ADJALEXU-2209-1318 (R1)EVALUATION OF ACCURACY OF 3-D PRINTED REDUCTION GUIDE IN THE TREATMENT OF ZYGOMATICO MAXILLARY COMPLEX FRACTURES (A RANDOMIZED CONTROLLED CLINICAL TRIAL)

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ABSTRACT

BACKGROUND: Fracture of Zygomaticomaxillary complex (ZMC) is considered to be one of the major facial fractures. it can lead to significant cosmetic and functional disorders. Three-dimensional (3-D) printing applications are gaining a remarkable attention in the field of craniomaxillofacial and plastic surgery. As the benefits of patient-specific 3-D printing become more established, surgeons are more likely to integrate this technology into their practice.

AIM OF THE STUDY: This study evaluated the accuracy of the use of 3-D printed reduction guide in the treatment of zygomatico maxillary complex fractures.

Patients & Methods: This study was conducted clinically on 12 adult patients with ZMC fractures indicated for open reduction and internal fixation. The patients were divided into 2 groups, (group A): the 3D printed reduction guide was used during the surgery and (group B): the surgical procedures were done without the reduction guide. The reduction and fixation time was recorded for comparison. Postoperative patient evaluation was performed with specific attention paid towards, accuracy of reduction, infra orbital nerve affection and postoperative ocular complications.

RESULTS: There was a statistically significant difference in the surgical reduction and fixation time between the two groups. The error differences were more reduced for all landmarks in group (A) compared to group (B). The mean AI was decreased for all landmarks in group (A) compared to group (B).

CONCLUSION: The use of 3D printed reduction guide offers shorter operation time and improves the reduction of the fractured segments in comparison to the conventional reduction techniques.

KEYWORDS: zygomatico maxillary complex fracture, 3-D printing, reduction guide, zygomatic symmetry.

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INTRODUCTION

Fracture of zygomaticomaxillary complex (ZMC) is considered to be one of the major facial fractures (1,2). The ZMC is a vital part serving as an important component of the buttresses of the middle third of the face. The ZMC also forms the malar eminence as it projects anterolaterally and contributes to the mid-facial width and the orbital rim contour; for these reasons, it plays a major role in terms of aesthetic appearance (3).

Fractures of the zygomatic complex can lead to significant functional and cosmetic problems including enophthalmos, trismus as a results of mechanical lock on the coronoid process, malar eminence depression and loss of sensation due to infra orbital nerve injury (4). Also, different orbital and ophthalmic complications can accompany the zygomatic complex fractures as the zygoma represents the lateral and anterior portion of the orbit. This complications include orbital blow-out or blow- in fractures and ocular injuries such as orbital content entrapment with diplopia and reduced ocular movements as well as exophthalmos or enophthalmos (5,6).

The aim of treatment of fractures of the zygomatic complex is to regain stability and restore cosmetic appearance through three-dimensional reduction and rigid fixation. After adequate reduction of the fracture has been achieved, it is critical to maintain stability and rigid fixation to prevent functional impairment and cosmetic complications. Open reduction and internal fixation has been used as the standard method for treating ZMC fractures (7,8).

Three-dimensional (3-D) printing applications are gaining a remarkable attention in the field of craniomaxillofacial and plastic surgery (9).

A variety of 3-D printing applications have been employed such as custom made models for preoperative planning, intraoperative cutting surgical guides, implants, surgical splints, and prostheses (10).

The advantages of 3-D printing include improved preoperative planning, surgical accuracy (11,12), reduced operating room time (12-14), and reduced post-operative complications (15).

For all these reasons, 3-D printing technology is considered a promising application in oral and maxillofacial surgery (16-19).

The objective of this study is to evaluate the accuracy of the use of 3-D printed reduction guide in treatment of zygomatico maxillary complex fractures. The null hypothesis in this study is that there is no significant difference between the 3-D printed reduction guide and traditional reduction in treatment of zygomatico maxillary complex fractures.

