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

Gido Bittermann, MD, DDS[1] Marc Christian Metzger, MD, DDS[1] Stefan Schlager, MD[2]
Wolf Alexander Lagrèze, MD, PhD[3] Nikolai Gross, MD[3] Carl-Peter Cornelius, MD, DDS[4]
Rainer Schmelzeisen, MD, DDS, PhD, FRCS[1]

[1] Department of Oral and Maxillofacial Surgery and Regional Plastic Surgery, Medical Center, University of Freiburg, Freiburg im Breisgau, Germany
[2] Biological Anthropology, Medical Center, University of Freiburg, Freiburg im Breisgau, Germany
[3] Eye Center, Medical Center, University of Freiburg, Freiburg im Breisgau, Germany
[4] Department of Oral and Maxillofacial Surgery, Ludwig-Maximilians-University Munich, Germany

Address for correspondence Gido Bittermann, MD, DDS, Department of Oral and Maxillofacial Surgery and Regional Plastic Surgery, Medical Center, University of Freiburg, Freiburg im Breisgau, Germany (e-mail: gido.bittermann@uniklinik-freiburg.de).

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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 zygomatic 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 sever reconstruction cases.[2,7–15] 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 reconstructions[21,22] (►**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**).

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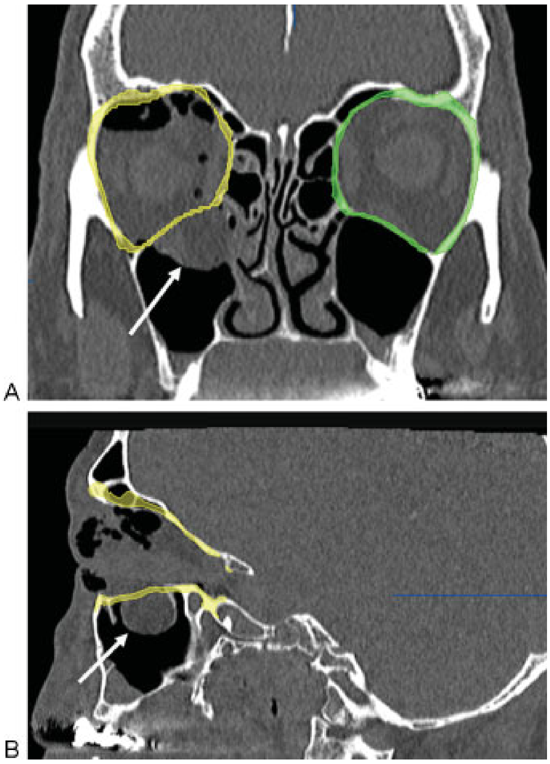

Fig. 1 Computed tomographic scan of a patient presenting a right orbital fracture with prolapsed periorbital soft tissue into the maxillary sinus (*arrow*). After segmentation, the unaffected left orbit (*green*) is mirrored in the median plane onto the affected side (*yellow*). **(A)** Coronal view and **(B)** Sagittal view.

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.[24–29]

Resorbable alloplastic membranes are suitable for small defects (up to 1 cm^2).[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[15,27,33–39] and a true to original reconstruction of the demanding 3D anatomy of the orbital walls is rarely achieved.[40–42]

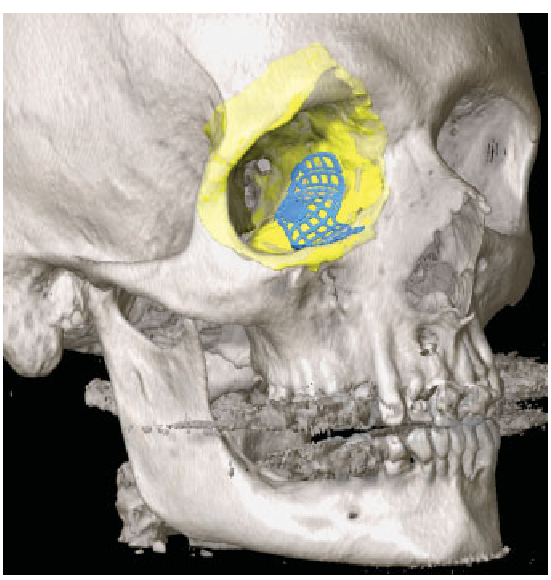

Fig. 2 Preoperative planning. Placement of a virtual orbital implant inside the right orbital cavity covering the defect of the orbital floor and the medial orbital wall presenting the wright positioning and size control of the implant.

