Low-profile titanium mesh in the use of orbital reconstruction: A pilot study

Article *in* The Laryngoscope · May 2012

Impact Factor: 2.14 · DOI: 10.1002/lary.23200 · Source: PubMed

5 authors, including:

Olivier Lieger
Universität Bern
29 PUBLICATIONS **388** CITATIONS
SEE PROFILE

Benoit Schaller
Inselspital, Universitätsspital Bern
46 PUBLICATIONS **450** CITATIONS
SEE PROFILE

Frauke Kellner-Weldon
Inselspital, Universitätsspital Bern
26 PUBLICATIONS **124** CITATIONS
SEE PROFILE

Tateyuki Iizuka
Universität Bern
68 PUBLICATIONS **1,715** CITATIONS
SEE PROFILE

The Laryngoscope

Low-Profile Titanium Mesh in the Use of Orbital Reconstruction: A Pilot Study

Olivier Lieger, MD, DMD; Benoit Schaller, MD, DMD; Frauke Kellner, MD;
Brigitte Messmer-Schai; Tateyuki Iizuka, MD, DDS

Objectives/Hypothesis: The purpose of this study was to share our clinical experience in the use and accuracy of a newly designed, low-profile titanium mesh (Modus OPS 1.5; Medartis, Basel, Switzerland) for primary internal orbital reconstruction.

Study Design: Observational study.

Methods: This study was conducted at the Department of Cranio-Maxillofacial Surgery at the University Hospital of Bern, Switzerland, starting November 2008. Patients were included who had a defect size of $\geq$2 cm^2 or fractures of more than one wall. The operations were performed within 14 days after trauma. To repair the orbital fracture, a newly designed titanium mesh was applied. The technical innovation in regard to these plates is the low-profile height of 0.25 mm along the border and 0.2 mm in the mesh area. Two different sizes of two different types of mesh are available for reconstruction. Preoperative computed tomography (CT) scans were obtained to assess the fracture size and location. A maxillofacial surgeon performed pre- and postoperative assessments (at 2 weeks, 12 weeks, and 6 months). Ophthalmologic assessments were performed preoperatively and 6 months after the operation. Postoperative CT scans were obtained within 12 weeks after the operation and the orbital volumes analyzed by a radiologist.

Results: Twenty-seven patients underwent surgery (11 female; average age, 55.2 years). Final postoperative ophthalmologic follow-up was obtained at a mean of 8.8 months (range, 4.0–20.1 months). Twenty-five patients (93%) had a successful treatment outcome without complications. In two patients, the plate was buckled in the posterior edge region and had to be replaced. Surgical revision was performed within 3 weeks after the first procedure. These patients showed good clinical and radiologic outcome after the second procedure. At the final assessment, none of the patients had experienced diplopia. Three patients showed slight enophthalmos (2-mm side difference), however, without any subjective functional or aesthetic concerns. According to the literature, an average orbital volume difference of up to 1.95 cm^3 is normal. In our study, radiologic volume assessment showed a side difference of $\geq$2 cm^3 in four patients, of which one patient presented with a clinically detectable enophthalmos.

Conclusions: The newly designed, thin titanium mesh is a reliable and safe implant for the repair of orbital defects. Owing to insufficient intraoperative control, two plates showed buckling at the posterior border, which made a repair necessary. Awareness of this problem may avoid such complications in the future. However, it would seem reasonable to improve the stability of the mesh by increasing the profile height, to minimize potential complications.

Key Words: Blow-out fractures, orbital fracture, orbital reconstruction, posttraumatic repair, titanium mesh.

Level of Evidence: 4

***Laryngoscope,* 000:000–000, 2012**

INTRODUCTION

In craniofacial trauma, the involvement of orbital structures is noted in up to 40% of cases.[1] Posttraumatic orbital deformities caused by incorrect reconstruction of orbital dimensions are severe complications causing enophthalmos, diplopia, and visual acuity disturbance. To prevent such complications, immediate repair of orbital injuries with the restoration of normal anatomy is indicated in orbital floor fractures. With the help of biodegradable implants, small and medium-sized defects are easily managed.[2,3] In extensive fractures, however, only calvarian bone and titanium mesh are considered to provide sufficient support of the orbital content.

Calvarial bone can be difficult to mould and to adapt to the form and size of the orbital lesion. In addition, donor site morbidity cannot be disregarded. Orbital reconstruction mesh, on the other hand, is always available and easier to apply. There are important requirements for these meshes, such as biocompatibility, excellent stability, optimal adaptability, and patient comfort. Recently, the company Medartis developed a titanium mesh featuring a low profile. For a patient to regain normal function, normal anatomy has to be

From the Department of Cranio-Maxillofacial Surgery (O.L.), Hospital Luzern, Luzern, Switzerland; and Department of Cranio-Maxillofacial Surgery (B.S., T.I.), Department of Radiology (F.K.), Department of Ophthalmology (B.M.-S.), University Bern, University Hospital, Bern, Switzerland.

Editor's Note: This Manuscript was accepted for publication December 21, 2011.

This work was funded by the International Bone Research Association, Basel, Switzerland. The authors have no other funding, financial relationships, or conflicts of interest to disclose.

Send correspondence to Olivier Lieger, MD, DMD, Department of Cranio-Maxillofacial Surgery, Hospital Luzern, 6000 Luzern 16, Switzerland. E-mail: olivier.lieger@ksl.ch

DOI: 10.1002/lary.23200

TABLE I.
Classification of Orbital Wall Defects.

Category	Description Note	Specification
I	Isolated defect of the orbital floor or the medial wall, 1–2 cm^2, within the anterior two-thirds	
II	Defect of the orbital floor and/or of the medial wall, >2 cm^2, within the anterior two-thirds	Bony ledge preserved at the medial margin of the infraorbital fissure
III	Defect of the orbital floor and/or of the medial wall, >2 cm^2, within the anterior two-thirds	Missing bony ledge medial to the infraorbital fissure
IV	Defect of the entire orbital floor and the medial wall, extending into the posterior third	Missing bony ledge medial to the infraorbital fissure
V	Same as IV, defect extending into the orbital roof	

Classification of orbital wall defects according to Jaquiery et al.[4]

reestablished. It therefore seemed reasonable to assess an implant that would facilitate orbital reconstruction without disturbing normal anatomy by its size, profile height, or properties.

The purpose of this study was to assess the use and accuracy of the low-profile titanium mesh for primary internal orbital reconstruction.

