Egypt, J. Plast. Reconstr. Surg., Vol. 44, No. 2, April: 337-352, 2020

Improving Aesthetic Outcome in Managing Acute and Chronic Upper and Midface Deformities Using Computer Assisted Planning

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ABSTRACT

Surgical procedures in the facial region are associated by a variety of difficulties. The anatomy of the maxillofacial region, the complexity of the bony architecture as well as the esthetic implications.

The three dimensional imaging and 3D printing, have been applied for the restoration the complex anatomy of craniofacial structures. In addition, mirror-imaging techniques advocating 3D computed tomographic (CT) scanning and 3D printing can maximize the surgical outcome on both the functional and esthetic reconstruction levels. A synthetic scaffold can be pre-molded to the individual prototype skull model to resemble the anatomic contour before applying it to cover the orbital defects.

Our aim is to show the importance and present our experience with three-dimensional virtual planning in solving a variety of acute and chronic clinical deformities within the scope of trauma in the cranio maxillofacial region.

25 patients were retrospectively recruited. Mean age was 33.5 years (range 13-59), male: female ratio = 2.6:1 (18:7). Eleven patients had acute injuries (44%) while the remaining 14 patients (56%) had chronic (malunited) fractures performed in 2 different centers treating maxillofacial deformities operated utilizing 3D planning protocols.

The advocation of the virtual planning techniques, three dimension printing and printed custom implant enabled an accurate reduction and fixation procedure of complex acute and chronic complex upper and midface fracture, which is reflected in very satisfactory aesthetic outcome.

Key Words: *Three dimension virtual planning – Cranio-maxillofacial deformities – Three dimension printing – Three dimension printed custom implant.*

INTRODUCTION

Surgical procedures in the facial region are associated by a variety of difficulties. The anatomy of the maxillofacial region, the complexity of the bony architecture as well as the esthetic implications are the reason for such difficulties. Knowledge in these fields has improved technicalities in surgical procedures of facial region and have imparted their effect on all aspects of treatment **[1]**. The complexity in surgical execution has even extended to the educational aspects of the practitioner dealing with deformities in this region **[2]**.

In 1980 the advent of three dimensional (3D) computer technologies presented an additional improvement that was set to change the course of surgical treatment in the maxillofacial region forever. The applications of this technology went through several stages of development **[3,4]**. This started with the improvement of the imaging systems and their associated software processing which greatly facilitated visualizing the relevant anatomy preoperatively. This imparted a better description and evaluation of the underlying deformities for the operating team **[5]**.

Stereo lithographic models printed from the modulated images were the next advancement. These were advocated for a variety of clinical applications and included a real time three dimensional realization of the underlying deformity **[3,4]**. Moreover, preoperative hardware adaptation and adjustment was facilitated. This application had its significant advance in operative time, accuracy of plate application and subsequently improved patient outcome **[6]**.

Despite this advantageous advancement in computer application and its inclusion into hospital protocols widely, some criticism was still in order.

These techniques had room for surgical error and hence this was the demerits that had to be addressed [2].

The next advance included the application of virtual planning. Virtual planning offered the advantage of minimizing human error. Combining virtual planning with the advanced digital printing soft wares gave rise to patient specific implants [3]. The solutions offered by patient specific implants suggest that these techniques will prove beneficial and indispensable to surgeons operating in the maxillofacial region [4].

Recently, 3D imaging and 3D printing, have been applied for the restoration the complex anatomy of craniofacial structures [4]. In addition, mirror-imaging techniques advocating 3D computed tomographic (CT) scanning and 3D printing can maximize the surgical outcome on both the functional and esthetic reconstruction levels [6].

Applying these techniques, a custom made prototype skull model that resembles the uninjured state can be obtained before surgery; therefore, the surgeon can plan and execute the surgery using a skull model as reference. A synthetic scaffold can be pre-molded to the individual prototype skull model to resemble the anatomic contour before applying it to cover the orbital defects [6].

Our aim in this study is to show the importance and present our experience with three-dimensional virtual planning in solving a variety of acute and chronic clinical deformities within the scope of trauma in the cranio maxillofacial region.

PATIENTS AND METHODS

Study type: A retrospective analysis of prospectively maintained records of 25 patients with upper and midface fractures. Types of fractures included the: Forehead, orbit, zygomatico-maxillary complex (ZMC) and palatal fractures.

Study setting: The study was performed in 2 different Centers treating Maxillofacial Deformities operated utilizing 3D planning protocols.

Study period: The study was done between September 2015 and August 2018.

A set of inclusion criteria was placed for the cases to be included in the study:

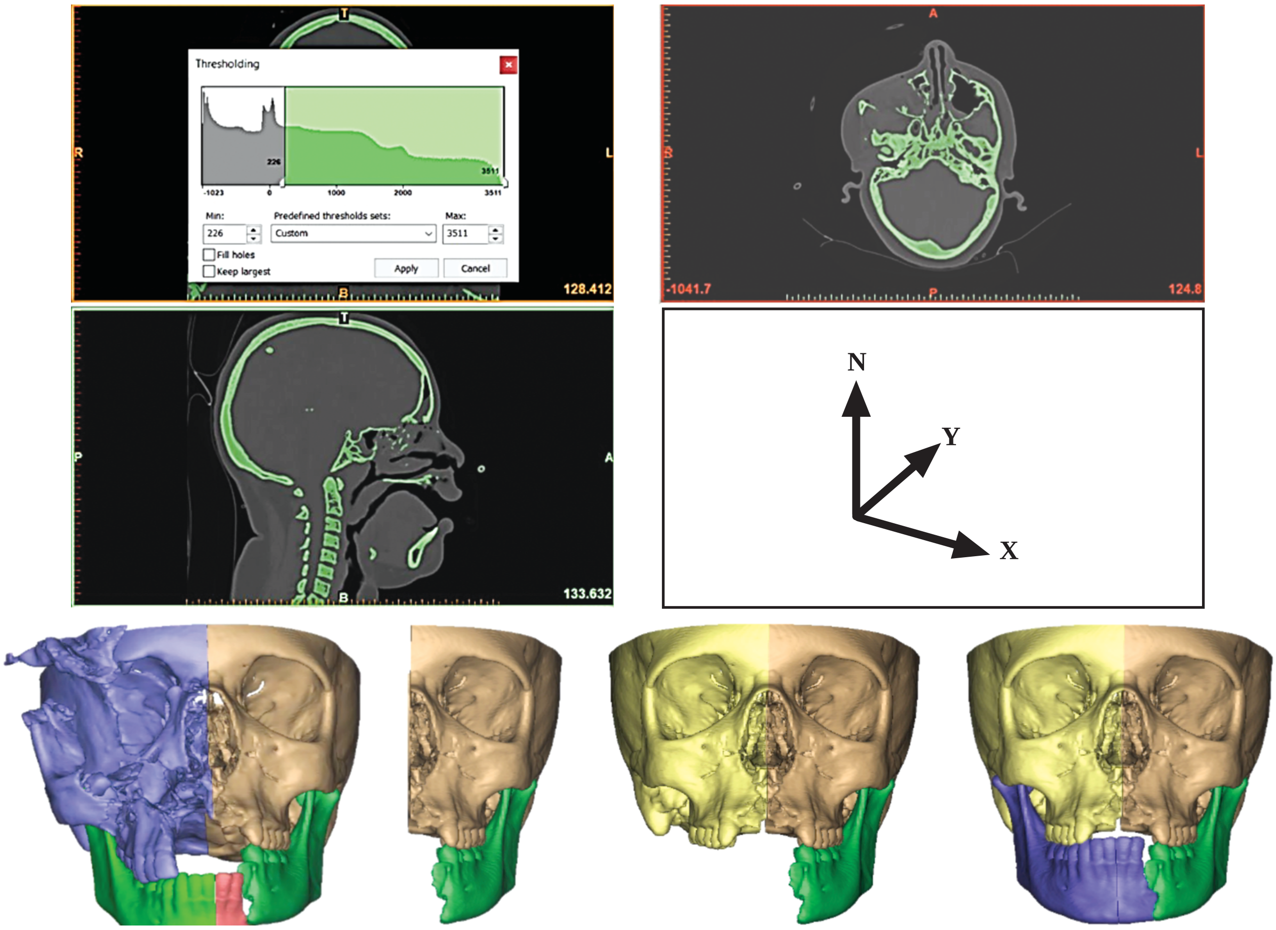
- Complete pre-and post-operative records.
- A full documentation of the follow-up period had to be available.
- Records of the planning protocols and techniques available.
- A follow-up period that exceeds 6 months.