MATERIALS AND METHODS

The study was a randomized controlled clinical trial with equal allocation ratio 1:1.the study conducted in accordance with the Consolidated Standards of Reporting Trials (CONSORT). Sample size was estimated based on the following assumptions: alpha error= 5% and study power= 80%. Sample size was calculated to be 5 per group and this was increased to 6 to make up for cases lost to follow up. The total sample size= number of groups × number per group= 2 X 6= 12.

Twelve Participants were selected from the Emergency Ward of Alexandria University Teaching Hospital. The selected patients were operated upon in the Oral and Maxillofacial Surgery Department, Faculty of Dentistry, Alexandria University.

Inclusion criteria

•Age >18 years.

•Unilateral ZMC fractures indicated for open reduction presented within two weeks from trauma.

•Radio-graphic evidence of ZMC fracture.

Exclusion Criteria

•Infected fracture site.

•Non displaced fracture.

•Comminuted fracture.

•The fractures of the skull bases and craniofacial anomalies, which can Potentially hamper confirmation along the median sagittal plane.

Randomization technique and allocation

Random allocation of each participant to group A (study group) or group B (control group) was performed by a trial independent individual using computerized method (www.randomizer.org) and the allocation ratio was intended to be in equal blocks to ensure that the study groups have equal number of participants.

Grouping

Patients who met the inclusion criteria were divided into two equal groups:

•Group A: the surgical procedure was done with the use of the 3-D printed reduction guide (six patients).

•Group B: the surgical treatment was done without the use of the reduction guide (six patients).

Informed Consent

All patients signed an Informed Consent Form before undergoing the operation to ensure and confirm their understanding of the outcome of the operation and the risks they might be subjected to during the intervention.

Materials

1.Standard titanium mini-plates.

2.Screws of 2.0 mm head diameter.

3.3D SLICER (www.slicer.org) software (version 5.0.2) was used for segmentation of the Digital Imaging and Communications in Medicine (DICOM) files, creation of the 3D virtual preoperative and postoperative models and registration of the symmetry records.

4.BLENDER (www.blender.org) software (version 2.93) was used for generation of the virtual mirrored model for the uninjured side and the design process of the 3D printed reduction guide.

Intervention

I.Presurgical phase

Preoperative assessment was performed including history taking, inta-oral and extra-oral clinical examination and radio-logical evaluation using CT scan with axial, coronal, sagittal and 3D reconstruction views. Preoperative virtual treatment planning and the design process of the 3D printed reduction guide was done (Fig.1&2).

II.Operative procedure

Open reduction and internal fixation was performed for all the patients. For Group (A): The 3D printed reduction guide was placed on the fracture segments to check its precise fitting on the bone surface. Reduction of the fractured segments to its proper anatomical position was then done with zygomatic hook guided by the 3D printed reduction guide (Fig. 3). For Group (B): The fractured segments were reduced into proper anatomical position by the traditional method using the zygomatic hook without the digital guide. The time needed for reduction and fixation of the displaced bone segments was recorded for all of the cases.

III.Follow-up Phase

The follow-up schedule was 24 hours, 1 week, 4 weeks, and 3 months postoperatively. The clinical follow-up included assessment of the sensory function of the infra orbital nerve and postoperative ocular complications such as enophthalamous or limited eye movements. Postoperative CT scan was taken within 2 days after surgery to assess adequate reduction of the fractured segments (Fig. 4).

Evaluation of accuracy

Evaluation of the accuracy of the surgical reduction was done using two different methods: chromatography and symmetry assessment. Chromatography was used to generate a color-graded error map to show the deviation between corresponding points on the postoperative and virtual planning models. The symmetry assessment was done based on comparing the preoperative and postoperative bilateral positions of certain radio-graphic anatomical landmarks.

Five pairs of landmarks were selected according to Boa et al., (20) which were distributed throughout the surface of the zygomatic bone. These landmarks included:

Orbitale (O) which is the most inferior point of the inferior orbital rim, Zygion (Z) which is most lateral point on the zygomatic arch, Maxillozygion (MZ) which is the most anterior point on the zygomatico-maxillary suture line below the lateral third of the orbit, Jugale (J) which is the most concave point between the lateral margin of the frontal process and the upper margin of the temporal process of the zygomatic bone and Suprajugal curvature (SJC) which is the most convex point of the posterior edge of the frontal process of the zygomatic bone superior to jugale.

