Computer-Assisted Design and Manufacture of Implants in the Late Reconstruction of Extensive Orbital Fractures

Olivier Lieger, MD, DMD; Robin Richards, PhD; Mingjun Liu, PhD; Tim Lloyd, FRCS(OMFS), FDSRCS(Eng)

**Objective:** To evaluate the use of computer-assisted designed and manufactured (CAD/CAM) orbital wall and floor implants for late reconstruction of extensive orbital fractures.

**Methods:** We performed a retrospective data review on 29 patients treated for extensive orbital fractures from January 1, 1997, through December 31, 2007, at the University College London Hospitals. The use of a CAD/CAM technique based on cross-sectional computed tomographic scans, generating an accurate stereolithographic model, enabled surgeons and technicians to plan and create the best dimension and position of the implant. Sheet titanium was then pressed to shape from a design outlined on a counterdie of the new reconstructed model.

**Results:** Twenty-nine patients with late enophthalmos due to complex orbital fractures underwent successful reconstruction surgery. Enophthalmos was corrected in all patients. Diplopia was improved in 14 patients, and extraocular movement was improved in 13.

**Conclusions:** The CAD/CAM implants represent a financially viable method for secondary reconstruction of the orbit. This method enables the surgeon to plan the operation in detail, facilitates the surgical procedure, and can help to improve the outcome.

Arch Facial Plast Surg. 2010;12(3):186-191

**ORBITAL FRACTURES ARE REPORTED IN MORE THAN 40% OF MAXILLOFACIAL INJURIES AND THEREFORE REPRESENT THE MOST COMMON TRAUMA TO THE MIDFACE.**

Posttraumatic orbital deformities caused by missed diagnosis or incorrect reconstruction of the preinjury anatomy of the orbit account for serious complications, including enophthalmos, diplopia, and visual acuity disturbance. The goal of the secondary operative reconstruction is to repair the orbit in an anatomically correct order and to mobilize and free periorbital tissue to achieve optimal positioning of the globe and to improve eye movement. Fat atrophy was long believed to be a central problem in the cause of enophthalmos. However, different studies showed that there is no evidence for this assumption.

To date, forward movement of the globe has often been achieved by volume reduction. The criterion standard implants for this procedure have been rigid calvarial bone grafts or large titanium mesh. Precise reconstruction, especially of the retrobulbar bulge, often was impossible. Today, advances in imaging techniques and navigation systems enable the surgeon to perform preoperative planning, which allows more accurate intraoperative placement of the implants. However, even with the help of these modern tools, bulky calvarial bone grafts or free hand-bent titanium mesh do not seem to be the optimal implants in precise anatomical reconstructions of the orbit.

Custom-made titanium implants created using computer-assisted design and manufacturing (CAD/CAM) are already common in reconstructive cranioplasty surgery. With the help of this experience and knowledge, we developed custom-made orbital implants. They enabled us to achieve optimal reconstruction in areas of limited visibility and nearby important anatomical structures such as the optic nerve.

The purpose of this study was to assess the outcome of secondary orbital repair using CAD/CAM implants in all patients treated during a 10-year period.

**METHODS**

**PATIENTS**

From January 1, 1997, through December 31, 2007, CAD/CAM implants for orbital reconstruction were produced at the Department of Medical Physics and Bioengineering at the University College London Hospitals for a total of 71 patients. These operations were mainly performed in 3 different centers. Thirty-two of these patients were treated at the University College London Hospitals for unilateral posttraumatic enophthalmos with or without diplopia. A side dif-
ference of at least 2 mm, measured by Hertel exophthalmometry, was considered to be enophthalmos. The medical records of these patients were scrutinized. Three patients were excluded from the study because of insufficient follow-up. Twenty-nine patients were examined preoperatively and postoperatively by ophthalmologists and maxillofacial surgeons (T.L.). The extent of the fracture was assessed with the help of preoperative computed tomographic (CT) scans and classified according to Jaquieyr et al (Table 1). The extent of enophthalmos was quantified with a Hertel exophthalmometer. Diplopia was determined with the Harms wall (an orthoptic method for analyzing the field of binocular vision), and ocular motility was evaluated by assessing 8 fields of gaze. In all patients, standard follow-up at 2 and 4 weeks and 3 and 6 months was performed by the maxillofacial surgeon (T.L.). Routine postoperative ophthalmological follow-up was performed between 5 and 7 months. For the present analysis, the most recent orthoptic and ophthalmological examination results were used.