Preoperative clinical, radiological assessment and planning:

All patient had facial deformities either due to acute trauma or chronic mal-united fractures. The etiology of trauma was due to road traffic accidents. Patient with acute trauma were primarily surveyed in the emergency department and further management was done afterward. The surgical plane was individualized according to type of trauma. Indication for surgical intervention was based on priority of correction of the functional and aesthetic by proper skeletal reduction and stability.

The patient age, functional deficit, fracture site, number, type, deformities all are factors to be considered. Patients or their parents were counseled and clearly discussed the nature of the trauma, limitations of surgical outcomes, and the possible secondary procedures to be carried afterward. Involvement of other specialties when needed is of utmost importance e.g.: Ophthalmological, ear nose and throat, and orthodontists according to each patient clinical condition.

Multi-slice cut scan performed. The DICOM images were imported to Mimics 10 software (Materialise NV, Inc, Leuven, Belgium). Thresholding and segmentation was performed to allocate the fractured facial bones. The images were manipulated to prepare a mirror image from the normal uninjured side. An intact full skull image was prepared. The data were exported as STL model for printing a stereo-lithographic model. The hardware to be applied is then applied to the model in order to act as a guide for proper reduction and fixation Fig. (1).



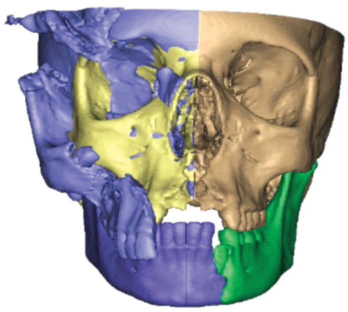


Fig. (1): From above downward: Importing DICOM files to Mimics 10 software (Materialise NV, Inc, Leuven, Belgium). Thresholding, segmentation and a mirror image from the normal uninjured side was done. An intact full skull image was prepared.

Surgical details:

All surgeries were performed under general anesthesia. Broad spectrum antibiotics were administered. In acute cases, adequate surgical debridement and through wash with and removal of foreign bodies i.e. gravel was done prior to sterilization.

The surgical technique used were tailored to each patient clinical condition:

1- Different surgical incisions adopted: Upper blepharoplasty, subcilliary, upper sulcus and lower sulcus incisions, coronal and current lacerations were used.

2- Centric occlusion is achieved using upper and lower arch bars and maxillary mandibular fixation was done if needed.

3- Identifying and Preserving important structures i.e.: Levator palpebrae superioris muscle, medial and lateral canthi, lose tooth, etc.

4- Guided with the 3 dimensional printed skull, skeletal stabilization i.e. open reduction internal fixation using different shapes of mini plate and screws and or titanium mesh according to the type, site and degree of comminusion. In such cases where exposure of the supraorbital bar or the roof of the orbit was needed, a bicoronal skin incision was employed with scalp reflection (preserving supra-orbital neurovascular bundle) until the bar is exposed. A limited frontal craniotomy is done with gentle dissection of the frontal dura to expose the floor of the anterior cranial fossa (i.e. orbital roofs) for reconstruction.

5- Identifying injured tissue layers and the repair was done from deep to superficial. Repair of any injured mucosal lining, Submuscular aponeurotic system, varies muscle injuries using 3/0 and 4/0 vicryle either in interrupted or continues type.

6- Application of suction drains if needed, followed by skin closure using 5/0 and 6/0 proline stitches.

Post-operative care:

Light compression dressing were applied to all patients. Patients laid down in semi sitting position. Cold fomentation for the first 48 hours followed by hot fomentation up to two weeks. Intravenous antibiotics administered till the drain is removed, shifting to oral route for one week. Drains removed when it's minimal amount (less than 30cc). Dressing is done at the 3rd postoperative day. The skin stitches were removed at the 5th or 7th postoperative days. All patients instructed to follow up in the outpatient clinic at one, three and six months afterward. Patients was informed about possible progress, and possible outcome which might need 2ry procedures.

Post-operative clinical and radiological assessment:

All patients were examined for the aesthetic outcome, presence of complications and multi slice cut scan was performed, the DICOM images were transferred to mimics software (MaterialiseNV, Inc, Leuven, Belgium). Deviations from normal will be quantified using a color map. The analysis statistics will be described applying the unsigned mode for point to point comparison. The absolute mean and standard deviation was reported.

Patients demographic, history, physical and clinical examination, clinical photographs and surgical procedures (number and type) and complications were collected. All patients or their parents signed an informed consent to be included in the study.

RESULTS

25 patients were retrospectively recruited. Mean age was 33.5 years (range 13-59), male: female ratio = 2.6:1 (18:7). Eleven patients had acute injuries (44%) while the remaining 14 patients (56%) had chronic (malunited) fractures (Diagram 1).

The ZMC was involved alone in 7 patients (28%), and along with the orbit in the remaining 18 patients (72%). Of the latter group, 8 patients had additional frontal bone fractures (32% of the whole cohort). Not all patients with orbital fractures had repair by titanium mesh, leaving 4 patients without orbital meshes implanted. Such decision was based on the intraoperative findings. This is contrary to the patients with forehead fractures, where all (n=7) but one had titanium mesh fixation. Maxillary titanium meshes were placed in 6 patients (24%). (Diagrams 2,3,4). Fixation was a 3-point fixation in the majority of the patients, 56% (n=14) and 4-point fixation in 44% (n=11).