Establishment of the 3D coordinate system (reference planes):

Construction of the coordinate system is a vital step for analyzing the symmetry. The nasion was considered to be the origin point for the 3 axes X,Y,Z and also for the coordinate system. The X axis is the mediolateral (right and left) coordinate, the Y axis is the anteroposterior coordinate and the Z axis is the superio- inferior coordinate. Three reference planes were established: the midsagital plane (YZ plane) passing through the nasion and sella, the transverse plane (XY plane) passing through the nasion and the 2 orbitals and peripendicular to the midsagital plane and the coronal plane (XZ plane) passing through the nasion and perpendicular to the midsagital and transverse planes. The nasion was considered the (0,0,0) point of the coordinate system.

Fractures of ZMC could be displaced in 3 directions : inward or outward (mediolateral) displacement that was analyzed by the distance between the landmarks and the sagital (YZ) plane, upward and downward displacement that was analyzed by the distance between the landmark and the axial (XY) plane, anterior or posterior displacement that was analyzed by the distance between the landmarks and the coronal (XZ) plane (Fig. 5).

Symmetrical errors were recorded as the differences in millimeters of linear measurements between the right and left landmarks in the three planes. The distances of each landmark to the three reference planes were measured as dS, dA, and dC in millimeters. Where d stands for difference, S for sagittal, A for axial and C for coronal. The values of dS, dA, and dC of the nasion were zero. For each paired bilateral landmark, the differences in dS, dA, and dC between the right side and left side indicated the discrepancy of the paired landmarks in 3 dimensions. For perfect symmetrical paired bilateral landmarks, the discrepancy in dS, dA, and dC must approach zero. The differences were measured twice by the same observer and the mean of the two scores was recorded to avoid bias in the measurements (Fig. 6).

Another technique for symmetry assessment is the calculation of the asymmetry index (AI) developed by Huang et al. in 2013 (21). The following equation was used to calculate the asymmetry index for each landmark:

$AI = \sqrt{(LdS - RdS)2 + (LdA - RdA)2 + (LdC - RdC)2}$, where L stands for left and R stands for right. The average AI for each of the five landmarks was calculated for each group.

Statistical analysis:

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp) Qualitative data were described using number and percent. The Shapiro-Wilk test was used to verify the normality of distribution. Quantitative data were described using range (minimum and maximum), mean, standard deviation and median. Significance of the obtained results was judged at the 5% level.

The used tests were: Chi-square test for categorical variables, to compare between different groups, Fisher's Exact for correction for chi-square when more than 20% of the cells have expected count less than 5,Student t-test for normally distributed quantitative variables, to compare between two studied groups, Paired t-test for normally distributed quantitative variables, to compare between two periods, ANOVA with repeated measures, for normally distributed quantitative variables, to compare between more than two periods, and Post Hoc test (Bonferroni adjusted) for pairwise comparisons and Cochran's test for qualitative variables, to compare between more than two periods with Post Hoc Test (Dunn's) for pairwise comparisons.