MATERIAL AND METHODS

Patients

Twenty-seven patients were treated using the low-profile titanium mesh. The operations were performed at the Department of Cranio-Maxillofacial Surgery at the University-Hospital of Bern, Switzerland, between December 2008 and October 2010. Selection criteria for this prospective study were adult patients (>18 years) presenting with a unilateral orbital blow-out or blow-in fracture of ($\geq$2.0 cm^2) causing an actual or expected functional or aesthetical deficit. Patients had to undergo surgery within 2 weeks of trauma. Exclusion criteria included individuals who did not have any vision on the affected side or who, according to ophthalmologists, should not have surgical treatment. Furthermore, patients who were unable to adequately understand written or oral information in German or French were excluded. Informed consent was obtained from each patient.

Before surgery, a maxillofacial surgeon examined the patient with regard to bone and soft-tissue lesions as well as concomitant injuries. An ophthalmologist then assessed eye lesions and quantified eye mobility, bulb positioning (Hertel exophthalmometry), and the field of binocular vision (Goldmann perimetry).

Preoperative 1-mm computed tomography (CT) scans were obtained to analyze size and location of the defect as well as extent of muscle entrapment. The fractures were classified according to the scores introduced by Jaquiery et al. (Table I).[4]

Intraoperatively and within the following 24 hours, three doses of amoxicillin/clavulanic acid (1.2 g) were administered intravenously.

Operations were performed with general anesthesia. For orbital repair, the titanium mesh (Medartis, Basel, Switzerland) was applied. The size of the mesh, the surgical approach, and any problems occurring during the application were recorded.

Follow-up by the maxillofacial surgeon was then performed 2, 6, and 12 weeks after the operation, analyzing the same aspects as were analyzed preoperatively. In addition, patients were asked about impairment due to the operation, including discomfort in the infraorbital rim region.

Postoperative CT scans were obtained within 12 weeks after the operation. To assess accuracy, postoperative orbital volume measurements were performed. The same radiologist evaluated volume changes and accuracy in reconstruction.

Ophthalmologic and Orthoptic Examination

The ophthalmology protocol included a preoperative and a follow-up assessment at 12 weeks after the procedure. Eye motility was measured in millimeters (monocular excursion in millimeters). Monocular visual field was assessed using the Goldmann perimetry test (measured in degrees in horizontal and vertical direction). The field of binocular vision was analyzed with the help of the Harms tangent screen (measured in percentage of the total). Enophthalmos was assessed using Hertel exophthalmometry (measured in millimeters).

Plate Design

The aim of the manufacturer (Medartis) was to develop a new orbital mesh that would allow the surgeons to improve the accuracy in orbital reconstruction. To achieve this goal, a thin but stable mesh had to be developed. It also had to be an implant that would perfectly fit into the area required and that would be easy to handle. To solve this problem, engineers looked for an optimal mesh geometry that would result in the most stable structure when loaded with the orbital content (Fig. 1). For this step, the software program TOSCA/ABAQUS (Simulia, Providence, RI) was used. To create a plate that would be moldable and precise in fit, a stable and rigid structure was combined with a flexible three-dimensional (3D) mesh structure. To achieve this combination, areas of the mesh that would presumably undergo little bending were identified. These regions were designed using a stable structure (Fig. 2). The

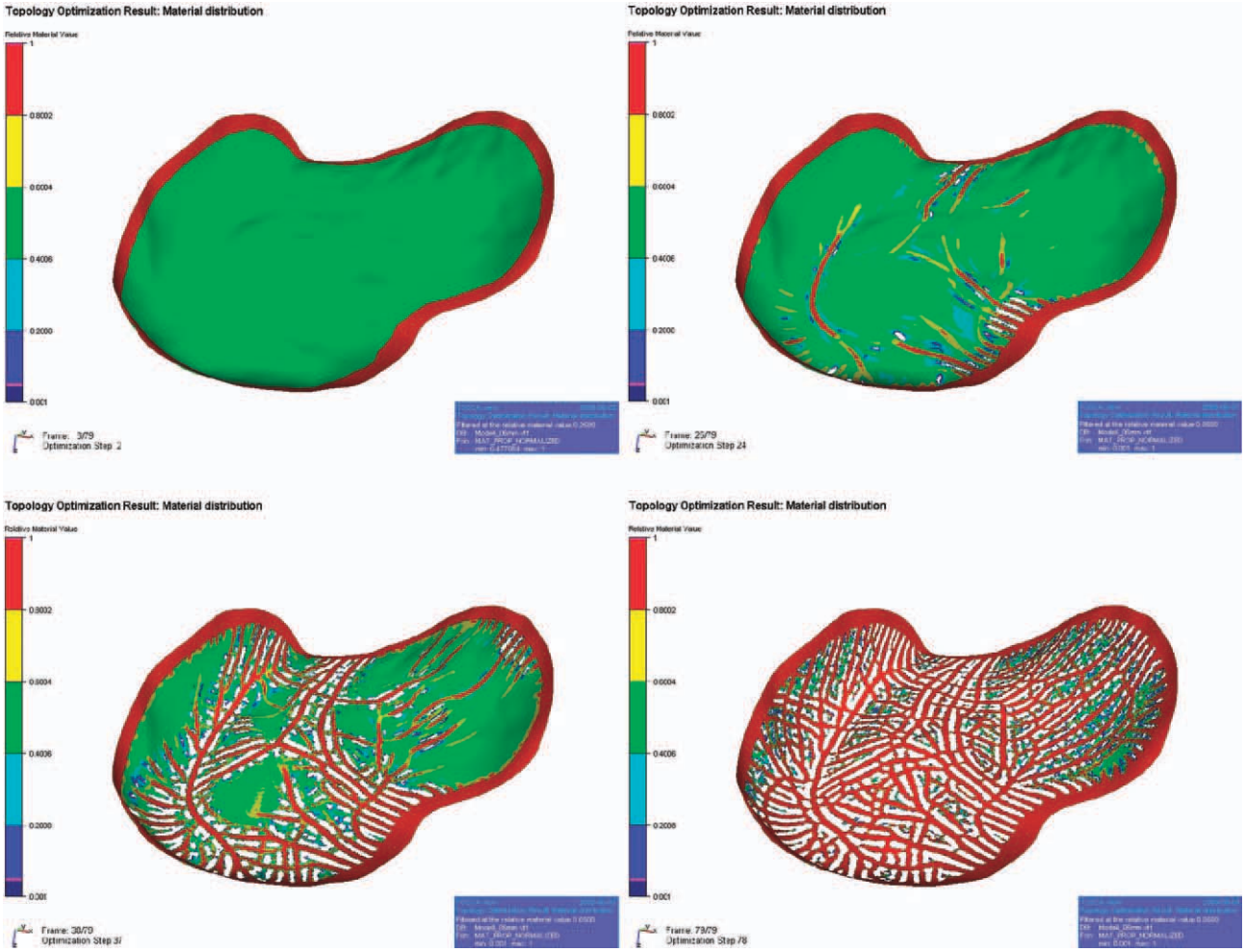

Fig. 1. Design process of optimal mesh geometry. View onto right orbital floor. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

remaining areas were replaced with the flexible 3D mesh (Fig. 3 and Fig. 4).