**GENERATING THE 3-DIMENSIONAL IMAGE**

To generate a 3-dimensional (3D) image, a thin-section CT scan (≤1 mm) of the patients’ orbits and periorbital region is obtained. The data are then transferred by local network to the Medical Graphics and Imaging workstation at University College London. A computer 3D model is reconstructed via in-house–developed 3D imaging software (Figure 1). The imaging software allows the user to assess the extent of the defect and make measurements to determine suitable attachment sites. By selecting the appropriate Hounsfield threshold level, the defective orbit floor can be examined closely. The orbital repair is achieved by mirroring the good orbit of the patient and aligning this with intact parts of the damaged orbit (Figure 2). Screw-fixing hole locations are determined by the thickness of the bones around the defect. Stereolithography files of the repaired structure and the damaged structure are exported from the software.

**PREPARATION OF REPAIR MODEL**

Two stereolithographic models, an untouched defect model and a repair model, are built using a rapid prototype machine. With older CT scans, the surface of the repair model may be slightly terraced because of the finite thickness of each CT section. To correct any irregularity, the surface of the reconstructed orbit may be smoothened with an ultrathin layer of plaster (Figure 3).  

**MANUFACTURE OF THE ORBITAL PLATE**

The plate is normally designed to have a small flange that fits to the contour of the middle of the infraorbital margin and extends far enough posteriorly to rest on intact bone. A notch is put on the flange, which lines up with the infraorbital foramen. This helps to achieve correct placement of the implant. The implant is secured anteriorly into the orbital rim by means

---

**Table 1. Classification of Orbital Wall Defects**

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Isolated defect of the orbital floor or the medial wall, 1-2 cm², within the anterior two-thirds</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Defect of the orbital floor and/or the medial wall, &gt;2 cm², within the anterior two-thirds</td>
<td>Bony ledge preserved at the medial margin of the infraorbital fissure</td>
</tr>
<tr>
<td>III</td>
<td>Defect of the orbital floor and/or the medial wall, &gt;2 cm², within the anterior two-thirds</td>
<td>Missing bony ledge medial to the infraorbital fissure</td>
</tr>
<tr>
<td>IV</td>
<td>Defect of the entire orbital floor and the medial wall, extending into the posterior third</td>
<td>Missing bony ledge medial to the infraorbital fissure</td>
</tr>
<tr>
<td>V</td>
<td>Same as category IV, extending into the orbital roof</td>
<td></td>
</tr>
</tbody>
</table>

*a According to the classification of Jaquieyr et al.**
of screws through holes in the flange. The required outline is defined on the repair model, which is transferred to a counterdie that is then inserted into the base ring of the pressure unit (Figure 4). A 25-cm flat, round sheet of commercially pure annealed titanium, 0.5 mm thick (American Society for Testing and Materials grade 1; Imperial Metal Industries alloy No. 115), is pressure formed between the upper and lower chambers of the unit. The plate is then trimmed to remove excess metal, and the holes are drilled and the notch is cut appropriately. Finally, the plate is cleaned, polished, etched, and anodized (Figure 5).

OPERATIVE PROCEDURES

All patients received perioperative prophylactic antibiotic therapy. Surgery was performed with the patient under general anesthesia. Subciliary or lower eyelid/midtarsal incisions were used to expose the infraorbital rim and the orbital floor. Subperiosteal dissection was used to identify stable bony structures around the defect. Subsequently, the sterilized implant was inserted and screwed to the bone using the predrilled holes (Figure 6). Postoperative occipitomental (Waters view) radiographs were obtained routinely (Figure 7).
This study was a retrospective analysis of 29 patients (26 male; average age, 33.4 [range, 16.2-56.3] years) with post-traumatic enophthalmos. The average interval between trauma and surgical enophthalmos correction was 1.6 years (range, 2 months to 4.1 years). Pure blow-out fractures were recorded in 16 patients. Ten patients sustained associated zygomaticomaxillary fractures and 3 had orbitonasal-ethmoidal fractures. Primary orbital revision was performed in 3 patients only, with the use of polydioxanone implants. All 3 patients had sustained a zygomaticomaxillary fracture and showed delayed postoperative enophthalmos. In all other patients, no primary orbital reconstruction was performed. The defect size was classified according to Jaquiey et al15 using the preoperative CT scans. According to that classification method, 20 patients sustained a class III defect and 9 patients sustained a class IV defect.

Preoperatively impaired ocular mobility and diplopia were seen in 24 patients (Table 2). Three patients had normal binocular vision, and 2 patients were blind on the affected side. Hertel exophthalmometer assessment showed a mean preoperative difference of 3.1 mm (range, 2.0-7.0 mm). Routine postoperative ophthalmological follow-up was performed between 5 and 7 months after surgery. The mean follow-up was 14 (range, 5.5-29.0) months. Diplopia was cured in 5 patients, with improvement in 9 others (Table 3); ocular motility was normalized in 4 patients and improved in 9. In 1 patient, diplopia resolved although the motility of the eye globe remained unchanged. No worsening of double vision or motility was recorded.