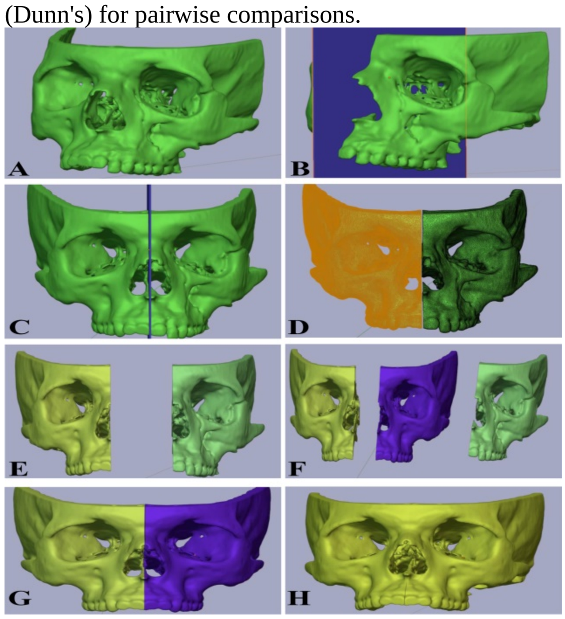

Figure 1: Creation of the virtual mirrored model. **(A)** 3D model in blender software. **(B&C)** Midsagittal plane for separation of the 3D model. **(D)** Separation of the 3D model into 2 halves. **(E)** 3D model showing Normal side yellow, fractured side green. **(F)** 3D model showing the normal side yellow, the fractured side green and the mirrored half purple. **(G)** Approximation of the 2 halves. **(H)** Creation of the 3D virtual mirrored model.

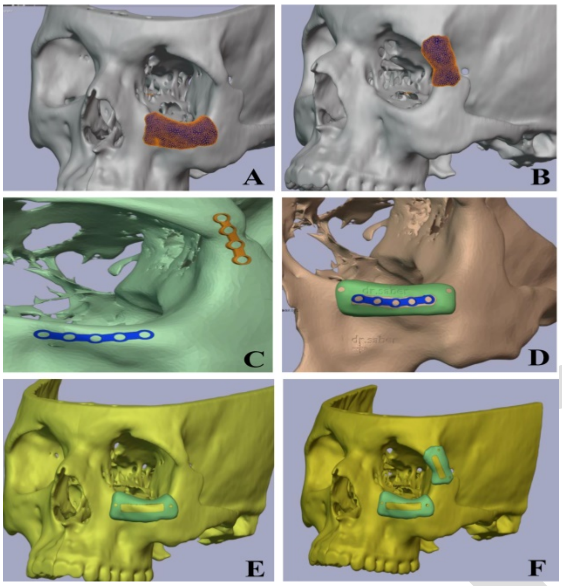

Figure 2: The design process of the reduction guide. (A) Designing the guide for the IOR. (B) Designing the guide for ZF fracture. (C) Placement of virtual plates. (D) Virtual plate in relation to the guide design. (E) Final design of the IOR guide. (F) Final design of the two guides.

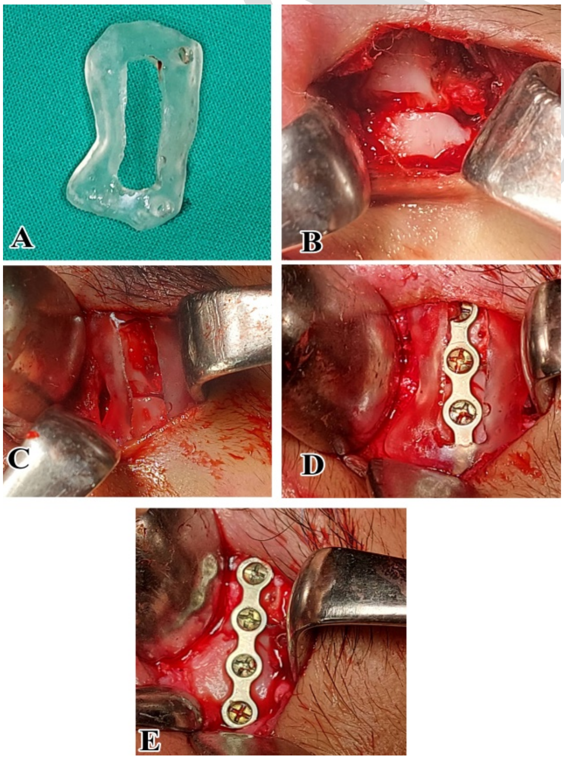

Figure 3: Operative photo showing: (A) 3D printed guide for reduction of the frontozygomatic suture fracture. (B) Exposure of the fracture. (C) Good adaptation of the reduction guide onto the bone surface. (D) Application of the mini-plate. (E) Miniplate fixation after removal of the guide

Figure 4: Preoperative vs. postoperative CT images. (A1) Preoperative and (A2) Postoperative CT axial cuts. (B1) Preoperative and (B2) Postoperative CT coronal cuts. (C1) Preoperative and (C2) Postoperative CT sagittal cuts.

