Original Article

The Role of Prebent Titanium Mesh with 3D-Printed Model in Reconstruction of Zygomatico-Orbital Fractures

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ABSTRACT

Purpose: This study aimed to evaluate the role of using a prebent titanium mesh on a 3D-printed model as an intraoperative guide to reconstruct orbito-zygomatic-maxillary complex (OZMC) fractures.
Subjects and method: TThis is a prospective, single-armed case series study carried out on twelve patients with unilateral displaced (OZMC) fracture indicated for orbital floor reconstruction as evidenced by clinical and radiographic examination. Open reduction and internal fixation were utilized to treat those fractures. Patients were collected from the Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Tanta University. Post-operative evaluation: all patients underwent regular follow-up for six months. The following parameters were evaluated: visual acuity, the external appearance of the eye including hypoglobus and enophthalmos, diplopia, ocular motility, the aesthetic results, layout angle, gab length, and the zygomatic reconstruction.
Results: motility of the affected eye in comparison with preoperative status as (P=0.001). The post-operative CT analysis showed that minimal layout angle and gap length values were highly correlated to obtain accurate reduction and fixation of OZMC. Significant improvements in the external appearance of the eye were obtained, including hypoglobus (P=0.001) and enophthalmos (P=0.003). Also, significant improvement in the limitation of ocular motility of the affected eye in comparison with preoperative status as (P=0.001). The post-operative CT analysis showed that minimal layout angle and gap length values were highly correlated to obtain accurate reduction and fixation of OZMC.
Conclusion: The clinical and radiographical data suggested that more accurate reduction and fixation of OZMC fractures can be achieved using a prebent orbital titanium mesh on patient-specific 3D-printed RP orbital models.

Key Words: Orbito-zygomatico-maxillary complex fracture, 3D printing, Accurate reduction and fixation.

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INTRODUCTION

The orbito-zygomatic-maxillary complex (OZMC) is the second most frequently fractured bone of the craniofacial skeleton. Low-energy injuries result in its separation at the articulating buttresses and in minor displacement. Moderate and high energy injuries lead to increased displacement and comminution. Surgical repair techniques consist of traditional closed reduction or open reduction and internal fixation.[1]

Successful management requires an accurate diagnosis and careful consideration of the complex 3-dimensional anatomy because even minimally displaced fractures in this region can result in functional and esthetic deformities. The imprecise reduction can result in significant malar flattening, facial asymmetry, changes in the orbital volume, and/or globe mispositioning.

Moreover, patients are at risk of functional consequences, including trismus from the impingement of local tissues and/or paresthesia due to nerve injury.[2,3,4]

Many technical adjustments such as C-arm techniques, ultrasound techniques, and intraoperative navigation systems have been developed to increase the accuracy of open reduction and internal fixation of the OZMC. The clinical application of these techniques has been limited because of limited skeletal visualization, technical difficulty, high costs, prolonged operative time, and limited equipment availability.[5–8]

Rapid prototyping, also known as three-dimensional (3D) printing, is an additive manufacturing technology that allows expedient and accurate reproduction of osseous anatomy.

It was originally introduced in the mechanical engineering field during the 1980s, and this technology has gained interest in craniomaxillofacial surgery as a tool for assessment and preoperative surgical planning. Rapid prototyping can provide an accurate anatomical

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representation of the osseous defect for orbital floor fractures, allowing the clinician to preoperatively adapt a titanium plate for reconstruction. [9,10]

SUBJECTS AND METHOD

This is a prospective, single-armed case series study carried out on twelve patients with unilateral displaced orbito-zygomatico-maxillary complex (OZMC) fracture indicated for orbital floor reconstruction as evidenced by clinical and radiographic examination. All patients were collected from Oral and Maxillofacial Surgery, Faculty of Dentistry, Tanta University, and Tanta University Hospitals. All patients signed informed consent before undergoing surgery. According to human research guidelines adopted by the REC at the Faculty of Dentistry, Tanta University, the ethical research committee ethically cleared the study.