Preformed Titanium Orbital Implants

Because of its excellent biocompatibility, titanium is a well-accepted alloplastic implant material.[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.[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.[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.[1,50–53] These techniques, in combination with intraoperative navigation, can improve the precision of surgical repair.[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.[61] The evaluation of the fitting accuracy was tested in a cadaver study with 16 orbits, resulting in a mean distance of 0.81 ± 0.74 mm.[62] Further clinical studies have shown the practicability of these standardized anatomical preformed orbital implants.[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.[21,29,40,64–67] 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.[68] 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**).

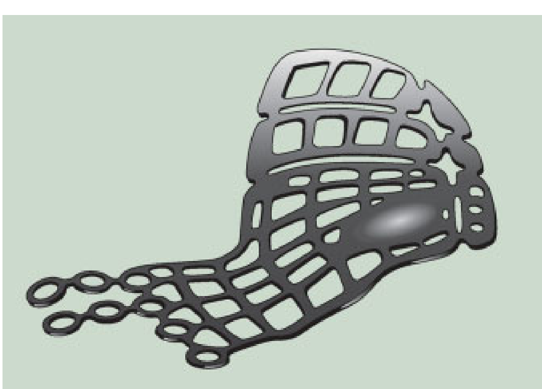

Fig. 3 Design of a preformed titanium orbital implant. Size modifications can easily performed by reducing the intersection bars.

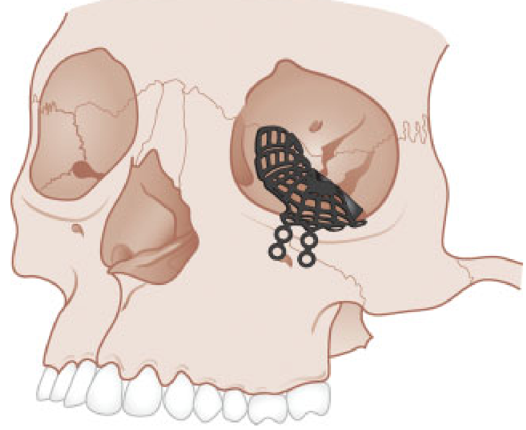

Fig. 4 Placement of the preformed orbital implant in an artificial skull. At the anterior aspect of the orbital rim, the fixation with one or two screws is possible.

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.[69–71] 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[72–86] (►**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.[77,79,80,87–90]

Functional Rehabilitation by Orbital Soft Tissue Surgery

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

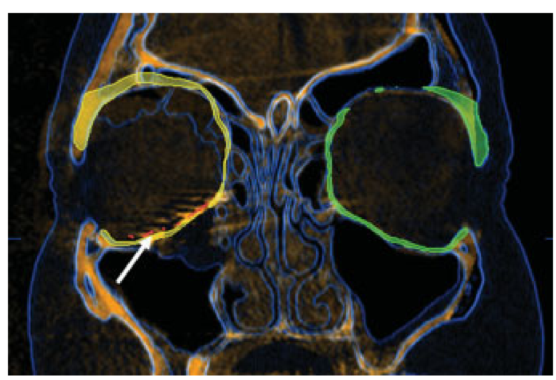

Fig. 5 Intraoperative image fusion of the preoperative (*blue outline*) and intraoperative data set (*orange*) in coronal view. In addition, the preoperative planning (segmentation and mirroring) and the intraoperative acquired was merged. The white arrow represents the real implant position comparing with the virtual planning one in red.

morbidity is attributed to ocular dysfunction resulting from displacement, scarring, and imbalancing of orbital soft tissue structures, leading to a diplopia and esthetical relevant disfiguration. 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.[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.[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 refixated 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.[93] Hence, optic canal decompression is obsolete. The same applies to megadose 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.[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.