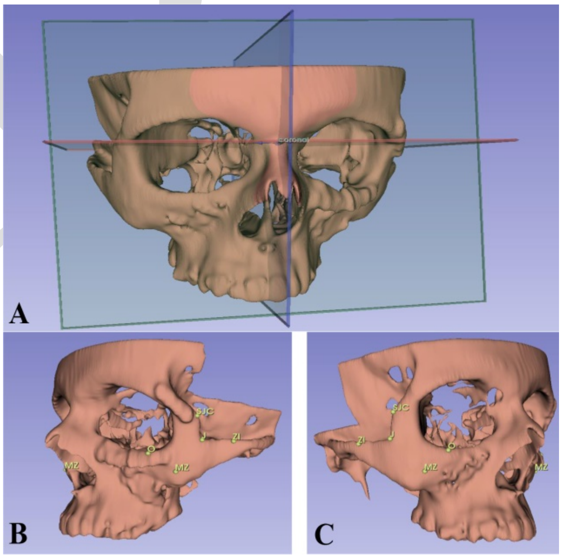

Figure 5: the coordinate system and the landmark registration. (A) Establishment of the coordinate system: the sagittal plane (blue), the axial plane (red) and the coronal plane (green). The nasion is the origin of the three planes. Registration of the anatomical radiographic landmarks on the (B) affected and (C) Normal sides of the skull.

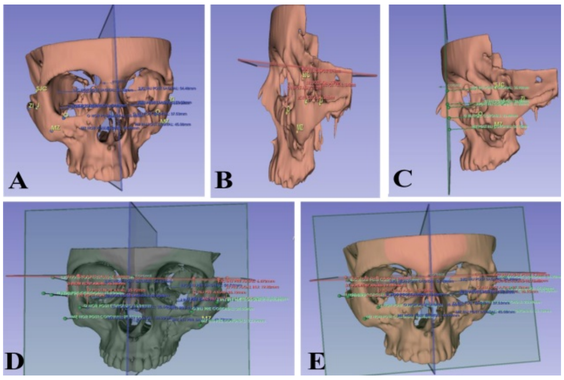

Figure 6: Recording the linear measurements differences. (A) Sagittal differences. (B) Axial differences. (C) Coronal differences. (D) All the measurements of Preoperative (gray model) and (E) Postoperative (pink model) records.

RESULTS

Epidemiology and demographic data

Patients' age ranged from 19 to 49 years old with a total mean of 28.9 ± 8.62. The mean age was 28 ± 10.55 for (group A) and 29.83 ± 5.98 for (group B). Road traffic accidents (RTA) were the etiologic factor in 58.3% of cases, while physical violence caused 25% of cases followed by falls representing 16.6% of the cases as shown in (Table1).

The surgical reduction and fixation time

For group (A) the surgical reduction and fixation time ranged from 40.0 to 72.0 minutes with a mean of 54.33 ± 11.15 minutes. In group (B) the range of the reduction and fixation time was 60.0 – 97.0 minutes, and the mean was 76.33 ± 13.35 minutes. There was a statistical significant difference (P = 0.011) in the surgical reduction and fixation time between the two groups as shown in (Table 2).

Infra orbital nerve affection and postoperative ocular complications:

Nine out of the enrolled twelve patients (5 in group A and 4 in group B) in this study complained of numbness (paresthesia) of the infra orbital nerve terminal branches after one week from the surgical operation. Except for three cases, all of the affected patients regained normal sensation by the end of the fourth postoperative week. Normal sensation has been regained at the 3rd month for all of the cases.

The change in the function of the infraorbital nerve across the follow-up period in each group was statistically significant ($p \leq 0.05$).

Ectropion and increased in scleral show were observed in one patient in the first follow-up period. The patient was managed with horizontal eyelid taping for two weeks postoperatively. The patient's lower eyelid had returned to its normal morphology by the end of the fourth postoperative week. For the rest of the cases, no ocular complications were recorded including normal eye movements.