With this structural combination, optimal moldability and stability could be obtained. A profile height of 0.25 mm along the border and 0.2 mm in the mesh area was defined. To assess the stability, finite element analysis as well as quasi-static bending test were performed and showed excellent results.

Operative Procedures

Surgical revisions were performed with general anesthesia. The orbital floor was routinely exposed via a transconjunctival incision (Fig. 5). In patients with involvement of the medial wall, a combined transconjunctival-transcaruncular approach was used. Herniated or incarcerated tissue was then complete repositioned. Stable borders around the bony defect in the orbital floor were exposed. The aluminum template was prebent and controlled in situ. Type and size of mesh were chosen and adjustments performed, as needed (Fig. 6). Following the bending of the titanium mesh according to the template, it was inserted and fixed with 1.5-mm screws.

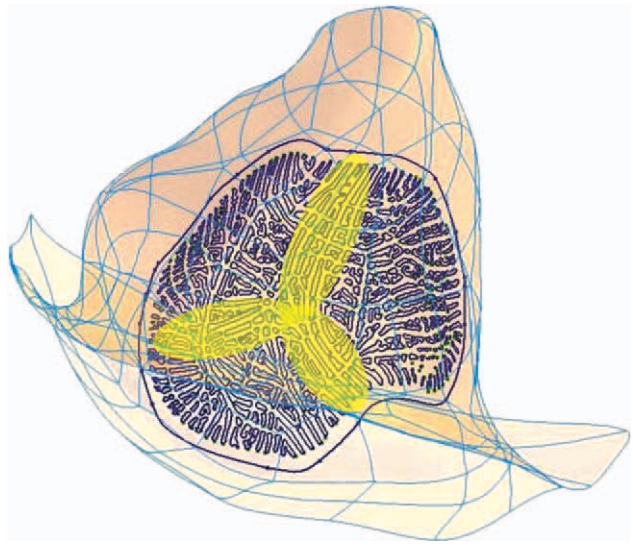

Fig. 2. Design process of optimal mesh geometry defining areas of the mesh that would presumably undergo only a little bending (marked in yellow). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

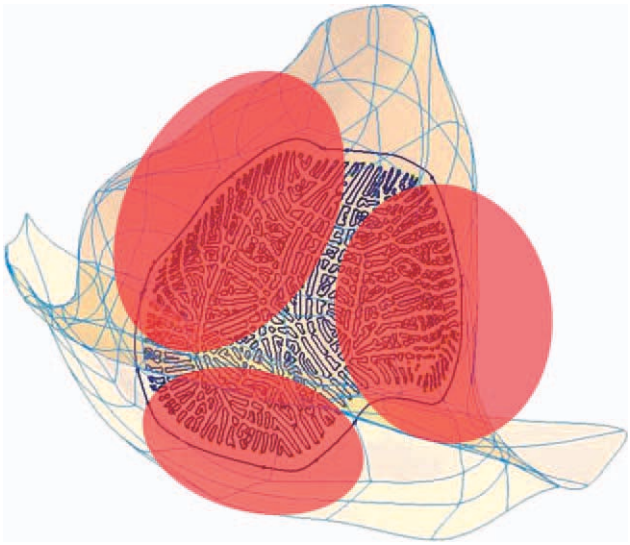

Fig. 3. Design process of optimal mesh geometry defining areas of the mesh that need to be flexible (marked in red). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Alternatively, the mesh could be preformed, using a sterilized skull model to shape and contour it to a normal orbit (Fig. 7). Finally, eye bulb mobility was controlled using fine forceps (forced duction test) and the wound closed Vicryl (Johnson & Johnson, Norderstedt, Germany) 5/0 rapid; optional). The surgery was performed by six different surgeons, of which four were trainees.

Image Acquisition and Analysis

All CT studies were performed on a LightSpeed Ultra 8-section multisection scanner (GE Healthcare, Milwaukee, WI). The CT protocol included unenhanced

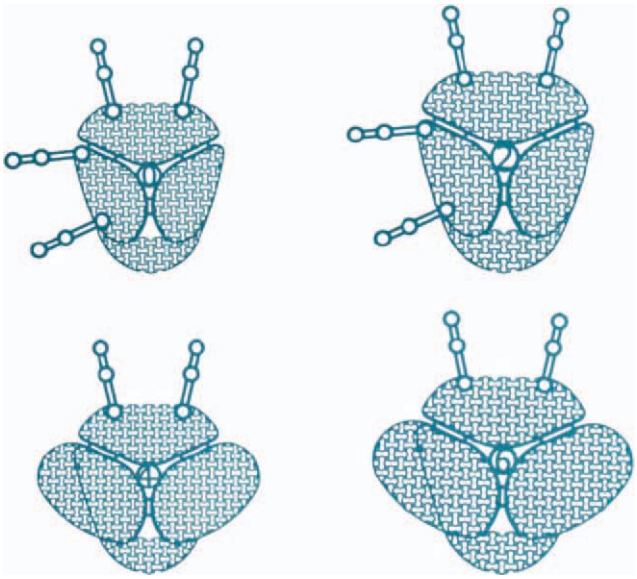

Fig. 4. Final design of the orbital meshes. The titanium meshes are available in two different types with two different sizes of each. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