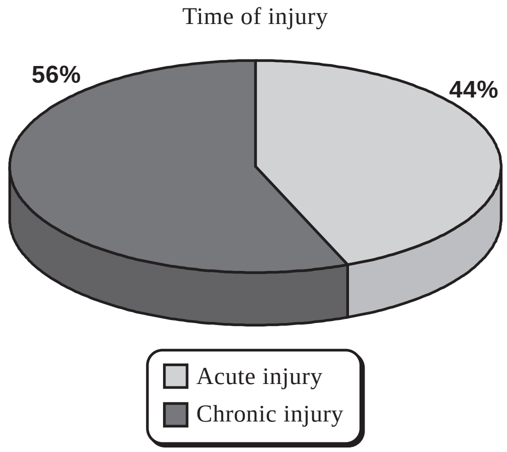


Diagram (1): Showing patients distribution as acute and chronic deformities.

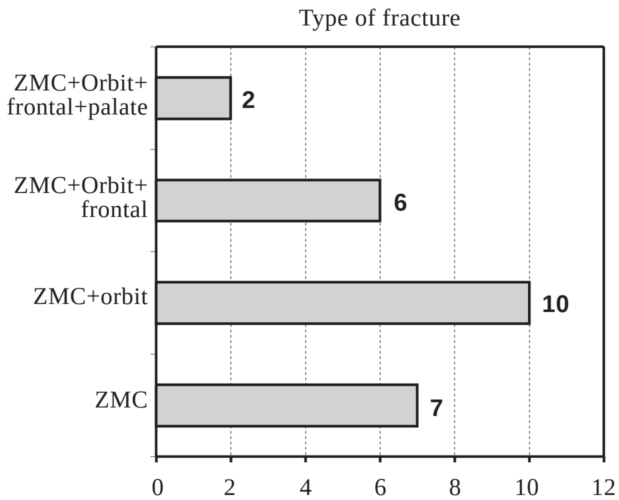


Diagram (2): Showing the distribution of different types of cranio-maxillofacial fractures.

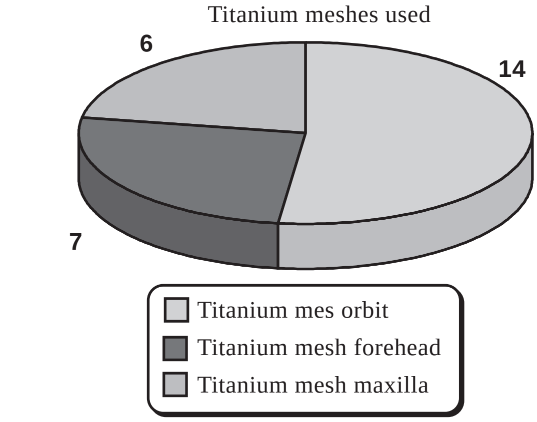


Diagram (3): Distribution of the titanium mesh used according to the site.

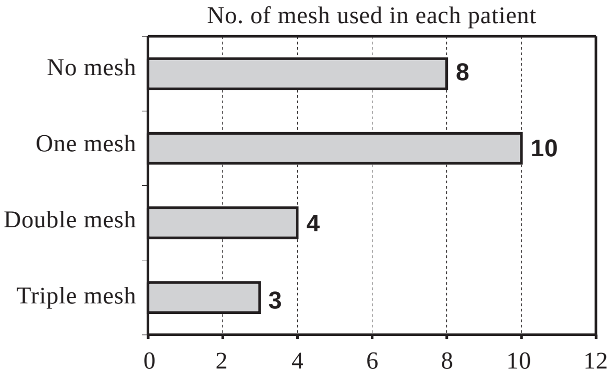


Diagram (4): Showing the number of titanium mesh used in each patient.

Statistical analysis:

Statistical analysis was performed using IBM SPSS Statistics Version 2.1 for Windows. Data was presented as mean and standard deviation (SD). The significance level was set at $p \leq 0.05$. Kolmogorov-Smirnov and Shapiro-Wilk tests were used to assess data normality. Data showed non-normal distribution, so Mann-Whitney test was performed to compare between healthy and fixed orbit volumes.

There was no statistically significant difference between healthy and fixed orbits volumes (Table 1 & Diagram 5). Complex cranio-maxillofacial fractures were assessed using the mirrored reconstructed images and the post-operative fixation images. The overall deviation mean from normal was calculated to be 1.41±0.15mm. The amount of deviation measured for each patient is presented in Table (2) and Diagram (6).

Table (1): Mean±SD of healthy and fixed orbit volume measurements (mm^3).

	Healthy orbit	Fixed orbit	*p*-value
Volume (mm^3)	33174.14± 3508.97	33525.69± 3873.53	0.580

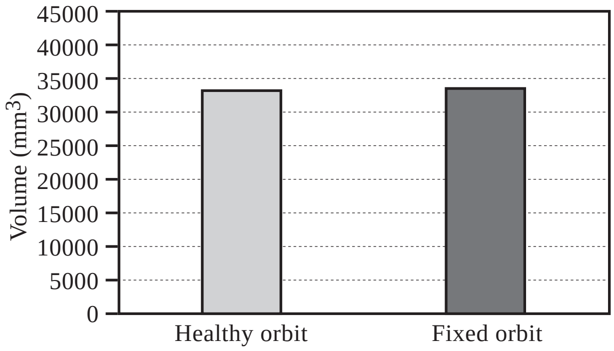


Diagram (5): Volume measurements (mm^3) of healthy and fixed orbits.

Table (2): Distance (deviation) away from the mirrored intact side (the Control): Measured in (mm).

Patient	Distance (deviation) away from the mirrored intact side (the Control)	Standard deviation
1	1.3008	1.208
2	1.478	1.1771
3	1.409	1.3493
4	1.3046	1.256
5	1.508	1.1265
6	1.784	1.637
7	1.276	1.158
8	1.56	1.439
9	1.125	1.148
10	1.367	1.256
11	1.374	1.272
12	1.3002	1.203
13	1.458	1.324
14	1.362	1.235
15	1.3579	1.246
16	1.3046	1.256
17	1.508	1.1265
18	1.784	1.637
19	1.276	1.158
20	1.56	1.439
21	1.567	1.256
22	1.374	1.272
23	1.3002	1.203
24	1.358	1.324
25	1.362	1.235

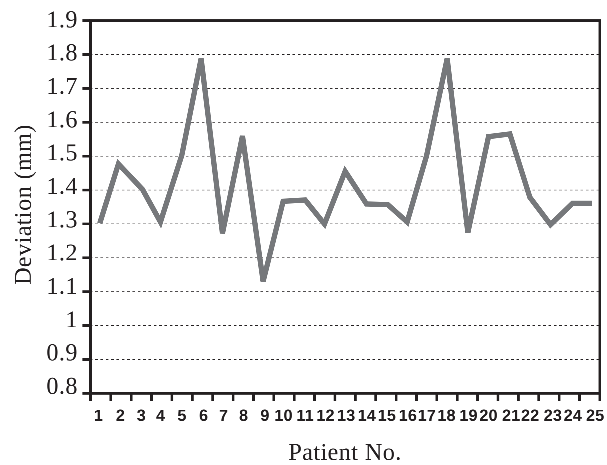


Diagram (6): Deviation (mm) from the contralateral side for each patient.

Their no significant complication recorded other than soft tissue atrophy over the frontal and periorbital region in two patients which will need touch up procedure in the form of fat injection. Fig. (2) till (21) show some of the cases included in the study.

Case (1)

Fig. (2): Male patients 19 years old with tetrapod fracture post road traffic accident. (upper raw): Pre-operative photos. (middle raw and lower raw): Pre-operative CT scan views.

