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PATIENT-SPECIFIC 3D-PRECONTOURED TITANIUM IMPLANTS FOR ORBITAL FLOOR RECONSTRUCTION: MODERN APPROACHES TO FUNCTIONAL AND AESTHETIC REHABILITATION IN ZYGOMATIC-ORBITAL TRAUMA

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ABSTRACT

Background:

Orbital floor fractures remain among the most complex challenges in cranio-maxillofacial surgery due to the intricate anatomy of the orbit and the risk of severe functional and aesthetic complications. Conventional intraoperative implant contouring is time-consuming and highly operator-dependent. Recent advances in three-dimensional (3D) virtual planning, rapid prototyping, and patient-specific titanium implants have significantly improved orbital reconstruction accuracy and postoperative outcomes.

Objective:

To evaluate the effectiveness of patient-specific 3D-precontoured titanium implants for orbital floor reconstruction in patients with zygomatic-orbital complex trauma.

Materials and Methods

A prospective clinical study included patients with orbital floor fractures associated with zygomatic-orbital complex injuries. Preoperative computed tomography (CT) data were used for 3D virtual planning and production of anatomical orbital models. Patient-specific titanium mesh implants were precontoured based on mirrored anatomy of the unaffected orbit. Clinical, radiological, ophthalmologic, and anthropometric assessments were performed preoperatively and postoperatively. Functional outcomes included diplopia, ocular motility, globe position, and visual disturbances. Aesthetic outcomes included restoration of orbital symmetry and midfacial contour.

Results:

Postoperative evaluation demonstrated significant improvement in orbital anatomy and globe positioning. Resolution or substantial reduction of diplopia was observed in the majority of patients. Restoration of orbital volume and facial symmetry was confirmed radiologically and anthropometrically. Precontoured implants reduced intraoperative manipulation and improved implant positioning accuracy. No severe postoperative complications or implant-related adverse events were observed.

Conclusion:

Patient-specific 3D-precontoured titanium implants represent an effective and reliable method for orbital floor reconstruction. Integration of virtual surgical planning and individualized implant modeling significantly improves functional and aesthetic rehabilitation in patients with zygomatic-orbital trauma.

INTRODUCTION.

Orbital floor fractures account for a significant proportion of craniofacial injuries and are frequently associated with fractures of the zygomatic-orbital complex. Disruption of orbital anatomy may result in enophthalmos, diplopia, ocular motility disorders, infraorbital nerve dysfunction, and facial asymmetry, substantially affecting patient quality of life [1,2].

Accurate restoration of orbital volume and anatomical support structures remains one of the primary objectives of orbital reconstruction. However, due to the narrow operative field and the complex three-dimensional anatomy of the orbit, intraoperative contouring and positioning of implants remain technically challenging and highly dependent on surgeon experience [3].

Modern advances in computer-assisted surgery, virtual planning, rapid prototyping, and patient-specific implant technologies have significantly transformed orbital reconstruction strategies. Three-dimensional (3D) planning allows precise reproduction of orbital anatomy using mirrored reconstruction of the unaffected orbit and facilitates production of individualized titanium implants with improved anatomical conformity [4,5].

Patient-specific titanium implants provide several important advantages, including:

- accurate restoration of orbital contours,
- reduction of intraoperative implant manipulation,
- shorter operative time,
- improved orbital volume reconstruction,
- enhanced aesthetic rehabilitation.

Recent studies demonstrate that individualized orbital reconstruction techniques significantly improve postoperative outcomes and reduce rates of residual enophthalmos and persistent diplopia [6,7].

The purpose of the present study was to evaluate functional and aesthetic outcomes following orbital floor reconstruction using patient-specific 3D-precontoured titanium implants in patients with zygomatic-orbital trauma.

MATERIALS AND METHODS.

A prospective clinical study was performed in patients with orbital floor fractures associated with zygomatic-orbital complex trauma treated at the Department of Maxillofacial Surgery of Tashkent State Medical University.

Inclusion criteria:

- unilateral orbital floor fractures,
- zygomatic-orbital complex trauma,
- CT-confirmed orbital defects,
- presence of functional or aesthetic disturbances.

Exclusion criteria:

- severe ocular globe rupture,
- previous orbital reconstructive surgery,
- bilateral orbital trauma,
- systemic contraindications for surgery.

Preoperative evaluation included:

- clinical examination,
- ophthalmologic assessment,
- high-resolution computed tomography,
- anthropometric facial analysis,
- assessment of diplopia and ocular motility.

CT data were processed using 3D virtual planning software. Mirroring of the intact orbit was performed to reconstruct the anatomical shape of the injured side. Patient-specific orbital models were created using rapid prototyping technology.