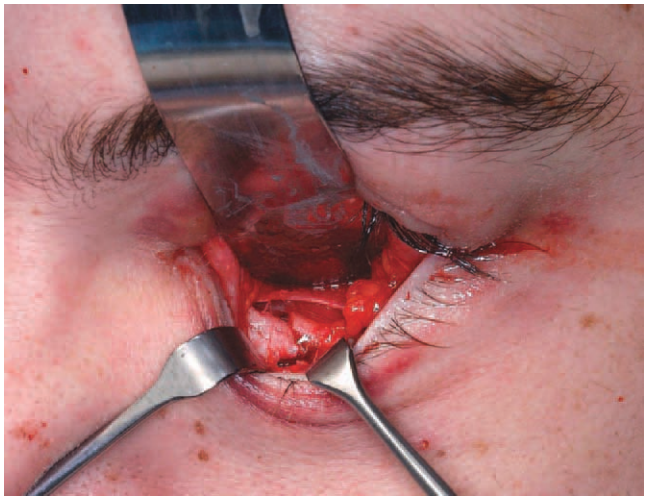

Fig. 5. Transconjunctival postseptal surgical approach. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

CT scanning with transverse sections of 1-mm thickness angled along the canthomeatal line to cover the orbitae (matrix, 512 × 512; 120 kV; 110–180 mA; 1 s/rotation). For segmentation and calculation of the orbital volumes, open-source OsiriX medical image software (version 3.7.1, http://www.osirix-viewer.com) was used according to the method described by Scolozzi et al. (Fig. 8 and Fig. 9).[5] For comparison, the measurements were performed on both orbits.

RESULTS

Patient Data

Twenty-seven patients (mean age, 55.2 years; range, 25–89 years; 11 females and 16 males) met the inclusion criteria. According to the classification by Jaquiery et al.,[4] 16 patients presented with a class III defect and 11 with a class IV defect. Eleven patients

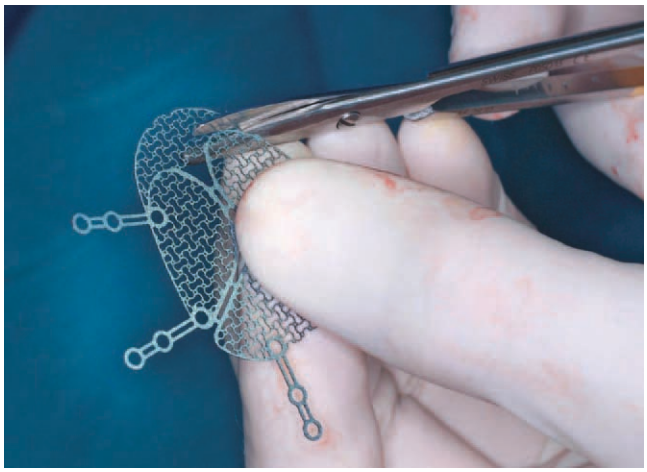

Fig. 6. Adjustment of the titanium mesh. According to the fracture type, the plates can be cut in different ways along the bars. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Fig. 7. Preforming of the titanium mesh implant with the help of a standard plastic skull. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

(41%) were female and 16 (59%) were male. Eleven fractures were caused by falls, seven by an altercation, four by sport accidents, four by blows to the face during work, and one by motor vehicle collision. Seventeen of the fractures were on the left side, and 10 were on the right. All operations were performed within 1 week (mean, 2 days; range, 1–7 days). Surgery was performed in all patients via a transconjunctival approach; in five patients the approach was extended through the caruncula. Twenty-two of the fractures were treated with the small 1-2 mesh, one with the large 1-2, three with the small 2-4, and one with the large 2-4 mesh. The 2-4 plates were used in patients presenting with class IV defects. All implants placed into the orbit were secured using one screw (n = 6), two screws (n = 20), or three screws (n = 1).

Clinical postoperative findings are listed in Table II. The average duration between the operation and the final clinical follow-up by the maxillofacial surgeon was 10.9 months (range, 4.9–18.0 months). In two patients, a revision surgery had to be performed because of buckling

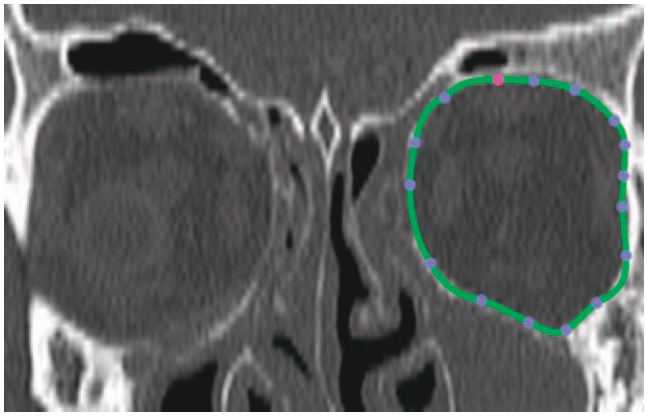

Fig. 8. Analysis of computed tomography scans delineating the region of interest on consecutive slices with OsiriX medical image software. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

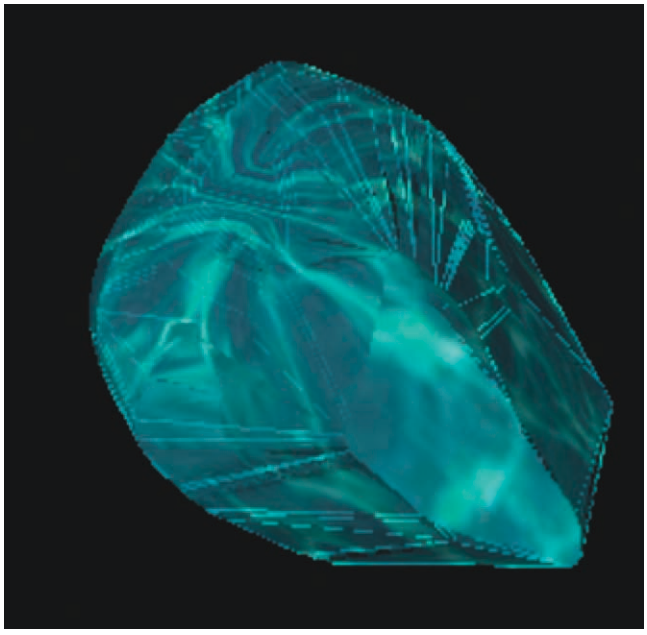

Fig. 9. Computed orbital volume display with OsiriX medical image software. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

of the posterior border of the mesh (Fig. 10). These findings were only evident in the CT control and could have led to long-term restriction of the eye movement or dysfunction. It was therefore decided to take the patients back to the operating room and have the mesh replaced. Both revisions were done 2 days after the first operation. In these two cases, volume analyses were performed using the postrevision CT scans. One patient experienced a postoperative entropium, which needed surgical revision.