Chromatography

Superimposition of the virtual planning and postoperative models revealed a high degree of similarity between the reduced ZMCs and the virtual surgical plans in both groups. The colour-mapping showed that most of the ZMC areas were green, which showed a highly successful operative procedures.

Quantitative assessment of symmetry:

Postoperative linear measurements showed that the error differences were more reduced for all the five landmarks in group (A) on the three planes (sagittal, axial and coronal) compared to group (B). These differences were statistically significant for the points (O and Z) on the axial and coronal planes, on the other hand, these differences weren't statistically significant for the rest of the points and planes.

The mean AI was decreased for all the five landmarks in group (A) compared to group (B) indicating better symmetry. This difference was statistically significant for the points (O, Z and SJC), on the other hand, this difference wasn't statistically significant for the points (MZ and J) as shown in (Table 3).

Table (1): Comparison between the two studied groups according to demographic data and etiological factors.

	Group A (n = 6)		Group B (n = 6)	
	No.	%	No.	%
Sex				
Male	5	83.33	4	66.66
Female	1	16.66	2	33.33
Age (years)				
Min. – Max.	19.0 – 49.0		22.0 – 41.0	
Mean ± SD.	28 ± 10.55		29.83 ± 5.98	
Median	22.5		29.5	
Cause	No.	%	No.	%
RTA	4	66.66	3	50.0
IPV	1	16.66	2	33.33
FFH	1	16.66	1	16.66

Table (2): Comparison between the two studied groups according to reduction and fixation time.

Reduction and fixation time	Group A (n = 6)	Group B (n = 6)	p
Mean ± SD.	54.33 ± 11.15	76.33 ± 13.35	0.011*

SD: Standard deviation
p: p value for comparing between the two studied groups

Table (3): Comparison between the two studied groups according to Al.

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O	Preoperative Mean ± SD.	8.72 ± 2.49	8.48 ± 1.91	0.858
	Postoperative Mean ± SD.	3.01 ± 0.94	5.40 ± 1.59	0.010*
	(p_0)	(0.001*)	(<0.001*)	
Z	Preoperative Mean ± SD.	6.53 ± 1.37	7.51 ± 2.61	0.435
	Postoperative Mean ± SD.	2.34 ± 0.75	4.65 ± 1.94	0.022*
	(p_0)	(<0.001*)	(<0.001*)	
MZ	Preoperative Mean ± SD.	11.28 ± 1.90	11.19 ± 1.64	0.932
	Postoperative Mean ± SD.	5.36 ± 1.04	5.82 ± 1.20	0.498
	(p_0)	(<0.001*)	(<0.001*)	
SJC	Preoperative Mean ± SD.	6.23 ± 1.36	6.84 ± 1.84	0.528
	Postoperative Mean ± SD.	2.53 ± 0.80	4.64 ± 1.47	0.012*
	(p_0)	(<0.001*)	(<0.001*)	
J	Preoperative Mean ± SD.	7.63 ± 2.92	8.08 ± 3.86	0.824
	Postoperative Mean ± SD.	6.04 ± 2.28	7.09 ± 3.56	0.557
	(p_0)	(0.004*)	(0.068)	

SD: Standard deviation
p: p value for comparing between the two studied groups
p_0: p value for comparing between Preoperative and Postoperative
*: Statistically significant at $p \le 0.05$

DISCUSSION

In the case of ZMC fractures, the therapeutic objective must concentrate on both facial function and contour. Markers like the degree of ocular movement, mouth opening and occlusion can be used to measure the restoration of function with objectivity. On the other hand, the amount of the surgeon's experience is a major factor in the restoration of face shape. Complex anatomical interactions exist between the zygoma and zygomatic arch and the nearby facial bones (22).

The zygoma has distinct proportions and intricate anatomical connections to neighbouring bones. The projection of the mid face is significantly influenced by the displacement of the zygoma and zygomatic arch following fracture (23).