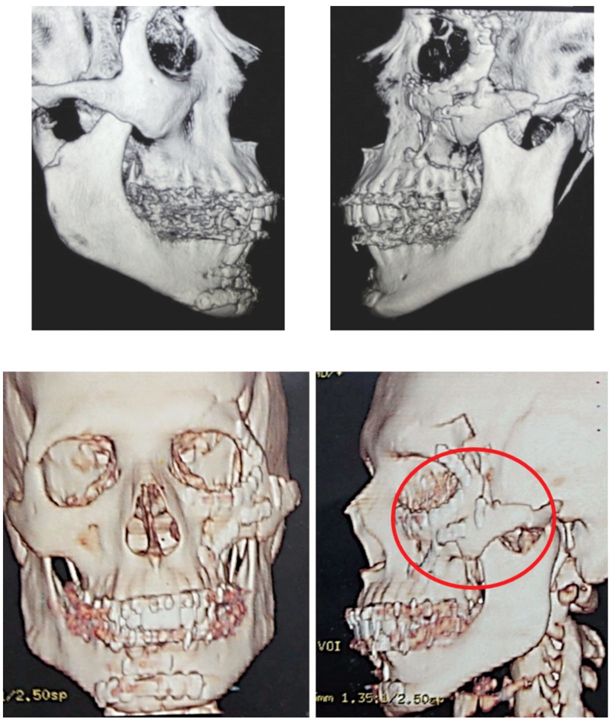


Fig. (3): (Upper raw): Post-operative CT scan photos. (Lower raw): CT scan views showing mal alignment of the zygomatic arch.

Fig. (4): (1st raw): Post-operative photos of the patient showing depressed and medially rotated left zygoma. (2nd raw and 3rd raw): Intra-operative photos showing the exposure of the zygomatic arch, corrective osteotomy and re-fixation. CT scan views. (4th raw): The printed three dimension model.

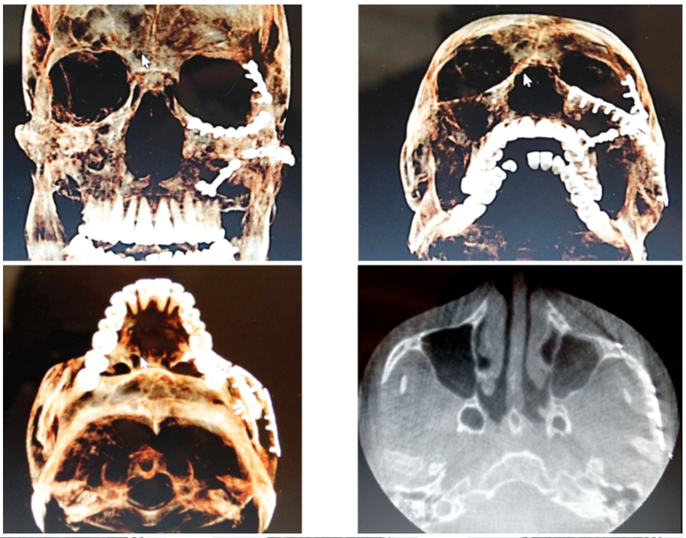


Fig. (5): (Upper and middle raw): Corrective osteotomy of the zygomatic arch, fronto-zygomatic, orbital rim and body of zygoma, post-operative CT scan. (Lower raw): 9 months post-operative photo.

Case (2)

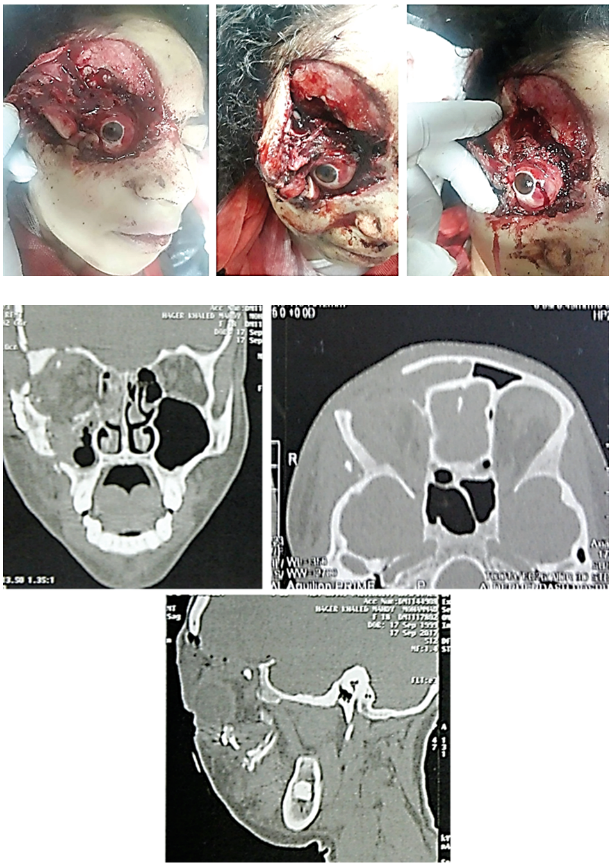


Fig. (6): Female patient 18 years old post road traffic accident with comminuted frontal, orbital floor and right zygoma, associated with tissue injury (upper raw): Preoperative photos, showing the severity of tissue injury. (Middle and lower raw): Preoperative CT scan.

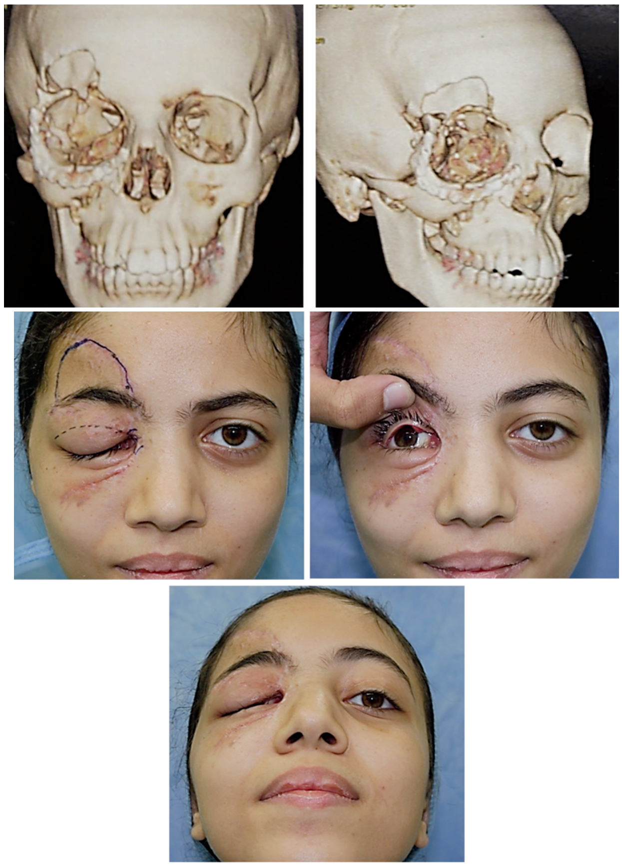


Fig. (7): (Upper raw): 1st stage pot-operative cut scan, showing fixation of the right zygoma without reconstruction of the right frontal bone and roof of the orbit. (Middle and lower raw): Early post-operative photos.