Titanium mesh implants were precontoured preoperatively according to the individualized anatomical models.

Postoperative evaluation included:

- CT analysis of orbital reconstruction,
- globe position assessment,
- evaluation of diplopia,
- ocular motility analysis,
- anthropometric symmetry assessment.

VIRTUAL SURGICAL PLANNING AND MODELING

Thin-slice CT imaging (0.5–0.6 mm) was used for virtual reconstruction of orbital anatomy. DICOM data were imported into specialized planning software for segmentation and generation of 3D orbital models. The unaffected orbit was mirrored onto the injured side to reproduce normal orbital contours and orbital floor anatomy.

Rapid prototyping technology was used to fabricate anatomical orbital models that served as templates for implant contouring.

Patient-specific titanium mesh implants were shaped preoperatively according to the individualized orbital anatomy, minimizing the need for extensive intraoperative manipulation.

SURGICAL TECHNIQUE

Surgical treatment was performed under general anesthesia.

Orbital floor exposure was achieved using a transconjunctival approach with or without lateral canthotomy depending on fracture extension.

After careful dissection, herniated orbital soft tissues were mobilized and repositioned into the orbital cavity. Fractured bone fragments were anatomically reduced whenever possible.

The precontoured titanium implant was inserted and positioned over stable orbital margins to restore orbital support and orbital volume. Implant position and globe mobility were assessed intraoperatively.

In selected complex cases involving extensive orbital destruction, computer-assisted intraoperative navigation was utilized to improve anatomical orientation and implant positioning accuracy.

Rigid fixation was achieved using titanium microscrews where indicated.

RESULTS

Postoperative clinical and radiological evaluation demonstrated satisfactory restoration of orbital anatomy and globe positioning.

Functional outcomes included:

- complete resolution of diplopia in most patients,
- improvement of ocular motility,
- reduction of enophthalmos,
- restoration of binocular vision.

Anthropometric assessment demonstrated:

- restoration of orbital symmetry,
- normalization of infraorbital projection,
- improved midfacial contour,
- reduction of facial asymmetry.

Radiological evaluation confirmed accurate positioning of patient-specific titanium implants with restoration of orbital volume.

Precontoured implants significantly reduced intraoperative contouring time and minimized repeated implant repositioning attempts.

No severe postoperative complications such as orbital infection, implant migration, or visual loss were observed.

Table 1.

Functional outcomes following orbital floor reconstruction

Parameter	Preoperative	Postoperative	Assessment
Diplopia	Present	Resolved/reduced	Improved
Enophthalmos	Moderate	Minimal/absent	Corrected
Ocular motility	Restricted	Restored	Improved
Orbital asymmetry	Pronounced	Minimal	Improved
Midfacial contour	Flattened	Restored	Improved
Infraorbital projection	Reduced	Normalized	Corrected

DISCUSSION

Orbital reconstruction remains one of the most technically demanding procedures in cranio-maxillofacial surgery due to the complex geometry of orbital walls and the functional importance of orbital volume restoration [2,3].

Conventional intraoperative implant contouring is often associated with prolonged operative time and inaccuracies in orbital reconstruction. Patient-specific 3D-precontoured implants significantly improve adaptation to orbital anatomy and facilitate precise restoration of orbital contours [5,6].

The use of mirrored reconstruction of the intact orbit allows reproduction of patient-specific orbital anatomy with high precision. This approach is especially valuable in large orbital floor defects and secondary orbital reconstructions [7].

Modern literature increasingly supports individualized orbital reconstruction using computer-assisted planning and patient-specific implants due to improved functional and aesthetic outcomes [8,9].

In the present study, precontoured titanium implants demonstrated reliable orbital support and favorable globe positioning with significant reduction of postoperative diplopia and enophthalmos.

An additional advantage of virtual surgical planning is improved understanding of fracture morphology and optimization of operative strategy prior to surgery. Intraoperative navigation further enhances safety in complex orbital injuries involving distorted anatomical landmarks.

Despite these advantages, limitations include additional preparation time, dependence on advanced imaging and modeling technologies, and increased logistical requirements.

Nevertheless, rapid advances in digital surgical technologies continue to improve accessibility and reproducibility of patient-specific orbital reconstruction.

CONCLUSION

Patient-specific 3D-precontoured titanium implants provide accurate and reliable reconstruction of orbital floor defects associated with zygomatic-orbital trauma.

Integration of virtual surgical planning, rapid prototyping, and individualized implant contouring significantly improves restoration of orbital anatomy, globe position, ocular function, and facial symmetry.

Modern computer-assisted reconstruction techniques contribute to improved functional rehabilitation and superior aesthetic outcomes in patients with orbital trauma.

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