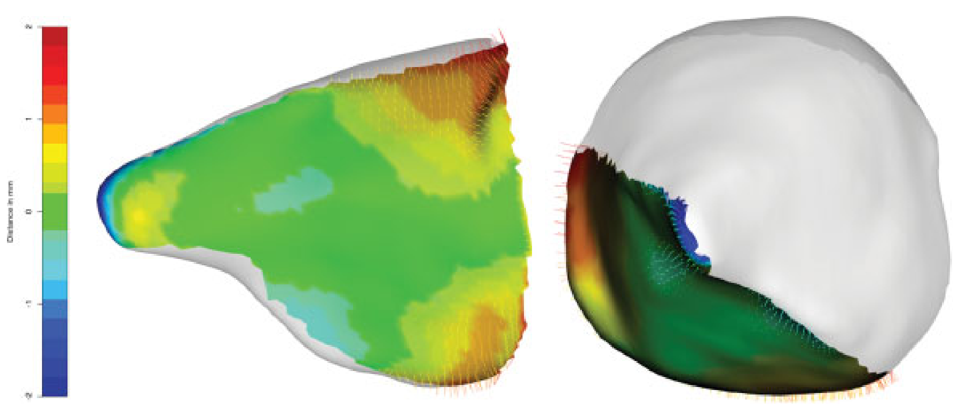

Fig. 6 Heatmap visualizing distances between “long” and “short” orbit—scaled to sample’s average Centroid size. Left: caudal view; right: frontal view.

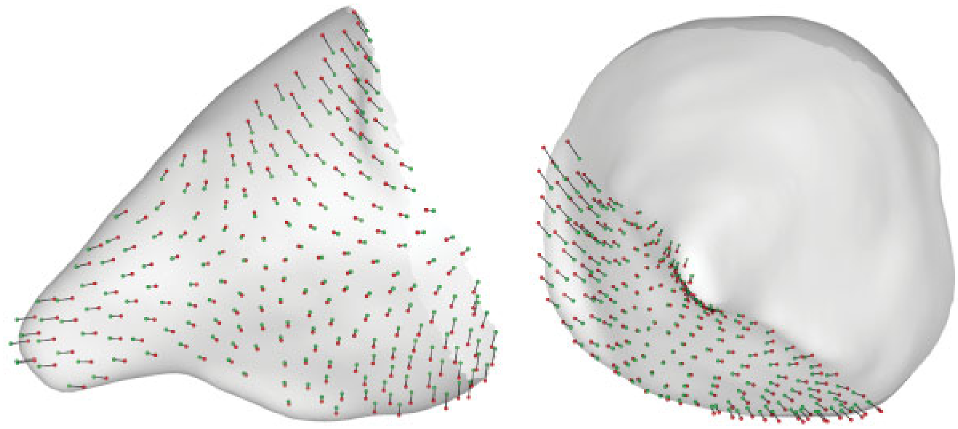

Fig. 7 Shape differences between "long" and "short" orbit. The surface represents the sample's average.

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 patent-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 sever trauma is often necessary for further functional rehabilitation.

