Orbital Reconstruction: Prefabricated Implants, Data Transfer, and Revision Surgery

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Abstract

External impact to the orbit may cause a blowout or zygomatico-maxillary fractures. Diagnosis and treatment of orbital wall fractures are based on both physical examination and computed tomography scan of the orbit. Injuries of the orbit often require a reconstruction of its orbital walls. Using computer-assisted techniques, anatomically preformed orbital implants, and intraoperative imaging offers precise and predictable results of orbital reconstructions. Secondary reconstruction of the orbital cavity is challenging due to fractures healed in malposition, defects, scarring, and lack of anatomic landmarks, and should be avoided by precise primary reconstruction. The development of preformed orbital implants based on topographical analysis of the orbital cavity was a milestone for the improvement of primary orbital reconstruction.

Keywords
- orbital reconstruction
- computer-assisted surgery
- preformed orbital implant
- intraoperative imaging

In craniomaxillofacial trauma orbital structures are involved in up to 40% of the cases due to its exposed position and its limited bone thickness.1 External impact to this area may cause blowout fractures or zygomatico-fractures involving the area of the orbital floor and/or the medial orbital wall.2–4 An enlarged orbital volume may result in diplopia and enophthalmos, especially when the deep orbital cone is affected.4,5 To prevent such complications precise reconstruction of the anatomical orbital structures is essential.6

Computer-Assisted Surgery

Computer-assisted surgery (CAS) started over 20 years ago and has developed as a standard procedure for severe reconstruction cases.7–15 CAS generates a precise three-dimensional (3D) “virtual patient” for intraoperative localization of the anatomy and of surgical instrumentation. Hassfeld et al presented the application of CAS for removal of skull base tumors, followed by other applications such as foreign body removal, implantology, and orthognathic surgery.16–20 Until now, CAS has been practiced as part of the surgical routine in posttraumatic orbital reconstructions21,22 (►Fig. 1).

After importing the 3D data set, atlas-based segmentation is been performed automatically in a so-called data preprocessing procedure.23 The segmented unaffected orbital cavity can be mirrored to the affected side presenting the virtual reconstruction. In addition, in bilateral fractures, special virtual implant models from standard computed tomographic (CT) data sets can be inserted, controlled, and used for size determination of the implant (►Fig. 2).
Orbital Reconstruction

The purpose of internal orbit floor reconstruction is the anatomical true to original 3D reconstruction considering shape and volume. Reduction of the thin bony fragments is often not possible or insufficient. Indications for covering or bridging the defect often exist to avoid a soft tissue displacement again. Therefore, inserting alloplastic material for supporting the soft tissue and to reshape the cavity often is indicated. Depending on the defect size and localization, materials with different rigidity have been recommended for the repair of orbital injuries.\textsuperscript{24–29}

Resorbable alloplastic membranes are suitable for small defects (up to 1 cm\textsuperscript{2}).\textsuperscript{30–32} For larger defects, reconstructions of the orbital walls with more stable bridging materials are essential. Autologous bone such as calvarium, iliac crest, or microvascular bone offer a possibility for rebuilding and augmenting orbital contours especially after tumor resection if radiation is planned. However, for trauma reconstruction harvesting morbidity weight too high, the bone parts cannot be really anatomically shaped and shrinking of the bone volume occurs by resorption. Alternatively, alloplastic materials such as titanium and porous polyethylene are used, however these materials except titanium have been tempered by some complications\textsuperscript{15,27,33–39} and a true to original reconstruction of the demanding 3D anatomy of the orbital walls is rarely achieved.\textsuperscript{40–42}

Preformed Titanium Orbital Implants

Because of its excellent biocompatibility, titanium is a well-accepted alloplastic implant material.\textsuperscript{28,43} Titanium fan plates which allow the adaptation to individual anatomy have shown to offer rigid support in extensive defects of the internal orbit.\textsuperscript{42,44–49}

Accurate bending and alignment for precise 3D reconstruction of the complex anatomy of the bony orbit is technique dependent and time consuming.\textsuperscript{21} To address this issue, some surgeons use sterilized skull models to assist with accurate intraoperative bending. CT data can be analyzed to fabricate stereolithographic models or alloplastic implants for reconstruction.\textsuperscript{1,50–53} These techniques, in combination with intraoperative navigation, can improve the precision of surgical repair.\textsuperscript{21,22,41,51,52,54–60} However, they are cost and time intensive and are not available for all institutions. Therefore, the intention was to design an anatomical preshaped orbital implant covering the orbital floor and medial wall fitting for most individuals which would be available at once without additional efforts.