Ophthalmologic and Orthoptic Assessment

Altogether, 42 comprehensive ophthalmologic investigations were performed in 25 patients according to the protocol. In three patients, preoperative ophthalmologic examination was reduced to a basic emergency examination due to compliance problems. In 10 patients, the clinical assessment had to be minimized because of swelling and pain. Only 14 patients had complete pre- and postoperative ophthalmologic examinations. Postoperative assessment was performed in all patients. The average duration between the operation and the last assessment was 8.8 months (range, 4.0–20.1 months).

TABLE II.
Postoperative Findings at Last Follow-up in 27 Patients.

	Defect Classification*	
Findings	III	IV
Diplopia, no.	0	1 (transient)
Enophthalmos (Hertel test), no.	0	3 (2-mm difference)
Complications, no.	1 (entropion)	0

*For an explanation of the defect classification, see Table I.

Fig. 10. Buckling of the posterior border of the misbent titanium mesh. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

The measurements of eye movements are presented in Table III.

Monocular visual field (Goldmann perimetry). In 14 patients with complete records, the assessments showed normal values. In the patients with postoperative exams only, one patient presented a restriction of 70%/35% (horizontal/vertical direction).

Field of binocular vision (Harms tangent screen). Presence and degree of pre- and postoperative impairment of binocular vision are summarized in Table IV and Table V. None of the patients reported diplopia at the final postoperative follow-up. Nevertheless, two patients with class III defects and five patients with class IV defects were found with an average reduction of binocular vision of 8.5% (class III; range, 7%–10%) and 4.4%, respectively (class IV; range, 5%–8%).

TABLE IV.
Preoperative Ophthalmologic Examination (n = 27).

	Defect Classification, No. (%)	
Finding	III (n = 16)	IV (n = 11)
No examination	6 (16)	4 (11)
No double vision	4 (10)	0 (4)
No double vision within 90%	3 (10)	2 (4)
No double vision within 80%	2 (10)	2 (4)
No double vision within 60%	1 (10)	0
Double vision at all gaze	0	0

Assessment of the field of binocular vision with the help of the Harms tangent screen measured in percentage of the total.

Exophthalmometry (Hertel). Preoperatively, six patients (3 in class III and class IV) presented with an exophthalmos (difference, ≥2 mm; mean, 2.4 mm; range, 4.0–2.0 mm), and one patient (class IV) had an enophthalmos (difference = −2 mm). Postoperatively, these patients showed normal Hertel values. Three patients with missing preoperative data showed a slight enophthalmos on the operated side at 6 months (both with a side difference of 2.0 mm). However, none of these patients was concerned or had noted the side difference.

CT Volume Analysis

Postoperative CT control showed buckling of the plate in the posterior border in two patients. These patients then underwent revision surgery. In all other patients, radiologic control showed a correct placement of the mesh (Fig. 11 and Fig. 12). According to the literature, an average orbital volume difference of up to 1.95 cm^3 is normal in healthy, uninjured individuals. Volume analysis confirmed the accuracy of reconstruction. The average difference between the uninjured and the

TABLE III.
Assessment of Eye Movements in 14 Patients.

Patient	Classification of Defect	Upper Gaze, mm		Lower Gaze, mm		Abduction, mm		Adduction, mm	
		Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative
1	IV	7 (8)	7 (8)	9 (9)	9 (10)	8 (9)	9 (10)	9 (10)	9 (10)
2	III	7 (8)	7 (7)	10 (11)	10 (10)	10 (9)	10 (10)	10 (10)	10 (9)
3	IV	5 (7)	7 (7)	12 (12)	12 (12)	11 (11)	11 (11)	11 (11)	11 (11)
4	III	7 (7)	10 (10)	8 (8)	10 (10)	9 (10)	11 (11)	10 (10)	11 (11)
5	III	4 (4)	5 (5)	10 (10)	10 (10)	7 (7)	7 (7)	9 (9)	9 (9)
6	IV	8 (8)	8 (8)	11 (10)	11 (10)	8 (9)	8 (8)	10 (11)	11 (11)
7	III	5 (7)	9 (9)	5 (11)	11 (11)	8 (10)	10 (10)	10 (9)	10 (10)
8	III	4 (4)	4 (4)	10 (10)	10 (10)	8 (9)	8 (9)	8 (8)	8 (8)
9	III	6 (6)	7 (9)	8 (8)	8 (6)	8 (9)	8 (8)	9 (8)	8 (8)
10	III	5 (6)	5 (5)	10 (10)	10 (11)	9 (9)	9 (9)	10 (10)	10 (10)
11	III	7 (8)	7 (7)	8 (9)	8 (8)	9 (10)	9 (10)	10 (10)	10 (10)
12	III	6 (8)	8 (8)	11 (10)	11 (11)	6 (10)	10 (10)	9 (10)	10 (10)
13	IV	7 (8)	7 (8)	8 (11)	10 (11)	9 (10)	10 (10)	8 (10)	10 (10)
14	III	6 (7)	8 (9)	8 (10)	10 (10)	10 (9)	10 (10)	9 (9)	9 (9)

Value of movement in the uninjured eye (in millimeters) is given in parentheses.

TABLE V.
Postoperative Ophthalmologic Examination (n = 27).

Finding	Defect Classification	
	III (n = 16)	IV (n = 11)
No double vision	14 (16)	6 (11)
No double vision within 90%	2 (16)	5 (11)
No double vision within 80%	0	0
No double vision within 60%	0	0
Double vision at all gaze	0	0

Assessment of the field of binocular vision with the help of the Harms tangent screen measured in percentage of the total.

reconstructed orbit was -0.44 cm^3 (range, -2.59 to 2.09 cm^3; standard deviation, 1.28 cm^3) (Table VI). A negative value indicates that the reconstructed side is smaller than the uninjured one.

DISCUSSION

In cases of orbital trauma, numerous factors have an impact on the clinical outcome and therefore the patient's satisfaction. Lesions of the muscular and neurologic system of the orbit can lead to important impairment of globe motility. Whether and to what extent such injuries occur can only be evaluated to a limited degree during the first assessments posttrauma. Other factors that influence the functional and aesthetic outcome are tissue entrapment and volume alteration of the bony orbit. These two problems can be addressed by surgical repair. Currently, however, there is no standard treatment protocol for the repair of orbital fractures.[6] There seems to be a consensus that in orbital fractures, a primary reconstruction should be performed and the normal anatomy reestablished as precisely as possible.[6–11] To reconstruct an orbital bony shape accurately, an implant should be stable, thin, and easy to handle.