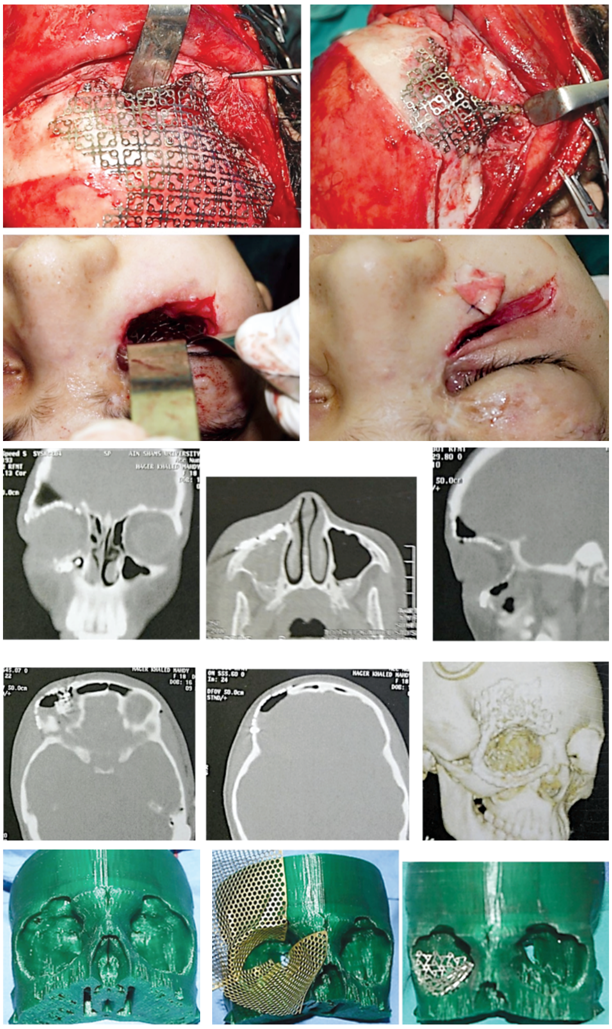
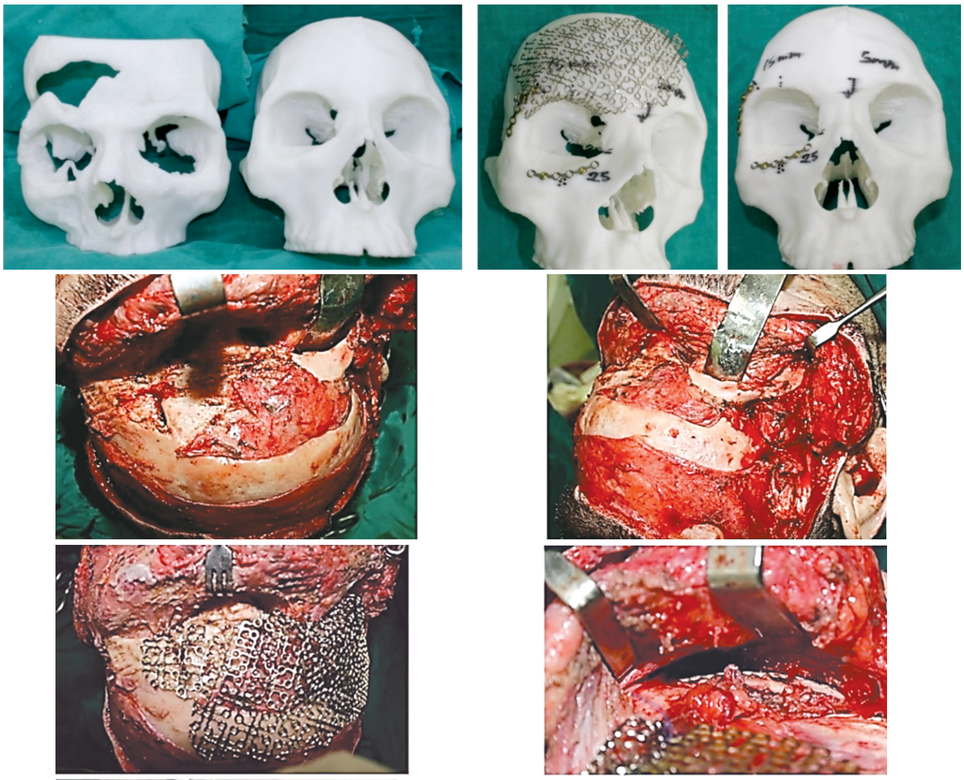


Fig. (8): (1st and 2nd raw): Intra-operative photos, showing reconstruction of the right frontal bone, roof and floor of the orbit, fronto zygomatic region using titanium mesh and conchal cartilage graft. (3rd and 4th raw): Early post-operative photos. (5th raw): The printed three dimension model and intra-operative adaptation.

Fig. (9): (Upper raw): Early pot-operative photos showing mal-position upper eye lid. (Middle) early post-operative photos after upper eye lid repositioning and full thickness skin graft over the lower eye lid. (Lower raw): Late post-operative photos.

Case (3)

Fig. (10): 32 years old male patient with chronic post traumatic cranio maxillofacial deformity. (Upper and middle raw): Preoperative photos showing the severity of the deformity at the frontal, orbital and ZMC region. (Lower raw): Preoperative CT scans with red circle and arrow showing the frontal defect and the malposition right ZMC. Yellow arrow shows the future corrective osteotomy sites.



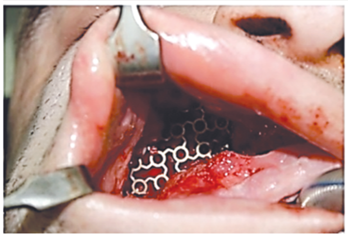


Fig. (11): (1st raw): The printed three dimension model and intra-operative adaptation of the titanium mesh, and the plate and screws. (2nd, 3rd and 4th raw): Intra-operative exposure of the frontal, orbital, ZMC including the zygomatic arch with application of the mesh and corrective osteotomy and fixation of the ZMC including the arch.

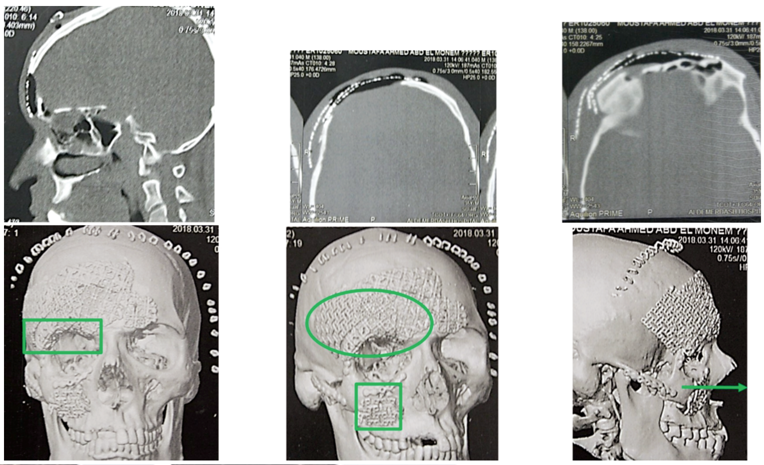


Fig. (12): (Upper raw): Post-operative Cut Scan showing the tetra pod fixation of the ZMC and reconstruction of the Fronto-orbital and maxillary region with titanium mesh. (Lower Raw): Post-operative photos.