By using CT data of unaffected orbital cavities, topographical analysis could be evaluated and mean shapes of the orbital floor and medial wall were recalculated.\textsuperscript{61} The evaluation of the fitting accuracy was tested in a cadaver study with 16 orbits, resulting in a mean distance of 0.81 \( \pm \) 0.74 mm.\textsuperscript{62} Further clinical studies have shown the practicability of these standardized anatomical preformed orbital implants.\textsuperscript{24,63}

Anatomy of Orbital Cavity and Implant Design

The S-shaped of the orbital floor has an initial shallow convex section behind the rim, then inclines upward behind the
globe, and inclines upward to meet the medial wall, creating a retrobulbar bulge. These convex curves of the medial wall and floor create a “postbulbar constriction” of the orbital cavity, which must be reconstructed when the orbit is rebuilt following fractures. This anatomical information was encoded into the design of the preformed orbital implants. Therefore, the titanium implants are available in two different sizes for each side. The posterior edge and medial wall of the implant can be trimmed to optimize the implant size for better fitting to the orbital cavity. In a central part, the implant has a stiff center for guarantee its stability in the form following the common anatomical form of the orbital floor. Intersection bars offer a fast trimming to size resulting in smooth edges. At the anterior aspect of the implant, two arms can be used for screw fixation at the anterior inferior orbital rim (Fig. 3).

Placement of Orbital Implants

The reconstruction of the orbital walls, the repositioning of the prolapsed soft tissue, and the restoration of the ligament are the conditions necessary for correct positioning and functionality of the eyeball. Preformed orbital titanium implants are commonly inserted through a transconjunctival incision for orbital floor defects or a combined transconjunctival and transcaruncular approach for two wall defects. Transconjunctival incision involves a smaller risk of lower eyelid retraction compared with the subciliary approach. Particularly in older patients with pronounced wrinkling, subtarsal lower eyelid incision is still an option.

The entire defect of the orbital floor and medial wall should be exposed and the bony margins visualized. During preparation, important anatomical landmarks as the orbital rim, the inferior orbital fissure, the posterior orbital edge, and the junction between orbital floor and medial wall should be exposed to guarantee the accurate placement. After removing the displaced soft tissue out of the maxillary sinus, the posterior orbital edge, commonly not fractured, has to be indicated. Onto this region, the orbital implant has to be placed to offer bony support. The optical nerve will be at least 10 mm behind the preparation and will be out of the hazard zone (Fig. 4).

Intraoperative Imaging for Quality Control

Since the introduction of the cone beam computed tomography (CBCT) technique in 1997, smaller devices have been available for 3D image data acquisition. The introduction of mobile CBCT devices in the operating theater has offered the intraoperative radiological control option, which showed a better outcome because surgical revisions could be avoided (Fig. 5). An implementation of this technology into the existing virtual planning and navigation methods is simple due to the standardized DICOM data format and allows the development of new possibilities with regard to patient registration and simulation.

Functional Rehabilitation by Orbital Soft Tissue Surgery

Apart from structural changes because of bony displacement and its surgical reconstruction as described earlier, much

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**Fig. 3** Design of a preformed titanium orbital implant. Size modifications can easily performed by reducing the intersection bars.

**Fig. 4** Placement of the preformed orbital implant in an artificial skull. At the anterior aspect of the orbital rim, the fixation with one or two screws is possible.

**Fig. 5** Intraoperative image fusion of the preoperative (blue outline) and intraoperative data set (orange) in coronal view. In addition, the preoperative planning (segmentation and mirroring) and the intraoperative acquired was merged. The white arrow represents the real implant position comparing with the virtual planning one in red.
is attributed to ocular dysfunction resulting from displacement, scarring, and imbalancing of orbital soft tissue structures, leading to a diplopia and esthetical relevant disfigurement. It results from dysfunction of extraocular muscles, eyelids, or neuronal structures. As a rule, soft tissue corrections should be performed after reconstruction of the bony frame and usually represent the last elements in a chain of surgical procedures.