References

1 Hoffmann J, Cornelius CP, Groten M, Pröbster L, Pfannenberg C, Schwenzer N. Orbital reconstruction with individually copy-milled ceramic implants. Plast Reconstr Surg 1998;101(3):604–612

2 Burm JS, Chung CH, Oh SJ. Pure orbital blowout fracture: new concepts and importance of medial orbital blowout fracture. Plast Reconstr Surg 1999;103(7):1839–1849

3 Nolasco FP, Mathog RH. Medial orbital wall fractures: classification and clinical profile. Otolaryngol Head Neck Surg 1995;112(4):549–556

4 Manolidis S, Weeks BH, Kirby M, Scarlett M, Hollier L. Classification and surgical management of orbital fractures: experience with 111 orbital reconstructions. J Craniofac Surg 2002;13(6):726–737, discussion 738

5 Fan X, Li J, Zhu J, Li H, Zhang D. Computer-assisted orbital volume measurement in the surgical correction of late enophthalmos caused by blowout fractures. Ophthal Plast Reconstr Surg 2003;19(3):207–211

6 Hammer B, Prein J. Correction of post-traumatic orbital deformities: operative techniques and review of 26 patients. J Craniomaxillofac Surg 1995;23(2):81–90

7 Watanabe E, Watanabe T, Manaka S, Mayanagi Y, Takakura K. Three-dimensional digitizer (neuronavigator): new equipment for computed tomography-guided stereotaxic surgery. Surg Neurol 1987;27(6):543–547

8 Salvolini U. Traumatic injuries: imaging of facial injuries. Eur Radiol 2002;12(6):1253–1261

9 Marsh JL, Gado M. The longitudinal orbital CT projection: a versatile image for orbital assessment. Plast Reconstr Surg 1983;71(3):308–317

10 Waitzman AA, Posnick JC, Armstrong DC, Pron GE. Craniofacial skeletal measurements based on computed tomography: Part I. Accuracy and reproducibility. Cleft Palate Craniofac J 1992;29(2):112–117

11 Farkas LG, Katic MJ, Forrest CR, et al. International anthropometric study of facial morphology in various ethnic groups/races. J Craniofac Surg 2005;16(4):615–646

12 Chau A, Fung K, Yip L, Yap M. Orbital development in Hong Kong Chinese subjects. Ophthalmic Physiol Opt 2004;24(5):436–439

13 Furuta M. Measurement of orbital volume by computed tomography: especially on the growth of the orbit. Jpn J Ophthalmol 2001;45(6):600–606

14 Bentley RP, Sgouros S, Natarajan K, Dover MS, Hockley AD. Normal changes in orbital volume during childhood. J Neurosurg 2002;96(4):742–746

15 Converse JM, Smith B, Obear MF, Wood-Smith D. Orbital blowout fractures: a ten-year survey. Plast Reconstr Surg 1967;39(1):20–36

16 Hassfeld S, Mühling J, Zöller J. Intraoperative navigation in oral and maxillofacial surgery. Int J Oral Maxillofac Surg 1995;24(1, Pt 2):111–119

17 Frodel JL Jr, Pacheco E. The use of intraoperative image-guided surgical techniques for reconstruction of orbital and zygomatic deformities. Facial Plast Surg 1999;15(1):83–89

18 Ploder O, Wagner A, Enislidis G, Ewers R. Computer-assisted intraoperative visualization of dental implants. Augmented reality in medicine in German]. Radiologe 1995;35(9):569–572

19 Wagner A, Ploder O, Enislidis G, Truppe M, Ewers R. Virtual image guided navigation in tumor surgery—technical innovation. J Craniomaxillofac Surg 1995;23(5):217–3

20 Marmulla R, Hilbert M, Niederdellmann H. Inherent precision of mechanical, infrared and laser-guided navigation systems for computer-assisted surgery. J Craniomaxillofac Surg 1997;25(4):192–197

21 Gellrich NC, Schramm A, Hammer B, et al. Computer-assisted secondary reconstruction of unilateral posttraumatic orbital deformity. Plast Reconstr Surg 2002;110(6):1417–1429