Fig. (13): Showing late post-operative result.

Case (4)

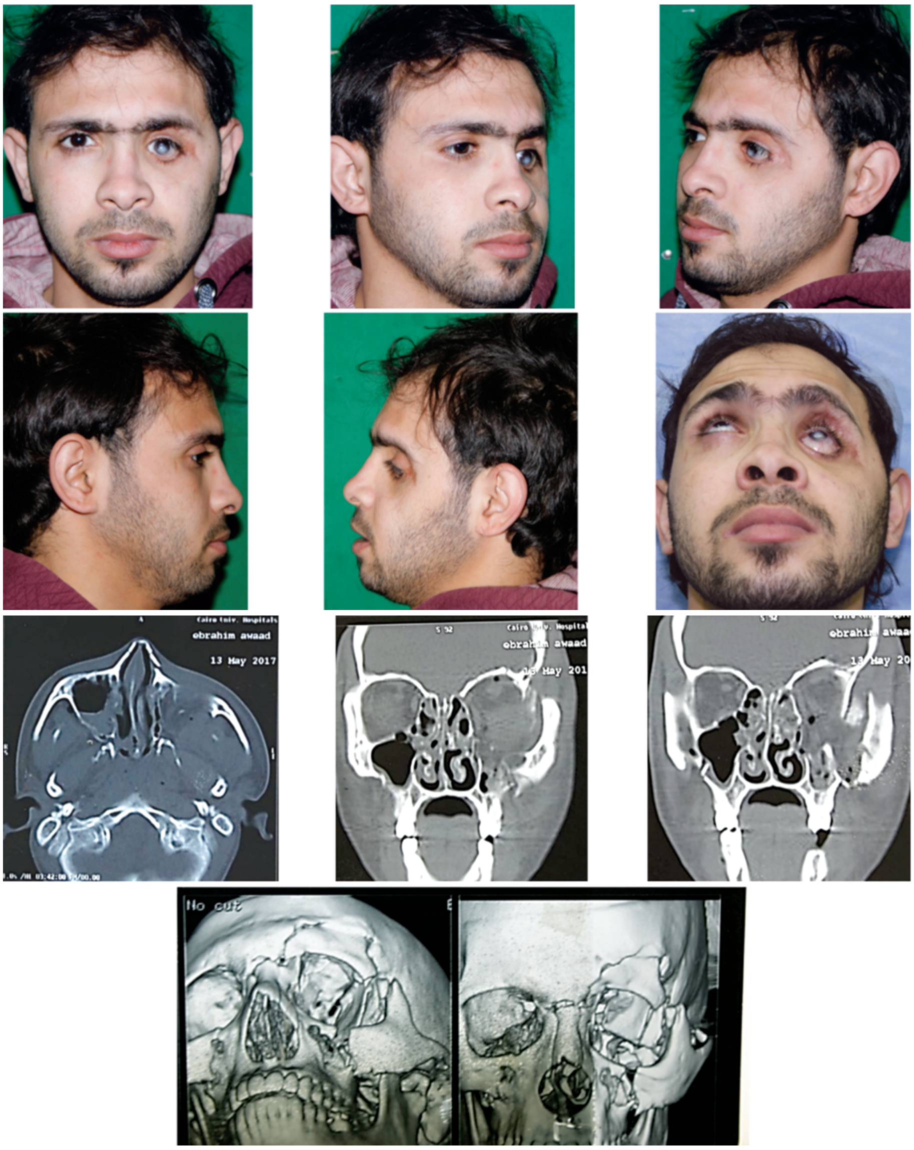


Fig. (14): 29 years old male patient with chronic post traumatic cranio maxillofacial deformity of the left ZMC complex and frontal bone complicated with corneal ulcer and opacity of the left cornea. (Upper and middle raw): Preoperative photos showing the severity of the deformity at the ZMC and frontal region. (Lower raw): Pre trauma CT scans.

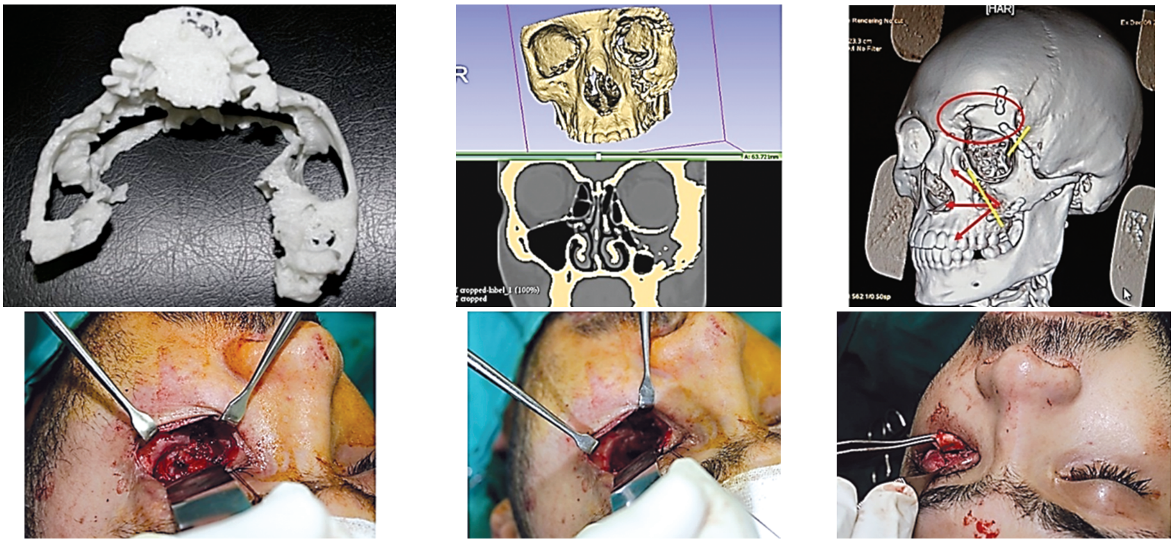


Fig. (15): (Upper raw): Preoperative planning and three dimension model with medially rotated and impacted right zygoma. 3 dimension cut scan with red circle and arrows showing the region to be corrected, yellow arrows indicate the line of osteotomy. (Lower raw): Intra-operative photos showing the degree of displacement of the orbital rim fracture and application of conchal cartilage augmenting of the orbital floor.