The correction of strabismus resulting from scarring or paralysis should lie in the hands of ophthalmic surgeons experienced in orbital and strabismus surgery closely cooperating with facial surgeons. In case of persisting diplopia that does not resolve within weeks after bony reconstruction, a precise 3D analysis of the ocular motility and eyeball position is mandatory before muscle surgery. Motility is ideally determined using a tangent screen with red-green goggles. The gaze direction of the affected eye can thus be plotted in relation to the fellow eye in the axial, sagittal, and coronal plane in nine different directions of gaze. On the basis of these data, the surgeon has to develop the most parsimonious surgical plan, that is, to achieve most benefit with the least amount of surgical manipulation. In general, it is often not possible to achieve normal ocular motility, if there is plenty of scarring, most often in the area of the orbital floor.\textsuperscript{91} While motility can be improved in some instances, the strabismus surgeon sometimes has to operate also on the healthy fellow eye. The goal is to achieve a useful field of binocular single vision in the straight-ahead direction, not in the entire field of gaze.\textsuperscript{92} In case of orbital soft tissue scarring, the usual dose-effect rules cannot be applied (e.g., 1.5 degrees change of gaze/mm recession or resection of a healthy rectus muscle). In our own experience, 17\% of patients perceived diplopia after orbital reconstruction necessitating subsequent strabismus surgery.

Eyelid deformations comprise ptosis, scar-related ectropion, rarely entropion, upward, or downward displacement of the medial or lateral lid angle. Surgical goals are the excision and release of scar tissue or the replacement of missing skin, for example, by free skin transplants from the retroauricular region. Ptosis can be corrected by graded resecting of the levator aponeurosis. The lid angles can be refixed by scar release and refixation at the orbital rim periosteum. Injured neuronal structures cannot be treated effectively. In acute optic nerve trauma, that is, traumatic optic neuropathy, any attempt to improve vision so far has been fruitless.\textsuperscript{93} Hence, optic canal decompression is obsolete. The same applies to megadoser steroid treatment. Quite often, orbital trauma is accompanied by closure of the structures draining the tears. Either the canaliculi or the nasolacrimal duct can become jolted or torn. This can be effectively stented immediately after trauma during reconstruction surgery or secondarily thereafter.

**Further Developments**

Considering the large amount of 3D DICOM data available in each hospital, larger and more precise cephalometrical and topographical analysis of anatomical mean shapes depending on different factors are possible. Besides this, specific algorithms such as the principle component analysis allow to analyze and to proceed not only cephalometric points but entire surface shapes and dimensions. Recently, these techniques have been used to generate standardized anatomical forms, clustered by different sizes to produce osteosynthesis plates and implants presenting better fitting and better biomechanical characteristics.\textsuperscript{53,61,63,94–96} Looking for variables to serve as predictor for shape as well as size variances in orbital floor reconstructions are the latest efforts in the orbital shape analysis.

Evaluating the different shape of the orbital cavity considering ethnic groups and/or gender predictors for orbital shape and depth could be determined. While population affinity was highly significant, gender was not reported to be significant. With regard to the orbital length, only 10\% of the variance could be explained by the ethnic group.

Rather more, the depth of the orbital cavity is linked to the shape of its medial wall and orbital floor. → Fig. 6 visualizes these distances in a map including the displacement vectors, whereas → Fig. 7 shows the displacement of its reference points (semilandmarks). The effect of the orbital length exists in a stretching of the S-shaped bulge. The longer the orbital cavity, the less steep the orbital bulge at the orbital floor and vice versa.

![Fig. 6](image-url) **Fig. 6** Heatmap visualizing distances between “long” and “short” orbit—scaled to sample’s average Centroid size. Left: caudal view; right: frontal view.
Conclusion

CAS procedures offer advantages in both primary and secondary orbital wall reconstruction. Navigation facilitates reconstruction in unilateral fractures through mirroring the unaffected side and in bilateral fractures by importing virtual models from standard CT data sets. A new standard for orbital reconstruction exist in combining anatomical preformed implants with intraoperative 3D imaging. Comparing the standardized preformed implants with patient-specific implants, the preformed titanium implants are available at once and the fitting accuracy has been presented sufficient. Topographical analysis of anatomical mean shapes of the human skull confirmed that length of the orbital cavity has the most impact of the orbital shape independent of gender and ethnic group. In addition, soft tissue surgery after severe trauma is often necessary for further functional rehabilitation.

References


Fig. 7 Shape differences between "long" and "short" orbit. The surface represents the sample's average.