22 Zizelmann C, Gellrich NC, Metzger MC, Schoen R, Schmelzeisen R, Schramm A. Computer-assisted reconstruction of orbital floor based on cone beam tomography. Br J Oral Maxillofac Surg 2007;45(1):79–80
23 Metzger MC, Bittermann G, Dannenberg L, et al. Design and development of a virtual anatomic atlas of the human skull for automatic segmentation in computer-assisted surgery, preoperative planning, and navigation. Int J CARS 2013;8(5):691–702
24 Scolozzi P, Jaques B. Computer-aided volume measurement of posttraumatic orbits reconstructed with AO titanium mesh plates: accuracy and reliability. Ophthal Plast Reconstr Surg 2008;24(5): 383–389
25 Gosau M, Schöneich M, Draenert FG, Ettl T, Driemel O, Reichert TE. Retrospective analysis of orbital floor fractures—complications, outcome, and review of literature. Clin Oral Investig 2011;15(3): 305–313
26 Jank S, Emshoff R, Schuchter B, Strobl H, Brandlmaier I, Norer B. Orbital floor reconstruction with flexible Ethisorb patches: a retrospective long-term follow-up study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;95(1):16–22
27 Yilmaz M, Vayvada H, Aydin E, Menderes A, Atabey A. Repair of fractures of the orbital floor with porous polyethylene implants. Br J Oral Maxillofac Surg 2007;45(8):640–644
28 Tang W, Guo L, Long J, et al. Individual design and rapid prototyping in reconstruction of orbital wall defects. J Oral Maxillofac Surg 2010;68(3):562–570
29 Guo L, Tian W, Feng F, Long J, Li P, Tang W. Reconstruction of orbital floor fractures: comparison of individual prefabricated titanium implants and calvarial bone grafts. Ann Plast Surg 2009;63(6): 624–631
30 Hidding J, Deitmer T, Hemprich A, Ahrberg W. Primary correction of orbital fractures using PDS-foil [in German]. Fortschr Kiefer Gesichtschir 1991;36:195–196
31 Eppley BL, Sadove AM, Havlik RJ. Resorbable plate fixation in pediatric craniofacial surgery. Plast Reconstr Surg 1997;100(1): 1–7, discussion 8–13
32 Dietz A, Ziegler CM, Dacho A, et al. Effectiveness of a new perforated 0.15. mm poly-p-dioxanon-foil versus titanium-dynamic mesh in reconstruction of the orbital floor. J Craniomaxillofac Surg 2001;29(2):82–88
33 Kozakiewicz M, Elgalal M, Loba P, et al. Clinical application of 3D pre-bent titanium implants for orbital floor fractures. J Craniomaxillofac Surg 2009;37(4):229–234
34 Morotomi T, Matsunaga K, Kusuhara H, et al. Long-term result of a biodegradable osteo-inductive copolymer for the treatment of orbital blowout fracture. J Craniomaxillofac Surg 2014;42(5): 443–447
35 Gierloff M, Seeck NG, Springer I, Becker S, Kandzia C, Wiltfang J. Orbital floor reconstruction with resorbable polydioxanone implants. J Craniofac Surg 2012;23(1):161–164
36 Browning CW. Alloplast materials in orbital repair. Am J Ophthalmol 1967;63(5):955–962
37 Weintraub B, Cucin RL, Jacobs M. Extrusion of an infected orbital-floor prosthesis after 15 years. Plast Reconstr Surg 1981;68(4): 586–587
38 Jordan DR, St Onge P, Anderson RL, Patrinely JR, Nerad JA. Complications associated with alloplastic implants used in orbital fracture repair. Ophthalmology 1992;99(10):1600–1608
39 Mauriello JA Jr. Inferior rectus muscle entrapped by Teflon implant after orbital floor fracture repair. Ophthal Plast Reconstr Surg 1990;6(3):218–220
40 Schramm A, Gellrich N-C, Naumann S, Bühner U, Schön R, Schmelzeisen R. Non-invasive referencing in computer assisted surgery. Med Biol Eng Comp Suppl. 1999;37:644–645
41 Schmelzeisen R, Gellrich NC, Schoen R, Gutwald R, Zizelmann C, Schramm A. Navigation-aided reconstruction of medial orbital wall and floor contour in cranio-maxillofacial reconstruction. Injury 2004;35(10):955–962