Many different materials have been described to bridge defects of the orbital floor and walls.[6,12] Mainly because of the work of Paul Tessier, autogenous bone grafts have been the implant of choice during the last few decades.[13,14] However, problems in the use of bone grafts such as unpredictable resorption, donor site morbidity, and demanding handling[15,16] have made alloplastic alternatives increasingly popular.[12,17–19] Of the group of alloplastic materials, titanium has proven to be one of the most reliable and safe implants for orbital reconstruction.[19–22]

So far, four different methods have been described in the surgical application of titanium mesh. An implant can be molded and tailored intraoperatively, it can be preformed by the surgeon pre- or intraoperatively with the use of a plastic skull, it can be purchased as 3D preformed mesh off the shelf, or it can be custom made with the help of a stereolithographic model. The first approach uses meshes, which need intraoperative trimming and molding to contour the conical shape of the orbit. Over the last few years, engineers have developed mesh designs with adapted shapes, which facilitate their handling and insertion to a great extent. In addition, templates have been introduced, which ease the molding of that plate outside the orbit and therefore prevent repetitive and potentially

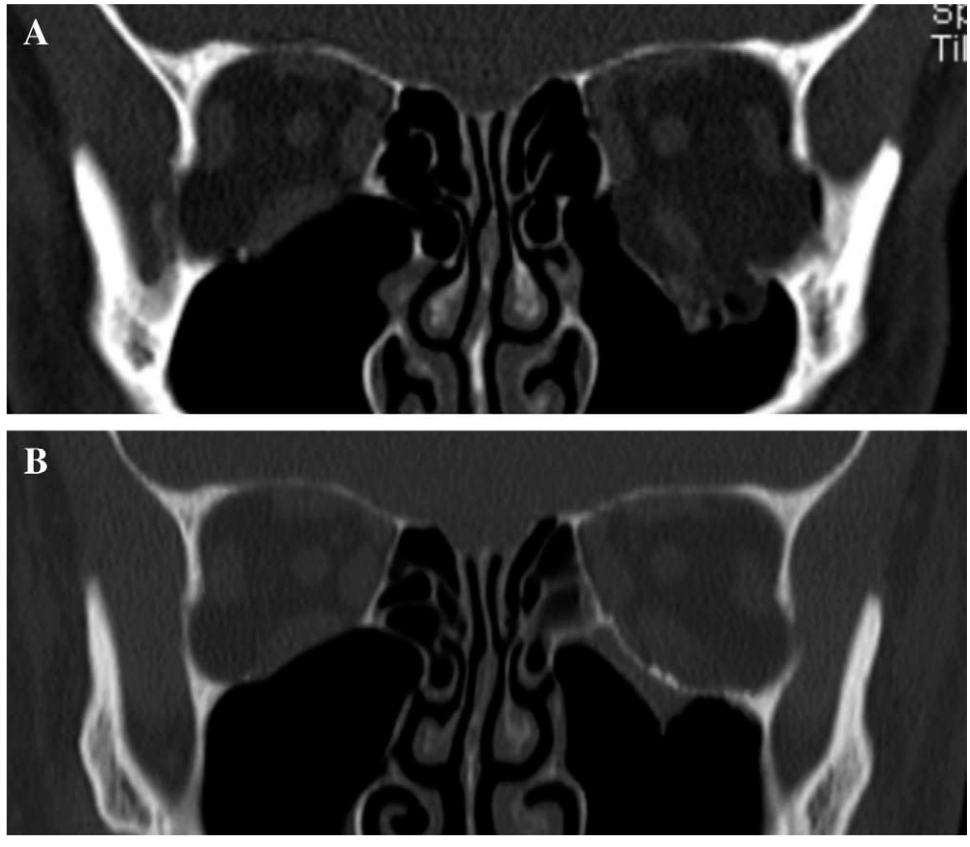

Fig. 11. Preoperative (A) and postoperative (B) computed tomography scan of a patient with a blow-out fracture of the right orbital wall.

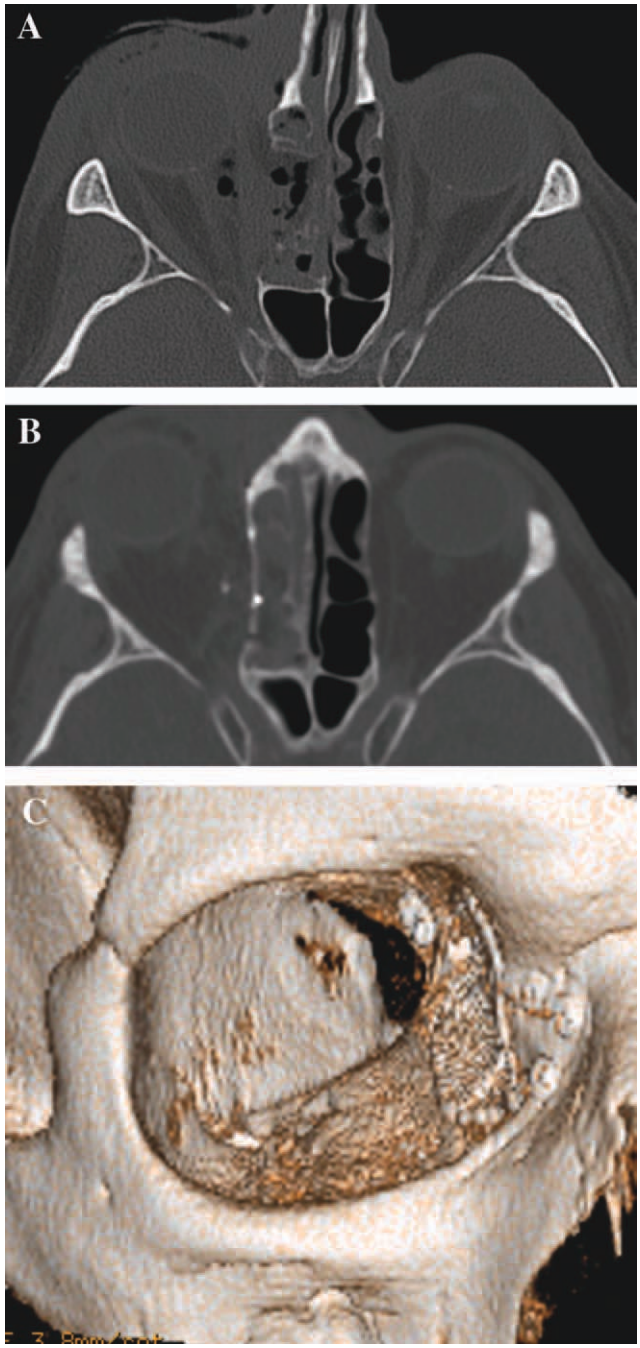

Fig. 12. Preoperative (A) and postoperative (B) computed tomography scan of a patient with a blow-out fracture of the right medial wall. (C) Three-dimensional reconstruction of postoperative situation. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

