Avaliação tomográfica de fraturas do complexo zigomático-orbitário tratadas com o auxílio de planejamento em Biomodelos

Tomographic evaluation of zygomatic-orbital fractures treated with planning on Biomodels

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RESUMO
A correção das fraturas do complexo zigomático-orbitário são desafiadoras ao cirurgião, pela complexidade da sua anatomia e sua íntima relação com múltiplos ossos da face. A prototipagem rápida pode ser um instrumento auxiliar no planejamento cirúrgico dessas fraturas com o objetivo de devolver a anatomia anterior ao trauma. Este é um estudo tomográfico de fraturas zigomático-orbitarias que foram tratadas com o auxílio de planejamento em biomodelos. Métodos: Foram incluídos seis pacientes com fratura unilateral da região zigomática-orbitaria classificados como Knight e North tipo III, IV, V e VI. A cirurgia para redução e fixação da fratura foi planejada com o auxílio de biomodelos 3D, onde a hemiface não afetada foi espelhada sobre o lado fraturado, e as placas de fixação foram pré-moldadas se baseando no lado espelhado, com o objetivo de garantir a correta projeção. A qualidade da redução cirúrgica foi avaliada usando pontos quantificáveis (parede lateral da órbita, projeção antero-posterior do zigoma e projeção do globo ocular), que foram mensurados nas imagens tomográficas pré e pós-operatórias. Resultados: Houve ganho estatisticamente positivo na variável de projeção antero-posterior do zigoma, porém a abordagem foi mais factível com poucos pontos de fratura. Conclusão: O planejamento com biomodelos se mostrou útil na recuperação da projeção zigomática, sendo necessário levar em consideração o alto custo e o tipo de fratura na hora de optar pelo planejamento com biomodelos.

Palavra-chave: Procedimentos Cirúrgicos Operatórios; Zigoma; Estereolitografia; Tomografia Computadorizada por Raio X.

ABSTRACT
The correction of fractures of the zygomatic-orbital complex is challenging to the surgeon, due to the complexity of its anatomy and its intimate relationship with multiple facial bones. Rapid prototyping can be an auxiliary tool in the surgical planning of these fractures in order to restore the anatomy prior to the trauma. In the present tomographic study, zygomatic-orbital fractures were treated with the aid of biomodels. Metods: The sample was composed of six patients with unilateral fracture of the zygomatic-orbital region classified as types III, IV, V, and VI (Knight and North classification). Surgery for the reduction and fixation of the fracture was planned with the aid of 3D biomodels, on which the unaffected side of the face was mirrored over the fractured side. The fixation plates were pre-molded based on the mirrored side to ensure the correct projection. The quality of the surgical reduction was evaluated using quantifiable points (lateral wall of the orbit, anteroposterior projection of the zygoma, and projection of the ocular globe), which were measured on the preoperative and postoperative tomograms. Results: A statistically positive gain in the anteroposterior projection of the zygoma was found, but the approach was more feasible with few fracture points. Conclusion: Biomodel planning proved useful in the recovery of the zygomatic projection. However, it is necessary to consider the high cost and type of fracture when opting for planning with biomodels.
Keywords: “Surgical Procedures, Operative”; “Zygoma”; “Stereolithography”; “Tomography, X-Ray Computed”

1 INTRODUCTION

Fractures of the zygomatic-orbital complex (ZOC) are highly frequent, resulting mainly from traffic accidents, physical aggression, and sports activities. The surgical treatment of ZOC fractures warrants particular attention due to the complex anatomy and possible involvement of other structures of the middle third of the face. Bone fracture reduction and fixation with titanium plates is challenging due to the restricted surgical access and the anatomy of the orbital region, which hinders the modeling process of the fixation plates.

The difficulty in ensuring the same anatomic position as prior to the trauma increases the risk of esthetic and functional problems, such as enophthalmos, diplopia (double vision), limited mouth opening, and facial asymmetry. It is therefore necessary to restore the anatomy as it was prior to the trauma in order to recover function and esthetics.