The last Hertel assessment showed an average improvement of 2.9 mm (range, 1.5-5.0 mm) with a postoperative mean difference of 0.2 mm (range, −0.5-2.0 mm). No difference in the Hertel assessment was found in 17 patients. In 12 patients, an important improvement was achieved. Only 2 of the patients showed a difference of 2 mm, which by definition is still classified as enophthalmos. In 1 of these patients, the postoperative results at 7 months showed an excellent result but wors-
enited as a result of posttraumatic globe shrinking. Clinical follow-up examination at 2 and 4 weeks and 3 and 6 months by the maxillofacial surgeon showed good wound healing in 28 patients, with no signs of infection. One patient had an infection in the region of the implant, which was successfully treated with antibiotics. None of the implants had to be removed. No additional orbital correction surgery was performed.

**COMMENT**

Posttraumatic enophthalmos occurs when no primary reconstruction of orbital injuries was performed or when insufficient outcome was obtained after primary reconstruction caused by poor mesh placement or contouring and resorption or displacement of bone grafts. In the treatment of enophthalmos and persisting diplopia, 3D orbital reconstruction remains the primary goal. It is generally agreed that the main reason for enophthalmos is an increase in volume of the posterior segment of the orbit and changes in the deep orbital cone area. Several methods and implant materials have been described for the reconstruction of bony orbital defects. Depending on the size of the defect, various materials are preferred. Some authors suggest using synthetic absorbable implants such as polyglactin and polydioxanone sheets to cover small defects. In larger orbital defects, however, the stability of these materials seems insufficient. In these cases titanium mesh, autogenous bone grafts, and hydroxyapatite blocks are widely used.

In secondary orbital reconstruction, autogenous calvarial bone grafts are still accepted as the criterion standard. However, there are important disadvantages of these grafts, such as minimal moldability, donor site defects, and potential resorption over time. Titanium is a widely used alloplastic implant material in maxillofacial reconstruction because of its availability, excellent biocompatibility, and osseointegration. It has proved to be ideal to cover larger defects in the repair of enophthalmos. Nevertheless, it is a great challenge for the surgeon to restore the correct 3D shape of the orbit by bending the implant. Especially in secondary repair, anatomical landmarks are often lacking because of extensive defects or bone remodeling. Modern preformed titanium mesh may facilitate the bending process but often leaves the surgeon with a feeling of insecurity after insertion. Unless a navigation system is used, it is very difficult to verify the correct anatomical 3D reconstruction. Especially when deep structures such as the retrobulbar bulge, the deep orbital cone, or the conjunc-

### Table 3. Comparison of Outcomes in 29 Patients

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Outcome, No. (%) of Patients</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Resolved</td>
<td>Improved</td>
</tr>
<tr>
<td>Diplopia (n=24)</td>
<td>5 (21)</td>
<td>9 (38)</td>
</tr>
<tr>
<td>Restricted ocular motility (n=26)</td>
<td>4 (15)</td>
<td>9 (35)</td>
</tr>
<tr>
<td>Enophthalmos (n=29)</td>
<td>20 (69)b</td>
<td>9 (31)</td>
</tr>
</tbody>
</table>

a Because of rounding, percentages may not total 100. 
b Overcorrection occurred in 3 of 29 patients (10%).
plants can be used successfully in the late repair of extensive orbital fractures. Although the costs may still be rather high, the use of custom-made implants will become more and more important because of their undeniable advantages over other methods.

Accepted for Publication: December 4, 2009.

Correspondence: Olivier Lieger, MD, DMD, Department of Cranio-Maxillofacial Surgery, Cantonal Hospital Lucerne, 6000 Lucerne 16, Switzerland (olivier.lieger@ksl.ch).

Author Contributions: Study concept and design: Lieger, Richards, Liu, and Lloyd. Acquisition of data: Lieger and Lloyd. Analysis and interpretation of data: Lieger and Lloyd. Drafting of the manuscript: Lieger and Lloyd. Critical revision of the manuscript for important intellectual content: Richards, Liu, and Lloyd. Statistical analysis: Lieger and Lloyd. Obtained funding: Lieger and Lloyd. Administrative, technical, and material support: Lieger, Richards, Liu, and Lloyd. Study supervision: Lloyd.

Financial Disclosure: None reported.

REFERENCES

17. Accepted Accessed August 18, 2009.

Announcement

Visit www.archfacial.com. As an individual subscriber, you may elect to be contacted when a specific article is cited by any of the hundreds of journals hosted by HighWire. You also may sign up to receive an e-mail alert when articles on particular topics are published.

(Reprinted) Arch Facial Plast Surg/Vol. 12 (No. 3), May/June 2010 www.archfacial.com

©2010 American Medical Association. All rights reserved.

Downloaded From: by a Non-Human Traffic (NHT) User on 11/16/2018