Accurate preoperative surgical simulations of the reduction of ZMC fractures can be accomplished by surgeons with the use of surgical planning tools and computer-generated STL models. But it has proven challenging to translate preoperative surgical plans into actual surgical procedures. Also it might be challenging to maintain or assess the accuracy of facial contour restoration (24).

The objective of this study was to evaluate the accuracy of the use of 3-D printed reduction guide in treatment of zygomatico maxillary complex fractures.

In the current study, the results of the reduction and fixation duration of the two groups indicate the value of the use of the 3D reduction guide in minimizing the surgical operation time. We believe that the shorter operating time in group (A) was due to the reduction guide which was used as a template for rapid reorientation of the fractured segment to their original pre-traumatic state. Also, the window that was created on the guide reduced the time needed for adaptation of the plates on the bone surface. A similar results were published by Montaser et al. (25).

We should mention that the infra orbital nerve was affected in nine out of the enrolled twelve patients (5 in group A and 4 in group B). Normal sensation has been regained at the 3rd month in all cases. We assume that the cause of increased number of cases with infraorbital nerve affection in group (A) was that more exposure of bone and more retraction of the soft tissues was needed for accurate placement of the reduction guide at the inferior orbital rim region.

The ideal form and location of the affected ZMC can be identified with reference to the uninjured side. Before surgery, the required reduction can be specified using a mirrored digital virtual model (20).

In the current study, the sella turcica's midpoint on frontal views, as well as the nasion (N), were the chosen points for establishment of the midsagittal plane, which was defined as being perpendicular to the FH plane. This approach used the stability of the FH plane and avoided apparent facial areas to mask the effect of trauma (20).

Chromatography was employed in this study to assess the preoperative plan and the postoperative outcomes. When the preoperative virtual CT and postoperative CT were superimposed, there was an astonishing correlation between the reduced ZMC in group A and the surgical plans; this is consistent with the findings reported by other authors (20,25). In early studies, the degree of postoperative ZMC symmetry was evaluated visually and qualitatively. In recent years, a number of techniques for precisely assessing facial asymmetry have been established. Most of these techniques are developed around the analysis of deviation utilizing bilateral landmark distances (26, 27).

In this work, we analyzed five pairs of landmarks that have consistent connections to the anatomy of the zygomatico- maxillary complex namely: orbitale (O), the zygion (Z), maxillo-zygion (MZ), suprajugal curvature (SJC) and jugale (J). This approach enhanced identification simplicity and decreased registration errors (28).

The landmarks, which included the orbital cavity, zygomatic arch, and zygomatic eminence, were dispersed throughout the surface of the zygomatic bone and represented the most probable ZMC fracture and displacement sites. It is thought that the extensive usage of these ZMC landmarks improves the capacity to evaluate symmetry, displaying the accuracy of reduction in various areas (20).

In this study, the symmetry of the ZMC was evaluated by two methods. The first method was to record the bilateral linear measurements difference in the position of the landmarks and the second method was calculating the asymmetry index.

The linear differences were statistically significant for the points (O and Z) on the axial and coronal planes, on the other hand, these differences weren't statistically significant for the rest of the points and planes. These results are consistent with the results published by other authors (25, 29, 30).

The outcomes of surgery in the two groups were determined by comparing preoperative and postoperative AIs. Surgery (with or without reduction guide) significantly decreased the AIs for most of the landmarks on the ZMC surface, indicating an effective improvement in symmetry. Moreover, significant differences in symmetry recovery across groups were evident around the infra orbital rim (O), zygomatic arch (Z), and posterior bony margin of the zygomatic body (SJC). The symmetry in these regions significantly affects facial dimension and attractiveness. These results demonstrate the benefit of using a 3D printed reduction guide to straighten fractured bones and enhance face symmetry.

We believe that the improved results of symmetry in group (A) were due to the virtual planning and the use of the reduction guide. 3D virtual treatment planning offered a better understanding of the anatomy, nature and direction of displacement of the fractured bone segments. The guide was implemented to transfer the virtual plan to the operating room to help in achieving the desired surgical outcomes. It also made the surgeons more confident and less apprehensive on performing the surgical procedures. The 3D planning also played a role in the surgical fixation of the fracture by applying a virtual plate into the 3D model and determining the location, size and number of the plates and screws needed for proper fixation. In group (B) the surgical reduction and fixation was dependant on the surgeon’s skills and experience (29).