The use of prototypes has offered benefits to craniomaxillofacial surgery, such as greater predictability and a shorter operating time due to the use of pre-molded plates, which are possible through more detailed planning. Stereolithography (SL) is a rapid prototyping process that enables constructing three-dimensional (3D) models with a richness of details. SL is used in the planning of craniofacial reconstructions, the correction of facial deformities, and distraction osteogenesis. However, this method has been used little as an aid in the reduction of fractures in the middle third of the face. Among the techniques for obtaining prototypes, the mirror-image method, in which the software mirrors the non-fractured side of the face over the fractured side, is a useful tool for assisting in surgery as well as the preoperative modeling of plates.

The aim of the present retrospective study was to evaluate the use of biomodels constructed using the mirror-image method for the treatment of unilateral fractures of the ZOC.
2 MATERIALS AND METHODS

Six patients with unilateral ZOC fractures and an indication for surgical treatment were operated between 2017 and 2019 at the oral-maxillofacial surgery and traumatology ward of Restauração Hospital in the city of Recife, Brazil. The patients had unilateral type III, IV, V, or VI fractures according to the Knight and North classification. Multi-slice computed tomography was performed on all patients and the tomograms were exported to the Meshmixer 3.3 software (Autodesk®) offered by the Tiradentes University Center of Pernambuco. The tomograms and areas of interest were evaluated with the software and the axes of the tomographic slices were corrected. The axial plane was adjusted to be parallel to the Frankfurt plane and perpendicular to the sagittal plane of the facial skeleton and the coronal plane was adjusted to be perpendicular to the Frankfurt and sagittal planes of the facial skeleton.

After the standardization of the images, the unaffected ZOC was mirrored over the contralateral fractured ZOC to form the mirror image. The data from the virtual model were then converted into SL format and the solid physical model was created with a cut thickness of 0.1 mm using acrylic resin and an A1 GTMAX 3D printer.

Once the resin prototype was produced, the planning of the surgery was executed. Titanium implants (plates) were molded on the mirrored prototype. The titanium plates were from the 1.5-mm system and were cut and modeled according to the planning. Under general anesthesia, the method planned with the aid of the prototype was applied. With the number of accesses defined in the planning, the fractures were reduced, the plates that had previously been modeled on the prototypes were transferred to the surgical site and affixed. Computed tomograms were performed in the preoperative and postoperative periods of all patients, where the proposed model was replicated. (Figure 1)

Fig. 1 - After studying tomograms, titanium plates were modeled on mirrored prototype. Image of Patient 6.
The parameters for the evaluation of the treatment of the fractures were obtained based on the comparison of the preoperative and postoperative tomograms (Figure 2).

**Fig. 2** – Image of three parameters studied: anteroposterior projection of zygoma (a,d), projection of ocular globe (b,e), and lateral wall of orbit (c,f). a, b, and c are preoperative images of Patient 3 and d, e, and f are postoperative images of the same patient, enabling comparisons of the preoperative and postoperative periods.

The following variables were evaluated:

- **Lateral wall of the orbit:** The disjunction of the lateral wall of the orbit was measured in millimeters, tracing a straight line from the point at which the lateral wall would be found if it had not been fractured, and bone displacement; the distance was measured to this line with standardization of the axial cut and using the non-fractured zygoma as reference.

- **Anteroposterior (AP) projection of the zygoma:** The difference in the AP projection was measured using the non-fractured zygoma as reference. The first axial cut in the cranial-caudal direction (on which the infraorbital foramen is exteriorized on the non-fractured side) was chosen. Tracing a straight line on the coronal plane in the most anterior region of the anterior nasal spine, the measurement from each zygomatic bone to this line was performed. The exact
measurement was located at a point equidistant from the infraorbital foramen on the sagittal plant on the non-fractured side. This distance was projected toward the fractured zygoma. The value for the non-fractured side was subtracted from that of the fractured side to determine the loss of projection or overcorrection of the zygoma.

- **Projection of the ocular globe:** The evaluation of the projection of the ocular globe was performed with axial cuts, using the non-fractured ZOC as reference for the ideal projection. The best slice located on the meridian of the globe including the optic nerve was selected. The distance between two parallel coronal planes was measured. The first plane included the point of the greatest projection on the anterior surface of the ocular globe. The second point included the posterior extremity of the lateral wall of the orbital apex on the sphenoid bone.

