony, emaciated appearance that is the characteristic hallmark of treatment for HIV. FWS does not improve upon discontinuation of HAART, and termination of treatment most likely contributes to the rising number of drug-resistant HIV strains, viral load rebound, and increased morbidity and mortality [14]. Because patients who have HIV currently live longer and healthier lives, many are beginning to seek surgical remedies for the cachexic appearance caused by FWS [25].

Although numerous different modalities have been used to treat patients who have FWS, none of these methods has produced satisfactory results. Traditional soft tissue augmentation modalities and standard rhinoplasty procedures have demonstrated limited success in cases of severe atrophy [24-26]. Other options, such as dermal fat grafts, local flaps, and free flaps have been tried also, but these techniques require procedures [24-26] similar to fat transfer procedures of injectable tissue fillers.
those techniques require multiple fields and lengthy procedures [24,26]. Similarly, other methods, such as fat transfer procedures, fat injections, and the use of injectable tissue fillers [9], collagen and various proprietary products, have been considered, but each is short-lived and does not address volumetric needs. The use of fillers in smaller amounts is an effective supplement to the primary implant.
procedure, however, particularly for small variations in the subcutaneous plane [23]. Local injection with synthetic soft tissue fillers, such as polyactic acid or hyaluronic acid, has shown some promise, however, the quantity of material required to fill large defects and the frequency of injections in severe cases of PWS drive up costs to significant levels over time [24,28,27]. In contrast, the use of solid synthetic volumetric fillers for surgical reconstruction of patients who have PWS, a relatively new development, has demonstrated excellent aesthetic outcomes. Talman and colleagues [24] used subcutaneous implants for the correction of PWS in three patients. One patient required repositioning of the implant following mild displacement. Two patients underwent additional soft tissue augmentation of the nasolabial fold to achieve satisfactory aesthetic result. In all cases, facial wasting was caused by atrophy of the subcutaneous fat with sparing of the deeper fat pads.

Binder and Bloom [25] reported on the largest series of 22 patients who had UV-related PWS and who were treated with custom midfacial and subcutaneous implants. Contrary to the experience of Talman and colleagues, this study found that atrophy in these cases occurred in both the subcutaneous subcutaneous fat and deeper fat pads. Fourteen of the 22 patients received custom implants for more severe midfacial deformities.

and if patients received oral implants for moderately severe cases of PWS were less favorable. CAM implants because a more vertical triangular implant, which was prohibited by the patient's preoperative procedures. In cases of oral implants, the oral surfaces of the implant were not fully lined with the anatomic position. The oral surface may be positioned and methods of fixation, suturing, and bolting techniques.

As judged by the patients' experienced aesthetic postoperatively. Because implants required in the sequence of anesthetized oral commissure, however, none found this type of treatment to be any more acceptable in all degree of aesthetic complications, such as preoperatively, facial nerve paralysis, displacement, and implant loss. Two cases of secondary implant loss were documented, and both cases were within 3 weeks without the second case, the patient had the implant. All other patients were satisfied with their aesthetics and recommended the procedure (Figs. 9 and 10).

Summary

The availability of 3D CAD/CAM technology in customizing of local isometric application of augmentation of the range of patients suffering from facial asymmetry, before the advancement of traditional orthodontic correction of severe deformities is precluded by the high cost of treatment and the sensitivity of the system. Evaluation of the versatility of implants and fitting to obtain a surface fit between two surfaces is an imaging and modeling system. Implants in a more rigid silicone elastomer using scanning, imaging, and modeling.
and 8 patients received off-the-shelf submucosal implants for moderately severe conditions. Severe cases of PWS were fitted optimally using CAD/CAM implants because of the need to produce a more vertical, triangular-shaped, and thicker implant, which was positioned in a more medial position than in routine midfacial augmentation procedures. In cases of misfitable atrophy, the implant rests only partially on bone, with the major portion of the implant extending inferiorly over the maxillary muscle (Fig. 8) [25]. Once the custom-designed implant is in position, the procedure fit is between the posterior surface of the implant and the underlying bone directs the implant into the correct anatomic position. Off-the-shelf submucosal implants may be positioned and stabilized using various methods of fixation, such as the percutaneousuture and bolster technique [26].

As judged by the patients and surgeon, all 22 patients experienced excellent aesthetic improvement postoperatively. Because of the large size of the implants required in the severely PWS cases, some patients experienced a minor limitation in superior oral commissure excursion or excessive smiling; however, none found this limitation to be problematic or of consequence compared with the overall improvement. Serious complications, such as permanent infraorbital paresthesia, facial nerve paralysis, or implant migration or extrusion, did not occur. Two cases of wound infection required removal of the implant, and in one case, the implant was replaced within 3 weeks without subsequent problems. In the second case, the patient decided not to replace the implants. All other patients expressed extreme satisfaction with their aesthetic outcome and would recommend the procedure highly to other patients (Figs. 9 and 10).

Summary

The availability of 3D CAD/CAM techniques for the customization of facial implants has expanded the application of augmentation surgery to a wide range of patients suffering from facial contour deformities. Before the advent of this technology, treating many of these patients might have been precluded by the high cost and morbidity associated with traditional orthognathic procedures. The sensitivity of the 3D imaging system allows the fabrication of versatile implants that wrap around corners and fit into recesses to address effectively minor surface discrepancies surrounding defects. The 3D imaging and modeling software can produce the custom implant in a more stable, custom-fitted prosthetic silicone allograft. The 3D state-of-the-art scanning, imaging, and modeling system increases versatility and sets new standards in the design and use of osseous implants for treating many difficult and challenging problems in aesthetic and acquired facial contour deformities. The future unfolds, the integration of 3D CAD/CAM technologies with computer advances in implant biomaterials technology will be exploited to provide other effective and cost-effective solutions for treating patients who have facial contour defects requiring reconstructive prostheses.

References