42 Gear AJ, Lokeh A, Aldridge JH, Migliori MR, Benjamin CI, Schubert W. Safety of titanium mesh for orbital reconstruction. Ann Plast Surg 2002;48(1):1–7, discussion 7–9
43 Scolozzi P, Momjian A, Heuberger J. Computer-aided volumetric comparison of reconstructed orbits for blow-out fractures with nonpreformed versus 3-dimensionally preformed titanium mesh plates: a preliminary study. J Comput Assist Tomogr 2010;34(1): 98–104
44 Ellis E III, Tan Y. Assessment of internal orbital reconstructions for pure blowout fractures: cranial bone grafts versus titanium mesh. J Oral Maxillofac Surg 2003;61(4):442–453
45 Glassman RD, Manson PN, Vanderkolk CA, et al. Rigid fixation of internal orbital fractures. Plast Reconstr Surg 1990;86(6): 1103–1109, discussion 1110–1111
46 Oliver AJ. The use of titanium mesh in the management of orbital trauma—a retrospective study. Ann R Australas Coll Dent Surg 2000;15:193–198
47 Kuttenberger JJ, Hardt N. Long-term results following reconstruction of craniofacial defects with titanium micro-mesh systems. J Craniomaxillofac Surg 2001;29(2):75–81
48 Schubert W, Gear AJ, Lee C, et al. Incorporation of titanium mesh in orbital and midface reconstruction. Plast Reconstr Surg 2002; 110(4):1022–1030, discussion 1031–1032
49 Lazaridis N, Makos C, Iordanidis S, Zouloumis L. The use of titanium mesh sheet in the fronto-zygomatico-orbital region. Case reports. Aust Dent J 1998;43(4):223–228
50 Schipper J, Ridder GJ, Spetzger U, Teszler CB, Fradis M, Maier W. Individual prefabricated titanium implants and titanium mesh in skull base reconstructive surgery. A report of cases. Eur Arch Otorhinolaryngol 2004;261(5):282–290
51 Hoffmann J, Cornelius CP, Groten M, Pröbster L, Schwenzer N. Using individually designed ceramic implants for secondary reconstruction of the bony orbit [in German]. Mund Kiefer Gesichtschir 1998;2(Suppl 1):S98–S101
52 Holck DE, Boyd EM Jr, Ng J, Mauffray RO. Benefits of stereolithography in orbital reconstruction. Ophthalmology 1999; 106(6):1214–1218
53 Metzger MC, Schön R, Zizelmann C, Weyer N, Gutwald R, Schmelzeisen R. Semiautomatic procedure for individual preforming of titanium meshes for orbital fractures. Plast Reconstr Surg 2007; 119(3):969–976
54 Schmelzeisen R, Schramm A. Computer-assisted reconstruction of the facial skeleton. Arch Facial Plast Surg 2003;5(5):437
55 Bite U, Jackson IT, Forbes GS, Gehring DG. Orbital volume measurements in enophthalmos using three-dimensional CT imaging. Plast Reconstr Surg 1985;75(4):502–508
56 Eufinger H, Wittkampf AR, Wehmöller M, Zonneveld FW. Single-step fronto-orbital resection and reconstruction with individual resection template and corresponding titanium implant: a new method of computer-aided surgery. J Craniomaxillofac Surg 1998; 26(6):373–378
57 Heissler E, Fischer FS, Bolouri S, et al. Custom-made cast titanium implants produced with CAD/CAM for the reconstruction of cranium defects. Int J Oral Maxillofac Surg 1998;27(5): 334–338
58 Perry M, Banks P, Richards R, Friedman EP, Shaw P. The use of computer-generated three-dimensional models in orbital reconstruction. Br J Oral Maxillofac Surg 1998;36(4):275–284
59 Chang PS, Parker TH, Patrick CW Jr, Miller MJ. The accuracy of stereolithography in planning craniofacial bone replacement. J Craniofac Surg 2003;14(2):164–170
60 Kermer C, Lindner A, Friede I, Wagner A, Millesi W. Preoperative stereolithographic model planning for primary reconstruction in craniomaxillofacial trauma surgery. J Craniomaxillofac Surg 1998; 26(3):136–139
61 Metzger MC, Schön R, Tetzlaf R, et al. Topographical CT-data analysis of the human orbital floor. Int J Oral Maxillofac Surg 2007;36(1):45–53