The data were analyzed descriptively and expressed as mean, standard deviation (SD), and median. The paired nonparametric Wilcoxon test was used to evaluate significant differences on the same side between evaluations and between sides in the same patient. This test was chosen due to the number of patients. A 5% margin of error was adopted for the decision on the statistical tests. The data were entered onto an EXCEL spreadsheet and IMB SPSS version 23 was used for the statistical calculations.

### 3 RESULTS

Table 1 displays the values obtained regarding the three parameters for the six patients in the preoperative period. Table 2 displays the values obtained in the postoperative period. Table 3 displays the extent of the gain for each parameter in each patient.
Table 1: Measurements in mm of the parameters used in the preoperative period.

<table>
<thead>
<tr>
<th></th>
<th>Right ocular globe</th>
<th>Left ocular globe</th>
<th>Anteroposterior projection of the right zygoma</th>
<th>Anteroposterior projection of the left zygoma</th>
<th>Lateral wall of the orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>59.857 mm</td>
<td>57.928 mm</td>
<td>9,115 mm</td>
<td>16,122 mm</td>
<td>2,974 mm</td>
</tr>
<tr>
<td>Patient 2</td>
<td>48,665 mm</td>
<td>45,806 mm</td>
<td>36.328 mm</td>
<td>42,303 mm</td>
<td>0 mm</td>
</tr>
<tr>
<td>Patient 3</td>
<td>52,366mm</td>
<td>46,063mm</td>
<td>18,842mm</td>
<td>12,008mm</td>
<td>5,092 mm</td>
</tr>
<tr>
<td>Patient 4</td>
<td>49,752 mm</td>
<td>49,576 mm</td>
<td>12,950 mm</td>
<td>7,101 mm</td>
<td>0 mm</td>
</tr>
<tr>
<td>Patient 5</td>
<td>58,429 mm</td>
<td>57,822 mm</td>
<td>8,130 mm</td>
<td>14,228 mm</td>
<td>5,777 mm</td>
</tr>
<tr>
<td>Patient 6</td>
<td>55,369 mm</td>
<td>53,522 mm</td>
<td>13,871 mm</td>
<td>21,618 mm</td>
<td>3,185 mm</td>
</tr>
</tbody>
</table>

Table 2: Measurements in mm of parameters used in the postoperative period.

<table>
<thead>
<tr>
<th></th>
<th>Right ocular globe</th>
<th>Left ocular globe</th>
<th>Anteroposterior projection of the right zygoma</th>
<th>Anteroposterior projection of the left zygoma</th>
<th>Lateral wall of the orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>53,555 mm</td>
<td>51,313 mm</td>
<td>16,733 mm</td>
<td>13,253 mm</td>
<td>2,964 mm</td>
</tr>
<tr>
<td>Patient 2</td>
<td>53,555 mm</td>
<td>51,313 mm</td>
<td>17,313 mm</td>
<td>17,439 mm</td>
<td>0 mm</td>
</tr>
<tr>
<td>Patient 3</td>
<td>54,568mm</td>
<td>52,660mm</td>
<td>12,640mm</td>
<td>12,951mm</td>
<td>0 mm</td>
</tr>
<tr>
<td>Patient 4</td>
<td>51,539mm</td>
<td>48,453mm</td>
<td>16,455mm</td>
<td>16,459mm</td>
<td>0 mm</td>
</tr>
<tr>
<td>Patient 5</td>
<td>52,259mm</td>
<td>52,544mm</td>
<td>22,261mm</td>
<td>24,322mm</td>
<td>5,574 mm</td>
</tr>
<tr>
<td>Patient 6</td>
<td>57,094mm</td>
<td>56,775mm</td>
<td>11,349mm</td>
<td>11,739mm</td>
<td>0 mm</td>
</tr>
</tbody>
</table>

Table 3: Shows the difference for each parameter evaluated in for each patient.