Patients had to meet the following criteria to be considered for surgery: 1) Patients with unilateral displaced OZMC fracture, 2) Patients with no prior history of orbital reconstruction, 3) Diplopia within 30° of primary gaze,

4) Radiological evidence of extraocular muscle entrapment (inferior rectus muscle) and/or positive forced duction test, and 5) Enophthalmos greater than 2mm. The patients with the following criteria were excluded from our study; 1) Bilateral OZMC fractures, 2) Rupture of the globe, 3) Hyphema, 4) Retinal detachment, 5) Traumatic optic nerve lesions.

Preoperative assessment:

The full clinical examination was carried out, including a complete dental examination, extra oral and intraoral examination, and photographic documentation. All findings had been registered. Ophthalmologic examination included evaluation of visual acuity, which was measured by distance eye chart[11], the external appearance of the eye including vertical dystopia (hypoglobus), which was measured by drawing an imaginary line horizontally across the patient's inter-pupillary axis and determine if the pupil of the affected eye is in the lower level in relation to the intact eye which revealed hypoglobus[12],

enophthalmos which was measured by the aid of exophthalmometer represented by four grades from 0 to 3 as follows: grade 0 = no enophthalmos, grade 1= mild enophthalmos (less than 1 mm), grade 2= moderate enophthalmos (ranged from 1 to 2 mm), grade 3= severe enophthalmos (over 2mm)[13], diplopia which was assessed if it was present in the primary position of gaze, within 30° degree or in a secondary position of gaze depending on the patient response by specialized ophthalmologist.[14],

ocular motility was tested by asking the patient to follow a moving target into the diagnostic positions of gaze observing the extent of movement of each eye. The amount of limitation of movement is classified as grade 1= slight limitation, grade 2= moderate limitation, grade 3= marked limitation or grade 4= no movement according to the observation of two independent examiners.[15]

Radiographic examination was done by obtaining a multiaxial CT scan of the face for proper diagnosis and treatment planning.

3D printed model fabrication:

After obtaining the preoperative CT scan, 3D simulation was performed using adequate software. The 3D printer was used to print the patient-specific model. The titanium orbital mesh was adapted accurately on the orbital floor surface of the 3D printed patient specific model. Care was taken to fully adapt the whole surface area of the mesh onto the model until the mesh was fully and passively seated without any rocking onto the model.

Surgical Technique:

In fracture at the zygomaticofrontal suture, surgical access was obtained by the lateral eyebrow approach. For surgical access to the inferior orbital rim and the orbital floor was obtained by transcutaneous infraorbital approach. The intraoral buccal vestibular incision was performed at the molar region as surgical access for the zygomatic buttress region.

The reduction of the ZMC fracture was made carefully. A preliminary fixation was done then the prebent titanium mesh was inserted into its accurate position as described before without any modification fully and passively. Once it was confirmed that the reduction was accurate, final fixation was done as necessary using titanium miniplates and finally, after the prebent titanium 0.3 mm mesh was used for reconstruction of the orbital floor.

Post-operative assessment:

Clinical evaluation:

All patients were regularly followed up immediately, 1st & 2nd weeks, then 1st & 2nd and 3rd months postoperatively. The same parameters of preoperative clinical evaluation were assessed, along with the aesthetic results, which were judged by means of photographs using the 3-score scale according to Freihofer 1995[16] as "good", "satisfactory", and "poor" (Table.1).

Radiographical evaluation:

CT scan was obtained immediately, 3rd and 6th months postoperatively for each patient to detect the accuracy of the reduction and fixation of the OZMC fracture and to evaluate the accuracy of the placement of the titanium mesh by measuring the following parameters: 1) The layout angle was defined as an acute angle between the titanium mesh and an arbitrary line representing the pre-morbid status of the orbital floor connecting the starting point of the orbital floor fracture to its end. This line reflects the normal bone contour and is easy to suppose from contralateral normal orbital floor.[17] 2) The gap length was defined as the distance from the distal tip of the titanium mesh to the posterior bone shelf margin.

3) The zygomatic reconstruction: Adequate zygomatic reduction was judged by evaluating any involved parts from the following reference points, including zygomatico-frontal suture, zygomatico-sphenoidal suture, zygomatico-maxillary buttress, inferior orbital rim, and zygomatic arch, which was judged by two experienced surgeons as good, satisfactory or poor.