62 Metzger MC, Schön R, Weyer N, et al. Anatomical 3-dimensional pre-bent titanium implant for orbital floor fractures. Ophthalmology 2006;113(10):1863–1868
63 Strong EB, Fuller SC, Wiley DF, Zumbansen J, Wilson MD, Metzger MC. Preformed vs intraoperative bending of titanium mesh for orbital reconstruction. Otolaryngol Head Neck Surg 2013;149(1):60–66
64 Farkas LG. Accuracy of anthropometric measurements: past, present, and future. Cleft Palate Craniofac J 1996;33(1):10–18, discussion 19–22
65 Mazock JB, Schow SR, Triplett RG. Evaluation of ocular changes secondary to blowout fractures. J Oral Maxillofac Surg 2004;62(10):1298–1302
66 Clauser L, Galiè M, Pagliaro F, Tieghi R. Posttraumatic enophthalmos: etiology, principles of reconstruction, and correction. J Craniofac Surg 2008;19(2):351–359
67 Mustardé JC. The role of Lockwood's suspensory ligament in preventing downward displacement of the eye. Br J Plast Surg 1968;21(1):73–81
68 Ben Simon GJ, Molina M, Schwarcz RM, McCann JD, Goldberg RA. External (subciliary) vs internal (transconjunctival) involutional entropion repair. Am J Ophthalmol 2005;139(3):482–487
69 Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur Radiol 1998;8(9):1558–1564
70 Ng P, Chu C, Young N, Soo M. Imaging of orbital floor fractures. Australas Radiol 1996;40(3):264–268
71 Hohlweg-Majert B, Metzger MC, Kummer T, Schulze D. Morphometric analysis - Cone beam computed tomography to predict bone quality and quantity. J Craniomaxillofac Surg 2011;39(5):330–334
72 Heiland M, Schmelzle R, Hebecker A, Schulze D. Intraoperative 3D imaging of the facial skeleton using the SIREMOBIL Iso-C3D. Dentomaxillofac Radiol 2004;33(2):130–132
73 Heiland M, Schulze D, Blake F, Schmelzle R. Intraoperative imaging of zygomaticomaxillary complex fractures using a 3D C-arm system. Int J Oral Maxillofac Surg 2005;34(4):369–375
74 Siewerdsen JH, Moseley DJ, Burch S, et al. Volume CT with a flat-panel detector on a mobile, isocentric C-arm: pre-clinical investigation in guidance of minimally invasive surgery. Med Phys 2005;32(1):241–254
75 Pohlenz P, Blessmann M, Blake F, Gbara A, Schmelzle R, Heiland M. Major mandibular surgical procedures as an indication for intraoperative imaging. J Oral Maxillofac Surg 2008;66(2):324–329
76 Korbmacher H, Kahl-Nieke B, Schöllchen M, Heiland M. Value of two cone-beam computed tomography systems from an orthodontic point of view. J Orofac Orthop 2007;68(4):278–289
77 Barker E, Trimble K, Chan H, et al. Intraoperative use of cone-beam computed tomography in a cadaveric ossified cochlea model. Otolaryngol Head Neck Surg 2009;140(5):697–702
78 Blake FA, Blessmann M, Pohlenz P, Heiland M. A new imaging modality for intraoperative evaluation of sinus floor augmentation. Int J Oral Maxillofac Surg 2008;37(2):183–185
79 Gröbe A, Weber C, Schmelzle R, Heiland M, Klatt J, Pohlenz P. The use of navigation (BrainLAB Vector vision(2)) and intraoperative 3D imaging system (Siemens Arcadis Orbic 3D) in the treatment of gunshot wounds of the maxillofacial region. Oral Maxillofac Surg 2009;13(3):153–158