harmful insertion of the mesh. The second approach uses models of an average orbit to preform the mesh outside the patient. The third approach applies mesh in different sizes, which is available off the shelf (MatrixORBITAL; Synthes, Oberdorf, Switzerland). The most sophisticated method—and probably also the most promising approach—is the use of custom-made implants. Preliminary results in the use of the preformed mesh by Synthes have shown good accuracy in reconstruction.[5] A preliminary comparison by the same author, between the use of nonpreformed versus preformed titanium mesh (both from Synthes) showed no differences in the accuracy of the reconstruction.[23]

Considering the complex anatomic structure of the bony orbit and the limited surgical visualization of the defect, one would certainly aim for a preformed implant, which does not need any further modification. In an extensive analysis of the orbital form, Kamer et al. demonstrated significant interindividual size variability.[24] With regard to the use of preformed orbital implants off the shelf, the authors recommend that, to fit each individual orbit, a larger number or preformed implants should be available to the surgeon. Kamer et al. also mention the possibility of manual implant malpositioning due to the lack of reliable anatomic landmarks that could serve as points of reference. Therefore, the ideal preformed implant is custom made with clear reference markings for optimal intraoperative positioning. The use of such implants has been described in the literature.[18,25,26] The downside of this technique is the limited availability and the production cost.

Taking into account the advantages and disadvantages of the different approaches mentioned, the most appropriate orbital mesh needs to be stable, thin, preferably preformed, easy in handling, and reasonable in cost. Unfortunately, it is not currently possible to create a 3D mesh with low-profile height because reducing the profile height causes the 3D mesh stability to be reduced or lost during transport or preoperative handling. The most popular titanium meshes feature a profile height between 0.3 and 0.6 mm (Orbital floor mesh 0.3 mm; KLS Martin, Jacksonville, FL; MatrixORBITAL 0.4 mm; Synthes; MEDPOR TITAN 0.6 mm; Stryker Medical, Portage, MI). In 2008, Medartis introduced an orbital mesh (Modus OPS 1.5) with a profile height of 0.2 to 0.25 mm, featuring a special architecture to optimize stability, with the option of intraoperative preformation using a plastic skull. Our goal was hence to find out whether and to what extent this new design could influence the use and accuracy of orbital reconstruction surgery.

In the clinical assessment we found that all patients presented with a good functional outcome. None of the patients experienced diplopia. Three patients showed slight enophthalmos (side difference of 2 mm) without any subjective functional or aesthetic concerns. These findings are comparable with the incidence and degrees of restrictions found in other studies.[4,27] Interestingly, the presence of enophthalmos did not correlate with the postoperative volumetric measurements of the reconstructed orbit. Just one of the patients presenting an enophthalmos showed a relevant difference of the orbital volumes (-2.59 cm^3; -9.7%); the other two patients had only small differences in orbital volumes. Out of 27 patients, 25 (93%) had a successful treatment outcome without complications. In the CT volume analysis, the difference between the reconstructed and the uninjured orbit was within the range of ± 2 cm^3 (0%–8%, respectively), as reported in studies in healthy individuals[28] and as found in patients in whom preformed mesh was inserted.[5] In two patients, however, the plate was buckled in the posterior edge region (Fig. 10) and needed

TABLE VI.
Volumetric Data of the Reconstructed and Uninjured Sides (n = 27).

Patient	Classification of Defect	Reconstructed Side, cm^3	Uninjured Side, cm^3	Volume Difference, cm^3	Volume Difference, %	Postoperative Enophthalmos, mm
1	III	27.39	26.58	−0.81	−3.0	0
2	III	29.76	28.28	−1.48	−5.2	0
3	IV	34.69	32.43	−2.26	−7.0	0
4	III	24.9	25.58	0.68	2.7	0
5	IV	27.01	25.28	−1.73	−6.8	0
6	III	20.95	21.60	0.65	3.0	0
7	III	26.5	26.31	−0.19	−0.7	0
8	IV	27.5	26.64	−0.86	−3.2	0
9	III	27.74	26.58	−1.16	−4.4	0
10	III	22.52	21.55	−0.97	−4.5	0
11	III	31.09	30.87	−0.22	−0.7	0
12	III	29.74	31.08	1.34	4.3	0
13	III	24.55	24.2	−0.35	−1.4	2
14	III	27.29	26.53	−0.76	−2.9	0
15	III	26.72	27.01	0.29	1.1	0
16	III	30.83	29.16	−1.67	−5.7	0
17	III	34.15	36.24	2.09	5.8	0
18	IV	29.27	26.68	−2.59	−9.7	2
19	IV	24.95	25.71	0.76	3.0	0
20	IV	29.34	29.21	−0.13	−0.4	0
21	IV	19.1	19.49	0.39	2.0	2
22	IV	18.9	20.46	1.56	7.6	0
23	IV	27.98	26.47	−1.51	−5.7	0
24	III	24.63	22.15	−2.48	−11.2	0
25	III	29.2	27.68	−1.52	−5.5	0
26	IV	26.02	27.56	1.54	5.6	0
27	IV	20.8	20.25	−0.55	−2.7	0

to be replaced. Luckily, these patients showed good clinical and radiologic outcome after the second procedure.

The incidence of misplacement of mesh is similar to the findings published in the literature, including assessments of preformed off-the-shelf mesh.[1,5] The complications described in this study most probably occurred because of insufficient visualization of the stable bony edges of the blow-out fracture, when inserting the mesh. However, because this surgical procedure is performed by senior staff and trainees alike, it needs to be as safe as possible. To minimize the risks of misplacement or misbending, we believe that the stability of the mesh should be improved by increasing the profile height. Unfortunately, there currently seems to be no alternative technical possibility to increase the stability of such a mesh. Further research in the fields of implant design and production is therefore essential. In addition, detailed analyses of the complex 3D anatomic architecture of the bony orbit are necessary. Such data could most probably facilitate the design of a new mesh, especially with regard to improved stability.