The MZ point, which symbolizes the zygomatic prominence is situated in the middle of the frontal surface of the zygomatic body. This point is challenging to uncover during surgery using minimal surgical incisions. This explains why mistakes were made here because the reduction guide did not often address this point. According to Matarasso , the buccal pad of fat which frontally and laterally covers the ZM point makes more contribution to face aesthetics than genuine optical impacts (31). Consequently correcting the asymmetry brought on by incorrect position of the (ZM) point. Bao et al. suggest more effective exposure of the ZMC, such as by coronal incision, to address this issue (20). Furthermore, Liu et al. anticipated that if a reduction guide was introduced to cover the zygomaticomaxillary buttress, the (ZM) error would be decreased (29). The (J) point can be accessed by the lateral eye brow approach, however doing so will need a larger incision and more tissue retraction, which will cause a large visible scar and will increase the tissue morbidity as well as the postoperative complications.

One of the advantages of this study is that we used two techniques to measure the symmetry in the same research. Analyzing the differences of the bilateral landmarks at each plane (sagittal, axial and coronal) provides information about the linear displacement of the landmark. On the other hand, the asymmetry index measurements gives an overall three dimensional representation of the facial symmetry at a specific landmark. As far to our knowledge, no research have combined the two approaches to assess the facial symmetry.

Currently, there are many commercial software packages available for designing the surgical guides. However purchasing these packages is very expensive. One of the advantages of this study is that we used free software (3D SLICER and BLENDER). Although it‘s not a specialized medical software, BLENDER is a valuable alternative of the overpriced software. The design process of the guide was fast and easy. The author needed one week of training on the software to be able to design the guide and perform the whole digital procedures independently (32).

When the treatment results were assessed, there were still mistakes in the distances and measures despite getting good results. Some of the factors that probably contributed to these errors include: errors in obtaining the CT DICOM data (errors in image acquisition), errors during segmentation of DICOM data using the segmentation or the computer aided design (CAD) software (errors in creating the 3D models or in designing the 3D reduction guides), and errors during 3D printing of the guides related to the rapid prototyping process (33, 34).

Operative errors can also be reduced but not entirely eliminated. Human faces are not perfectly symmetrical, which suggests that template designs based on mirror-duplicates will contain some faults. The fact that the resin templates are somewhat flexible is another factor (29).

The primary benefit of having surgeons create the virtual operating plan and guides is that the plan would be more relevant to surgical principles and is simpler to execute. With the aid of a guiding template, operators may also feel more assured and less apprehensive, especially while reducing the comminuted zygomatic bodies (35).

A major advantage of this study is that the whole preoperative digital process including segmentation of the CT data, generating the 3D models, mirroring process, virtual treatment planning and 3D reduction guide designing was performed by a surgeon who was member in the surgical team conducted the surgical procedures.

The same surgeon also carried out the postoperative digital process, which involved creation of the reference planes, registering landmarks, superimposition of the 3D models, creating colour maps, quantifying the variations between preoperative and postoperative distances from reference planes as well as calculating the asymmetry index.

CONCLUSIONS:

1. Surgical intervention including open reduction and internal fixation (with or without the use of the reduction guide) significantly improves the facial symmetry and restore hard and soft tissues functions.
2. Preoperative virtual surgical planning for maxillofacial fractures is becoming a vital method for assessment of the difficulty of the cases and formulation of the proper patient specific treatment plan.
3. The use of 3D printed reduction guides offer shorter operation time and decreased reduction errors.
4. The use of 3D printed reduction guides improved the reduction of the fractured segments in comparison to the conventional reduction techniques.
5. The asymmetry index (AI) is an easy and valuable method to assess the facial symmetry.

CONFLICT OF INTEREST

The authors declare that they have no conflicting of interests

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