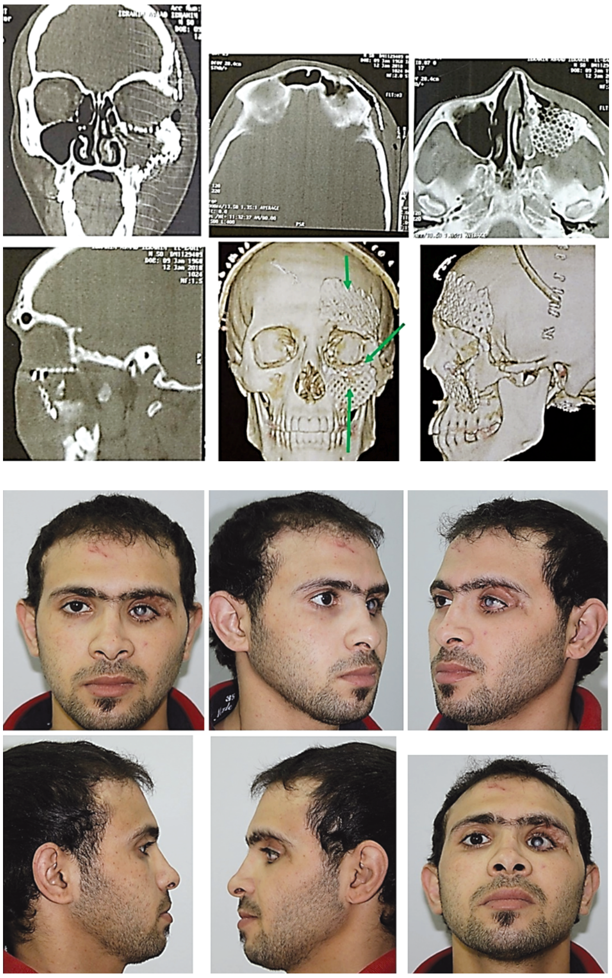


Fig. (16): (1st and 2nd raw): Post-operative CT scan showing the tripod fixation of the left zygoma in its new position, and reconstruction of the orbital, frontal and maxillary region with titanium mesh. (3rd and 4th raw): Late post-operative result.

Case (5)

Fig. (17): Male patient 15 years old with acute maxillo facial injury post road traffic accident. (1st an 2nd raw): Preoperative photos showing the severity of the facial lacerations and crushing of the frontal orbital and ZMC with down ward displacement and splitting of the right upper maxilla. (3rd and 4th raw): Pre-operative CT scan showing crushing and sever displacement of the frontal, orbital, ZMC and palate associated with fracture mandible.

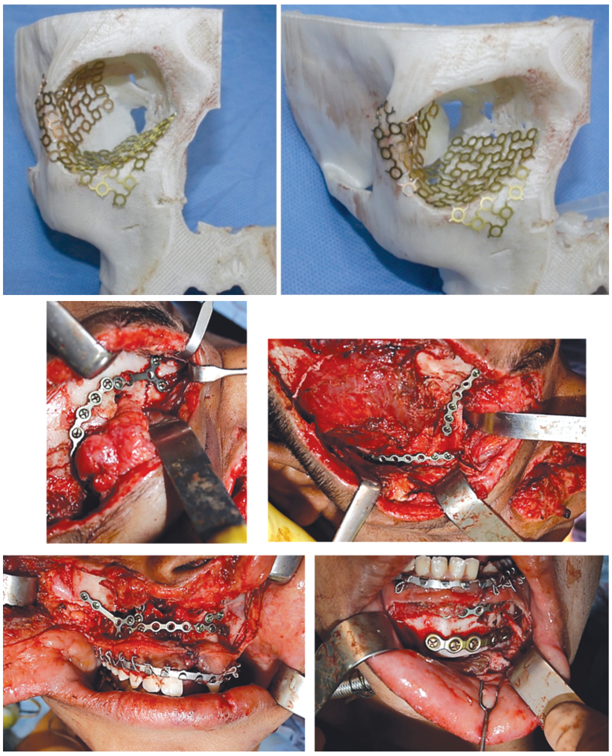


Fig. (18): (1st raw): Printed three dimension model and intraoperative bending of the orbital mesh for the floor and lateral orbital regions. (2nd and 3rd raw): Intra-operative photos with exposure of the frontal, orbital, zygomatic arch, naso-orbito ethmoid, ZMC and mandible and reconstruction with mini plate and screws.

Fig. (19): Early post-operative result (6 weeks).

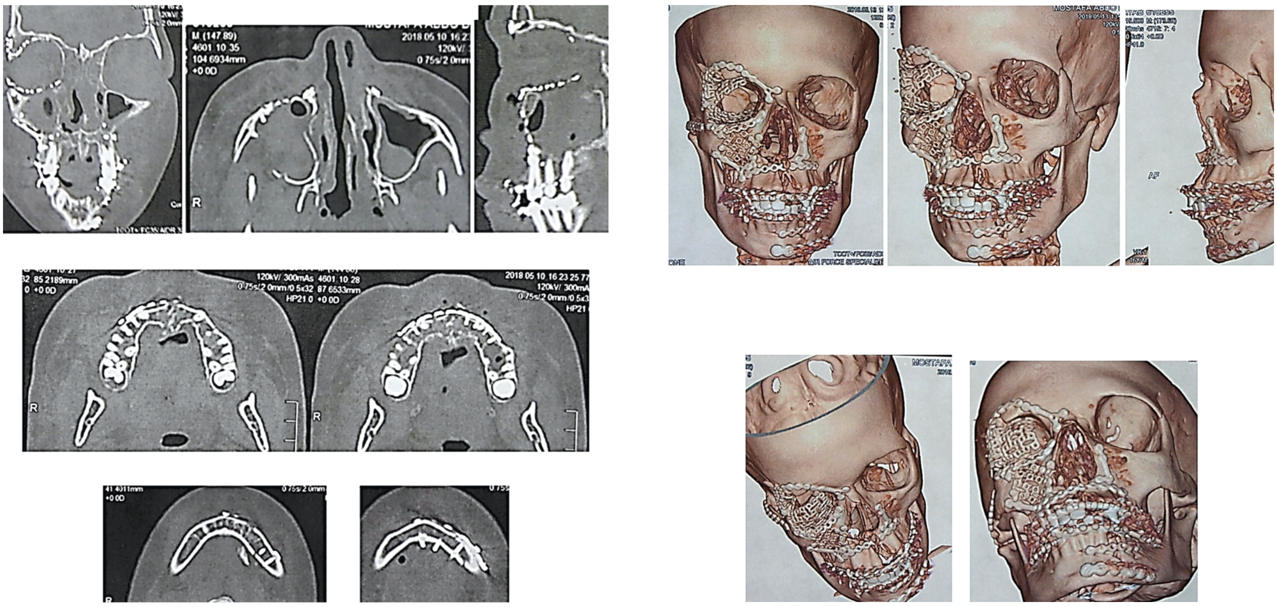


Fig. (20): Showing different views of the post-operative CT scan with adequate reduction of the fractures and application of titanium mesh and the mini plate and screws.

Fig. (21): Late (7 month) post-operative photos with adequate reduction and accepted symmetry. He is scheduled for squint surgery due to post-traumatic weakness of the lateral and inferior rectus muscles.

DISCUSSION

The complexity of the anatomy and deformities of the cranio-maxillofacial region entail the use of modern technologies like the virtual planning (VP), 3 Dimension modeling (3DM) and 3 dimension printed custom implants (3DPCIs), as these deformities commonly include not only skeletal but also soft tissue components.