CONCLUSION

Even though the low-profile titanium mesh proved to be a reliable implant, it had its limitations. In two patients, the mesh showed buckling in the posterior aspects, which needed revision surgery. This problem is most probably because of insufficient stability. Unintentional buckling of the mesh could be avoided by paying special attention to the borders of the plate after insertion. However, a mesh for orbital repair, which can be used by specialists and trainees alike, should be as safe as possible. With regard to this problem, we would suggest an increase in stability at the expense of a low profile.

Acknowledgments

The authors thank Andreas Mullis and Michael Breitenstein (Medartis, Basel, Switzerland) for their valuable collaboration.

BIBLIOGRAPHY

1. Ellis E III, El-Attar A, Moos KF. An analysis of 2067 cases of zygomaticoorbital fracture. *J Oral Maxillofac Surg* 1985;43:417–428.
2. Buchel P, Rahal A, Seto I, Iizuka T. Reconstruction of orbital floor fracture with polyglactin 910/polydioxanon patch (ethisorb): a retrospective study. *J Oral Maxillofac Surg* 2005;63:646–650.
3. Lieger O, Schaller B, Zix J, Kellner F, Iizuka T. Repair of orbital floor fractures using bioresorbable poly-L/DL-lactide plates. *Arch Facial Plast Surg* 2010;12:399–404.
4. Jaquiery C, Aeppli C, Cornelius P, Palmowsky A, Kunz C, Hammer B. Reconstruction of orbital wall defects: critical review of 72 patients. *Int J Oral Maxillofac Surg* 2007;36:193–199.

5. Scolozzi P, Momjian A, Heuberger J, et al. Accuracy and predictability in use of AO three-dimensionally preformed titanium mesh plates for post-traumatic orbital reconstruction: a pilot study. *J Craniofac Surg* 2009; 20:1108–1113.
6. Burnstine MA. Clinical recommendations for repair of orbital facial fractures. *Curr Opin Ophthalmol* 2003;14:236–240. Review.
7. Ellis E 3rd, Tan Y. Assessment of internal orbital reconstructions for pure blowout fractures: cranial bone grafts versus titanium mesh. *J Oral Maxillofac Surg* 2003;61:442–453.
8. Metzger MC, Schon 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: 969–976.
9. Metzger MC, Schon R, Schulze D, Carvalho C, Gutwald R, Schmelzeisen R. Individual preformed titanium meshes for orbital fractures. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006;102:442–447.
10. Metzger MC, Schon R, Weyer N, et al. Anatomical 3-dimensional pre-bent titanium implant for orbital floor fractures. *Ophthalmology* 2006;113: 1863–1868.
11. Schon R, Metzger MC, Zizelmann C, Weyer N, Schmelzeisen R. Individually preformed titanium mesh implants for a true-to-original repair of orbital fractures. *Int J Oral Maxillofac Surg* 2006;35:990–995.
12. Kirby EJ, Turner JB, Davenport DL, Vasconez HC. Orbital floor fractures: outcomes of reconstruction. *Ann Plast Surg* 2011;66:508–512.
13. Tessier P. Autogenous bone grafts taken from the calvarium for facial and cranial applications. *Clin Plast Surg* 1982;9:531–538.
14. Wolfe SA. The influence of Paul Tessier on our current treatment of facial trauma, both in primary care and in the management of late sequelae. *Clin Plast Surg* 1997;24:515–518.
15. Manson PN, Ruas EJ, Iliff NT. Deep orbital reconstruction for correction of post-traumatic enophthalmos. *Clin Plast Surg* 1987;14:113–121.
16. Grant MP, Iliff NT, Manson PN. Strategies for the treatment of enophthalmos. *Clin Plast Surg* 1997;24:539–550.
17. Park HS, Kim YK, Yoon CH. Various applications of titanium mesh screen implant to orbital wall fractures. *J Craniofac Surg* 2001;12:555–560.
18. Lieger O, Richards R, Liu M, Lloyd T. Computer-assisted design and manufacture of implants in the late reconstruction of extensive orbital fractures. *Arch Facial Plast Surg* 2010;12:186–191.
19. Gear AJ, Lokeh A, Aldridge JH, Migliori MR, Benjamin CI, Schubert W. Safety of titanium mesh for orbital reconstruction. *Ann Plast Surg* 2002;48:1–7; discussion 7–9.
20. Mackenzie DJ, Arora B, Hansen J. Orbital floor repair with titanium mesh screen. *J Craniomaxillofac Trauma* 1999;5:9–16; discussion 17–18.
21. Schubert W, Gear AJ, Lee C, et al. Incorporation of titanium mesh in orbital and midface reconstruction. *Plast Reconstr Surg* 2002;110: 1022–1130; discussion 1031–1032.
22. Sugar AW, Kuriakose M, Walshaw ND. Titanium mesh in orbital wall reconstruction. *Int J Oral Maxillofac Surg* 1992;21:140–144.
23. 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;34:98–104.
24. Kamer L, Noser H, Schramm A, Hammer B. Orbital form analysis: problems with design and positioning of precontoured orbital implants: a serial study using post-processed clinical CT data in unaffected orbits. *Int J Oral Maxillofac Surg* 2010;39:666–672.
25. Fan X, Zhou H, Lin M, Fu Y, Li J. Late reconstruction of the complex orbital fractures with computer-aided design and computer-aided manufacturing technique. *J Craniofac Surg* 2007;18:665–673.
26. Zhang Y, He Y, Zhang ZY, An JG. Evaluation of the application of computer-aided shape-adapted fabricated titanium mesh for mirroring-reconstructing orbital walls in cases of late post-traumatic enophthalmos. *J Oral Maxillofac Surg* 2010;68:2070–2075.
27. Al-Sukhun J, Lindqvist C. A comparative study of 2 implants used to repair inferior orbital wall bony defects: autogenous bone graft versus bioresorbable poly-L/DL-Lactide [P(L/DL)LA 70/30] plate. *J Oral Maxillofac Surg* 2006;64:1038–1048.
28. Forbes G, Gehring DG, Gorman CA, Brennan MD, Jackson IT. Volume measurements of normal orbital structures by computed tomographic analysis. *AJR Am J Roentgenol* 1985;145:149–154.