RESULTS

Insignificant changes were reported in our study regarding the visual acuity of the affected eye (Figure 1) In return to the preoperative status at which all patients (100%) showed hypoglobus, postoperatively, ten patients (83.3%) showed an absence of hypoglobus. Only two patients (16.3%) showed persistent hypoglobus (Figure 2)

In our study, post-operative measurements of enophthalmos revealed significant improvement compared to preoperative enophthalmos measurements as P1=0.003. Only two patients (16.7%) were measured as grade 3 enophthalmos postoperatively (Figure 3)

Our study reported that four patients who reported diplopia preoperatively (33.3%) reported no diplopia postoperatively. Only one patient (8.3%) reported persistent diplopia (Table.2).

Our results showed significant improvement in the limitation of ocular motility of the affected eye compared with preoperative status as (*P*1=0.001). 11 patients (91.7%) showed no limitation of ocular motility postoperatively.

Only one patient (8.3%) showed marked limitation of ocular motility (grade 3) until the first month postoperatively. A mild improvement was obtained at the second month postoperatively as the patient showed moderate limitation of ocular motility (grade 2) (Figure 4).

According to the Freihofer scale, nine patients (75%) represented (Good) aesthetic results. Only three patients (25%) were representing (Satisfactory) aesthetic results. No poor aesthetic results were obtained in our study.

Insignificant changes of the layout angle were obtained in our study during the follow-up periods as the mean of the immediate post-operative evaluation was (8.88) with a Standard deviation of (±9.28) which was very close to those of 6th months postoperatively (Mean=8.95 & S.D= ±9.36). After the 6th month (Figure 5).

The gab length showed insignificant changes at the different follow-up periods. The mean of the immediate post-operative evaluation was (2.77) with an SD of (±3.48),

then during the 6th month postoperatively (Mean=2.90 & S.D= ±3.55) (Figure 6).

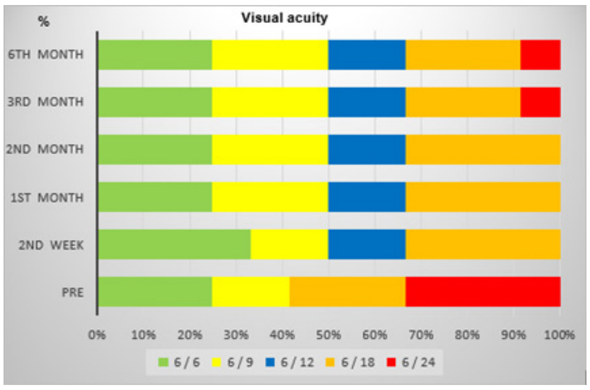
Nine patients (75%) were carefully evaluated and categorized as (Good). 2 patients (16.7%) cases no 4&12 were categorized as (satisfactory). Only one patient (8.3%), case no.11, showed (Poor) OZMC reduction accuracy (Figure 7).

Table (1): showing the aesthetic results according to Freihofer.

Good	When the observers will be satisfied and there will be hardly any deviation from normal or asymmetry
Satisfactory	When there will be slight deformation which will be felt not to require any further surgery
Poor	When further surgery is necessary as there will be a considerable departure from normal

Table (2): Showing changes in diplopia in all follow up periods in relation to the preoperative status.

Diplopia		Pre	2nd week	1st month	2nd month	3rd month	6th month
No	N	7	11	11	11	11	11
	%	58.3%	91.7%	91.7%	91.7%	91.7%	91.7%
Within 30° of primary gaze	N	3	1	1	0	0	0
	%	25.0%	8.3%	8.3%	.0%	.0%	.0%
In secondary gaze of vision	N	2	0	0	1	1	1
	%	16.7%	0%	0%	8.3%	8.3%	8.3%
P 1(comparison with Pre)			0.143	0.143	0.121	0.121	0.121
P 2(comparison with 2nd weeks)				1.0	0.368	0.368	0.368



Figurre (1): Bar chart showing changes in visual acuity of the affected eye in all follow up periods in relation to the