These modern technologies are used to facilitate the analysis, diagnose the anatomic difficulty, simulate and orient the surgery, individualized the procedure according to each patient clinical situation, facilitate patient education, anticipate the results, and support the educational field in craniofacial surgery **[7-10]**.

The main indication of 3D virtual planning and printing in cranio-maxillofacial surgery include orthognathic surgery, planning vectors and osteotomies in distraction ostiogenesis, acute and chronic traumatic maxillofacial fractures and deformities, cranioplasty, facial skeletal contouring and augmentation **[11-26]**. The study included 11 patients with acute and 14 patients with chronic deformities all of which are due to road traffic accidents. 7 patients presented with ZMC fracture, 10 patients presented with ZMC and orbital fractures, 6 patients with ZMC, orbit and frontal bone fractures and lastly 2 patients presented with ZMC, orbit, frontal bone and palatal fractures. All of them managed with open reduction internal fixation with mini plate and screws. Corrective osteotomies was done and preplanned according to the vectors used to regain proper reduction and symmetry. Conchal cartilage graft was used in six patients to correct enopthalmous.

Previous concept and main concerns in planning is the number and site of fixation is the location and the number of fractured buttresses, which need fixation for optimal stability. Applying the concept of 1 point, 2 point, 3 point and 4 points of fixation is based on the maximum stability with the minimal hardware to be used. This is called functionally stable fixation **[27]**. There is no standardization for the strategic fixation of zygomatico-maxillary complex fractures. Gahari et al., 2019 **[28]** 16 investigated eight articles, five out of eight revealed that 3 point fixation was superior to 2 point fixation for the treatment of zygomatico-maxillary complex fractures. In our study 14 patient needed 3-point fixation, while 11 patients needed 4-point fixation with 56% and 44% respectively.

The evidence of using the advanced 3D technologies is still under great concern. Many factors are considered a challenge: Criteria of using the 3D technologies, the relation between local in house printing and outsourcing to industry, the time needed for the production and its delivery, its value in medical education, the optimal biomaterials to be used for 3DPCIs, and short and long term results **[29,7-10,16,30]**.

We printed the 3 dimension models using local private companies, it took 24 to 48 hours from processing the DICOM files. We used the 3 dimensional models as a scaffold to pre bend the plate and screws and the titanium mesh used according to the reconstructed site. 16 titanium mesh placements were used in all patients, 14 orbital, 7 forehead and 6 for maxillary reconstruction. 3 patients used all the 3 types of meshes, 3 patients used orbital and forehead meshes only. 1 patient needed orbital and maxillary mesh and 8 patients needed no meshes at all. There was no recorded case with infection or extrusion which is the most common complication recorded in literature.

There are inherent drawbacks to the use of advanced 3D computer technology, including potentially increased cost, the risk of infection or extrusion of alloplastic biomaterials, and unexpected discrepancies between simulated and actual operative results **[7-10,13,19]**. Employing 3D technologies also does not absolve the surgeon from the responsibility of sound clinical judgment, planning, and execution. The educational role of 3D technology in craniofacial reconstruction also continues to be defined. Soft tissue atrophy is of utmost importance to be considered in the preoperative surgical planning, we recorded two patient with frontal and periorbital soft tissue atrophy which entails reconstruction with fat injection.

Previous authors support Polyether Ether Ketone (PEEK) as well suited to craniofacial reconstruction, given it approximates the physical properties of human cortical bone. Although long-term studies are still needed, this literature reports relatively low complication rates associated with PEEK implants **[31,32,33,34]**. We have not experienced complications attributed to the 3DPCI and using titanium mesh as regard implant infections or extrusions, however the PEEk is considered the best material used now, for its least complication and smooth contour.

Complex zygomatico-maxillary fractures are a common finding. The prevalence has been reported to reach up to 40% of facial fractures. Various nomenclatures have been applied to coin the fractures of this region. It has been the consensus of many authorities that the term ZMO (zygomatico maxillary orbital complex) is the most accurate term. This is because it delineates the difference between the isolated simple zygomatic arch fractures and the more complex forms of ZMO **[35]**.

Fractures in this region are associated with changes in facial appearance complications such as hypoglobus, diplopia or changes in facial geometry might occur **[36,37]**. The complex anatomy of the zygoma contributed to the formation of the malar eminence. Furthermore, it participates in the formation of a part of the orbital cavity. Hence, trauma to this bony complex results in derangement in both form and function. Reestablishing the form and anatomical position of this traumatized bone is a paramount to a successful repair **[38]**.

The primary outcome in surgical treatment of ZMO fractures focuses on restoration of facial symmetry **[39,12]**. Differences within the range of 2mm in facial symmetry are virtually imperceptible and the face is considered symmetric **[40]**. The current study found that the There was no statistically significant difference between healthy and fixed orbits volumes. The overall deviation mean from normal was calculated to be 1.41±0.15mm. which lies within the acceptable range as it will not result in a virtually perceptible deformity.

Applying the principles of 3dimention preformed meshes and pre bent plates has become the standard practice in many centers. It has been documented that high resolution preoperative 3dimension imaging followed by 3dimesion planning can minimize the advent of asymmetrical outcomes **[41,42]**. The use of pre-fabricated hardware and surgical navigation techniques have become an integral adjunct in complicated cases **[43,44,45]**. Studies have documented that the application of these techniques minimize the deviation from the facial angles and orbital volume of the unaffected side **[46]**.

The methodology utilized in this study is in accordance with many previous work groups who attempted comparative assessment of the repaired side to the unaffected side **[47]**. The mean of the calculated orbital volume closely resembles that calculated in Nada et al., study (The mean (SD) orbital volume was 27.9 (4.0) cm^3 before operation and 27.5 cm^3 (4.1) postoperatively (t = 0.959; p = 0.338). However other studies have showed different measurements. Olivera et al., 2019 investigated twenty-four orbits. The Mean orbital volume (SD) was 24.02 (2.43) cm^3. Despite attempting to account for inter observer error the study proved that the measurements were highly reproducible with minimum error **[10]**. In our study we found the volume of the orbit to be 33174.14±3508.97mm^3 (p-value = 0.580). Calculation of the orbit can be highly variable as it is based on obliterating the foramina of the orbit on the software.

The calculation of orbital volume as a reference to accurate orbital repair is not without scrutiny. Olivera et al., concluded in 2019 that “Although reproducible and reliable, radiological volume assessments have not yet shown a clear correlation with clinical outcomes and postoperative management decisions should be based mainly on clinical findings **[10]**.

Conclusion and recommendation:

The advocation of the virtual planning techniques, three dimension printing and printed custom implant enabled an accurate reduction and fixation procedure of complex acute and chronic complex upper and midface fracture, which is reflected in very satisfactory aesthetic outcome. The deviation from normal was imperceptible to the observer which is one of the primary outcomes in these surgical procedures. Calculation of the orbital volume does not have a clinical reflection although it is necessary to enable the calculations of the deviation from normal unaffected side. The three dimension model printing doesn't consider the soft tissue injury which is difficult to be anticipate, however three dimension reconstruction could be investigated in further studies to improve the surgical outcome. The use of at home three dimensional printing is very useful as regard time and cost management, which should be further investigated for the possibility of its introduction. Despite the high cost of printing the PEEK material we need to investigate its cost efficacy in further studies.

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