80 Hamming NM, Daly MJ, Irish JC, Siewerdsen JH. Effect of fiducial configuration on target registration error in intraoperative cone-beam CT guidance of head and neck surgery. Conf Proc IEEE Eng Med Biol Soc 2008;2008:3643–3648
81 Mischkowski RA, Zinser MJ, Ritter L, Neugebauer J, Keeve E, Zöller JE. Intraoperative navigation in the maxillofacial area based on 3D imaging obtained by a cone-beam device. Int J Oral Maxillofac Surg 2007;36(8):687–694
82 Pohlenz P, Blake F, Blessmann M, et al. Intraoperative cone-beam computed tomography in oral and maxillofacial surgery using a C-arm prototype: first clinical experiences after treatment of zygomaticomaxillary complex fractures. J Oral Maxillofac Surg 2009;67(3):515–521
83 Pohlenz P, Blessmann M, Blake F, Heinrich S, Schmelzle R, Heiland M. Clinical indications and perspectives for intraoperative cone-beam computed tomography in oral and maxillofacial surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103(3):412–417
84 Rafferty MA, Siewerdsen JH, Chan Y, et al. Intraoperative cone-beam CT for guidance of temporal bone surgery. Otolaryngol Head Neck Surg 2006;134(5):801–808
85 Rafferty MA, Siewerdsen JH, Chan Y, et al. Investigation of C-arm cone-beam CT-guided surgery of the frontal recess. Laryngoscope 2005;115(12):2138–2143
86 Zizelmann C, Gellrich NC, Metzger MC, Schoen R, Schmelzeisen R, Schramm A. Computer-assisted reconstruction of orbital floor based on cone beam tomography. Br J Oral Maxillofac Surg 2007;45(1):79–80
87 Feuerstein M, Mussack T, Heining SM, Navab N. Intraoperative laparoscope augmentation for port placement and resection planning in minimally invasive liver resection. IEEE Trans Med Imaging 2008;27(3):355–369
88 Hamming NM, Daly MJ, Irish JC, Siewerdsen JH. Automatic image-to-world registration based on x-ray projections in cone-beam CT-guided interventions. Med Phys 2009;36(5):1800–1812
89 Teber D, Guven S, Simpfendörfer T, et al. Augmented reality: a new tool to improve surgical accuracy during laparoscopic partial nephrectomy? Preliminary in vitro and in vivo results. Eur Urol 2009;56(2):332–338
90 Aschendorff A, Maier W, Jaekel K, et al. Radiologically assisted navigation in cochlear implantation for X-linked deafness malformation. Cochlear Implants Int 2009;10(Suppl 1):14–18
91 Cruz OA, Lynch JT, Roper-Hall G. Management of vertical ocular deviations secondary to restrictive conditions. Am Orthopt J 2011;61:19–22
92 Loba P, Kozakiewicz M, Nowakowska O, Omulecki W, Broniarczyk-Loba A. Management of persistent diplopia after surgical repair of orbital fractures. J AAPOS 2012;16(6):548–553
93 Lagrèze W. Treatment of optic neuropathies—state of the art [in German]. Klin Monatsbl Augenheilkd 2009;226(11):875–880
94 Probst FA, Mast G, Ermer M, et al. MatrixMANDIBLE preformed reconstruction plates—a two-year two-institution experience in 71 patients. J Oral Maxillofac Surg 2012;70(11):e657–e666
95 Metzger MC, Vogel M, Hohlweg-Majert B, et al. Anatomical shape analysis of the mandible in Caucasian and Chinese for the production of preformed mandible reconstruction plates. J Craniomaxillofac Surg 2011;39(6):393–400
96 Metzger MC, Schön R, Schmelzeisen R. Preformed titanium meshes: a new standard? Skull Base 2007;17(4):269–272