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Patient-specific puzzle implant preformed with 3D-printed rapid prototype model for combined orbital floor and medial wall fracture

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Summary *Background:* The management of combined orbital floor and medial wall fractures involving the inferomedial strut is challenging due to absence of stable cornerstone. In this article, we proposed surgical strategies using customized 3D puzzle implant preformed with Rapid Prototype (RP) skull model.
Methods: Retrospective review was done in 28 patients diagnosed with combined orbital floor and medial wall fracture. Using preoperative CT scans, original and mirror-imaged RP skull models for each patient were prepared and sterilized. In all patients, porous polyethylene-coated titanium mesh was premolded onto RP skull model in two ways; Customized 3D jigsaw puzzle technique was used in 15 patients with comminuted inferomedial strut, whereas individual 3D implant technique was used in each fracture for 13 patients with intact inferomedial strut. Outcomes including enophthalmos, visual acuity, and presence of diplopia were assessed and orbital volume was measured using OsiriX software preoperatively and postoperatively.
Results: Satisfactory results were achieved in both groups in terms of clinical improvements. Of 10 patients with preoperative diplopia, 9 improved in 6 months, except one with persistent symptom who underwent extraocular muscle rupture. 18 patients who had moderate to severe enophthalmos preoperatively improved, and one remained with mild degree. Orbital volume ratio, defined as volumetric ratio between affected and control orbit, decreased from 127.6% to 99.79% ($p < 0.05$) in comminuted group, and that in intact group decreased from 117.03% to 101.3% ($p < 0.05$).

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Conclusion: Our surgical strategies using the jigsaw puzzle and individual reconstruction technique provide accurate restoration of combined orbital floor and medial wall fractures.

Introduction

The management of combined orbital floor and medial wall fractures involving the inferomedial strut is challenging because of the absence of peripheral bony structures to support implants. The importance of the maxilloethmoidal junction or inferomedial strut in orbital reconstructive surgery has previously been reported.[1–3] When the inferomedial strut is intact, it can be used to support several individual implants over each of the fractures. However, when this support is compromised, the proper placement of implants is technically challenging for craniofacial surgeons because of the absence of a stable cornerstone.[3,4]

Various surgical approaches to repair combined orbital floor and medial wall fractures have been described.[4–6] The transconjunctival and transcaruncular incisions are time-tested approaches for orbital fracture repair; however, neither of the incision alone is large enough to permit adequate surgical exposure and placement of large implants. Combined transconjuctival and transcaruncular orbitotomy with disinsertion of the inferior oblique muscle near its origin, despite the divided muscle being reapproximated with sutures after fracture repair, can cause vertical or torsional diplopia if the muscle becomes impaired.[2] The orbit can be reconstructed without impairing the inferior oblique muscle using multiple small implants; however, there is a risk of implant buckling and displacement.

With advances in three-dimensional (3D) printing technologies and computer-aided design/manufacturing, precise preoperative planning for orbital reconstruction has become feasible. Computer-aided design software can be used for reconstructing 3D computed tomography (CT) images of the orbit. Such technologies allow the creation of patient-specific implants. We previously reported the use of individually manufactured rapid prototype (RP) skull models and premolded synthetic scaffolds using computer-aided mirroring and 3D printing techniques for optimal reconstruction of the traumatized orbit.[7,8]

The application of our novel technique in combined orbital floor and medial wall fractures allows accurate 3D restoration of the orbit. We designed customized implants for orbital floor and medial wall defects, which are molded on a RP skull model, resembling a jigsaw puzzle. Here we propose a novel surgical strategy to repair combined orbital floor fractures based on the inferomedial strut involvement.

Methods

Patients

Patients diagnosed with combined orbital floor and medial wall fractures were retrospectively reviewed at our institution. All patients underwent reconstructive surgery performed by two surgeons from March 2011 to May 2016. The inclusion criteria were as follows: combined orbital floor and medial wall fractures of the isolated orbit unilaterally, no previous history of intraocular disease or orbital trauma, surgery performed within 1 month of the occurrence of orbital fracture, and a follow-up of at least 6 months. All patients underwent CT scan preoperatively on their first visit and postoperatively on the second day. Indications for surgery were suspected presence of muscle incarceration, fracture size >2 cm^2 or forecasting an enophthalmos, and significant diplopia in the field of gaze. Electronic medical records were reviewed for patient demographics (including age, sex, and follow-up period), trauma etiology, concomitant facial bone fracture, and time period between onset of truama and surgery. All studies on humans were approved by the ethics committees of our institution and were in agreement with the Declaration of Helsinki.

Each patient underwent preoperative CT (slice thickness, 0.6 mm). Using preoperative CT scans, original and mirror-imaged RP skull models were prepared for patients with combined orbital floor and medial wall fractures. 3D simulation was performed using Mimics 3D software (Materialise NV, Inc., Leuven, Belgium). Contralateral orbit images were flipped over to obtain the ideal normal contours of the traumatized orbit. An RP skull model (AMK, Inc., Goyang-si, Gyeonggi-do, Korea) representing the individual model of the uninjured state was then developed using a 3D printer (Projet660 Pro; 3D Systems, Inc., Rock Hill, SC, USA). All preoperatively manufactured RP models were sterilized, and titanium Medpor implants were intraoperatively designed to fit onto the mirror-imaged orbit before insertion into the damaged orbit (Figure 1).

Surgical technique

Our technique combined transcaruncular and transconjunctival approaches to gain access to the medial and inferior subperiosteal spaces. An extended transconjunctival approach with a lateral paracanthal incision was used as necessary, according to our previously reported method.[9] Dissection was performed with retractors through the inferior orbital rim, where the periosteum was opened with needle cautery. The anterior, lateral, and superomedial limits of the fracture were defined by subperiosteal dissection using a Freer elevator. The inferior and medial dissections were joined to create a dissection plane; herniated or entrapped tissue was carefully released, and the posterior aspects of the fracture were identified. The origin of the inferior oblique muscle was identified immediately posterior to the inferomedial orbital rim. We took particular care to avoid division of the inferior oblique muscle, and the remaining bridge of soft tissue around the muscle was sharply divided. Care was taken during this procedure to avoid damage to the lacrimal sac, which lies immediately medial to the inferior