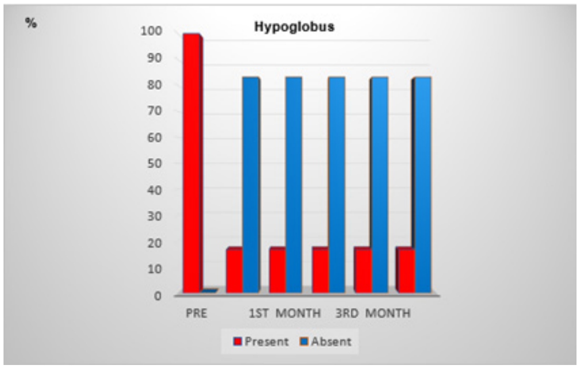


Figure. (2): Column chart showing changes in vertical dystopia (Hypoglobus) in all follow up periods in relation to the preoperative status.

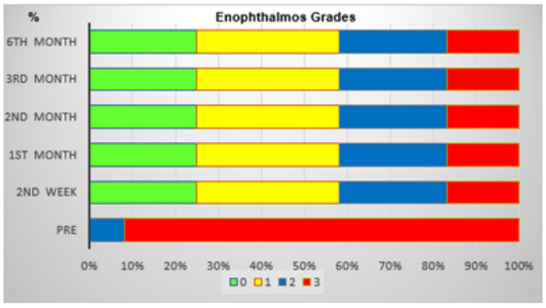


Figure (3): Bar chart showing changes in enophthalmos in all follow up periods in relation to the preoperative status.

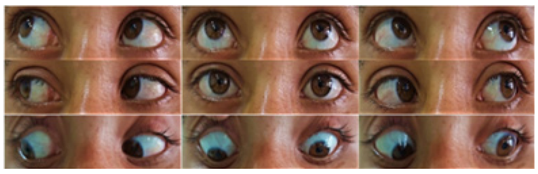


Figure (4): 6th month postoperative clinical photograph showing no limitation of the ocular motility of the left eye (affected side).

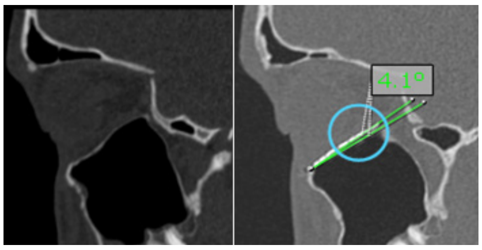


Figure (5): 6th months postoperative CT scan showing:
1- The contour of the contralateral normal orbital floor of the right eye.
2- measurement of the layout angle of the affected left eye which equals (4.1°).

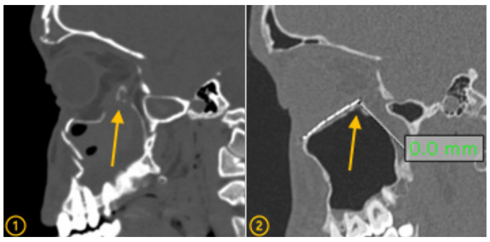


Figure (6): Sagittal views of CT face showing the following:
1- Preoperative CT scan showing fractured orbital floor of the left eye.
2- 6th months postoperative CT scan showing measurement of the gab length which equals (0mm).

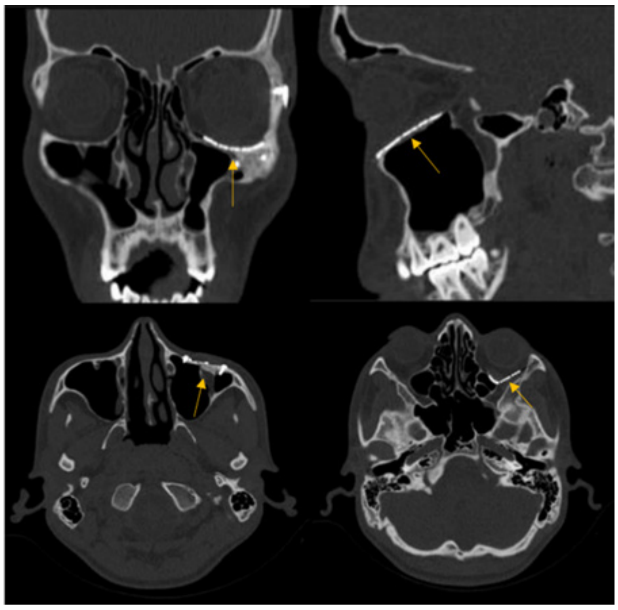


Figure (7): 6th months postoperative multiaxial CT face bony window showing accurate OZMC fracture reconstruction.

DISCUSSION

The most frequent cause of the OZMC fracture in this study was road traffic accidents in 58.3% (7 patients), followed by falls in 25% (3 patients), followed by assault in 16.7% (2 patients). Kumar et al.,[18] El-Mahallawy YA et al.,[19] So Young Ji et al.[20] reported road traffic accidents as the most common cause of their studies.

Regarding the evaluation of the visual acuity in our study, ten patients (83.3%) reported that they have the same visual acuity just like the pre-morbid status in agreement with Kumar et al.[18], who said that all his eight patients (100%) didn't write any alteration in the visual acuity. In our study, only two patients reported decreased visual acuity compared to the pre-morbid status. They had wide orbital floor fracture, which led to inaccurate reconstruction of the orbital floor as the orbital mesh was displaced downward, leading to residual post-operative enophthalmos, hypoglobus, and diplopia. It is well known that a change of the position of the eyeball may lead to displacement and stretching of the optic nerve, which may result in traumatic optic neuropathy with subsequent decreased visual acuity.[21]

In our study, evaluation of the external appearance of the eye showed significant resolution in both hypoglobus and enophthalmos postoperatively after adequate orbital floor reconstruction. This is consistent with Mittal et al. [22], Choudhury et al. [23]and Zhang et al.[24]. In case no.11&12 persistent hypoglobus and enophthalmos was found postoperatively as the posterior end of the titanium mesh wasn't supported by the posterior margin of the bone. So, the mesh was displaced downward in the maxillary sinus leading to increased orbital volume with the subsequent presence of hypoglobus and enophthalmos postoperatively. In our study, significant improvement of ocular motility and diplopia was obtained successfully after adequate subperiosteal dissection of the orbital floor and release of any incarcerated tissues, which was confirmed by intraoperative forced duction test. Ceylan et al. [25] reported similar results. Despite the negative forced duction test, only one case (no.12) showed persistent ocular motility and diplopia limitation, which could be due to incorrect reconstruction, muscle fibrosis, or nerve palsies. Resolution of the persistent diplopia was obtained during the follow-up period, and the ophthalmologic examination was recommended using prism glasses. In our study, the mean of the layout angel was (8.88 ±9.28) ranged from(3.8-35.9°), and the mean of the gab length was (2.77±3.48) ranged from (0-11.39 mm). YC Kim et al. reported that for orbital floor fractures, the average layout angle of the inserted mesh was 2.23° in the RP skull model group and 4.69° in the conventional group. In contrast, the average gab length was 5.21 mm (ranged from 1.47 to 21.76 mm) in the RP skull model group and 6.64 mm (ranged from 1.47 to 21.76 mm) in the conventional group.[17]

The availability of a post-operative CT-Scan gives an immediate clue and confirmation about the success of the utilized treatment modality, along with the patient's subjective acceptance and symptoms. However, the evaluation of the layout angle and the gab length after the management of OZMC fracture add a new feature to determine the accuracy of the treatment postoperatively objectively. Our study found that the insertion of the prebent orbital titanium mesh without any modification after the preliminary reduction and fixation of the OZMC fracture added new intraoperative evidence about the accuracy of the reduction and fixation of the OZMC fractures. In some cases, in our study the prebent orbital titanium mesh couldn't be seated properly due to inaccurate reduction, which required intraoperative revision for the reduction and fixation.

CONCLUSION

The presence of intact eye functions and adequate external appearance was extremely important to judge the accuracy of the reduction and fixation of the OZMC fractures. Despite the radiographic analysis done in our study to judge the accuracy of the reduction and fixation, the excellent clinical outcome and the absence of patient complaints are the golden standards for a successful operation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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