<table>
<thead>
<tr>
<th></th>
<th>Lateral wall of the orbit</th>
<th>Anteroposterior projection of the zygoma</th>
<th>Ocular globe projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>0.01mm</td>
<td>3,52mm</td>
<td>0.31mm</td>
</tr>
<tr>
<td>Patient 2</td>
<td>0mm *</td>
<td>5,849mm</td>
<td>0.035mm</td>
</tr>
<tr>
<td>Patient 3</td>
<td>5,092mm</td>
<td>6,523mm</td>
<td>4,395mm</td>
</tr>
<tr>
<td>Patient 4</td>
<td>0mm *</td>
<td>5,845mm</td>
<td>2.91mm</td>
</tr>
<tr>
<td>Patient 5</td>
<td>0.203mm</td>
<td>4,037mm</td>
<td>0.322mm</td>
</tr>
<tr>
<td>Patient 6</td>
<td>3,185mm</td>
<td>7,357mm</td>
<td>1.528mm</td>
</tr>
</tbody>
</table>

Table 4 displays the results regarding the ocular globe, anteroposterior projection of the zygoma, and lateral wall of the orbit per side (fractured and non-fractured) and evaluation (preoperative and postoperative) as well as the difference in means between evaluations. The lowest mean for the ocular globe corresponded to the non-fractured side post-treatment (52.03 mm), ranging from 52.87 mm to 52.99 mm among the other three measurements. The largest difference in means between evaluations of the ocular globe occurred on the non-fractured side (0.96 mm); on the fractured side, the difference in means was 0.08 mm higher in the preoperative period compared to the postoperative period. For the fixed margin of error (5%), no significant differences (p > 0.05) were found between evaluations per side or between sides per evaluation. The mean fractured-non-fractured difference was -0.12 in the preoperative period and 0.92 in the postoperative period, with no significant difference (p > 0.05) between evaluations or between groups with regards to the pre-post difference. These findings show that
differences were larger in the preoperative period than the postoperative period, but this difference did not achieve statistical significance.

For anteroposterior projection of the zygoma, the highest mean occurred in the preoperative period on the fractured side (21.01 mm) and the other means ranged from 14.43 to 16.18 mm. On the fractured side, the mean was 5.04 mm higher at the preoperative evaluation than the postoperative evaluation; on the non-fracture side, the mean was 1.75 mm higher at the postoperative evaluation than the preoperative evaluation. However, no significant differences (p > 0.05) were found between evaluations on either side. A significant difference (p < 0.05) was found between the fractured and non-fractured sides at the preoperative evaluation and this difference was diminished significantly at the postoperative evaluation. The mean fractured-non-fractured difference was 6.58 in the preoperative period and -0.21 in the postoperative period. This difference was significant (p < 0.05) between evaluations and between groups with regards to the preoperative and postoperative difference, showing a significant improvement in measurements at the postoperative evaluation.

The mean of the lateral wall of the orbit was 1.42 mm, with the value higher at the preoperative evaluation than the postoperative evaluation, but this difference did not achieve statistical significance (p > 0.05).

Variability expressed by the standard deviation was low for the measurement of the ocular globe, as this measurement was less than 1/3 of the corresponding means. In contrast, the anteroposterior projection of the zygoma and lateral wall of the orbit at the preoperative evaluation exhibited considerable variability, as evidenced by the larger standard deviations.
Among the six patients studied, three required the installation of titanium screens on the orbital floor due to the observation of traces of comminuted fractures not found during the previous tomographic study. This caused a bone defect in the region during the process of surgical reduction. The three individuals for whom planning needed to be altered during the act of surgery were Patients 1, 3, and 6 (Figure 3).

**Fig. 3** - In Patient 3 (a), installation of half-moon plate in frontozygomatic region and region of infraorbital margin. (b) However, an unattached bone fragment was found in the region of the infraorbital margin during surgery, which had not been visible in the tomogram. The bone fragment was removed and a titanium screen needed to be placed in the infraorbital margin to correct the defect (c).
4 DISCUSSION

The use of biomodels as an aid for the treatment of zygomatic bone fractures has both benefits and challenges. Surgical planning for the correction of facial fractures with the aid of prototyping is used more for large mandibular defects\(^6,7\) and there are few reports on the use of prototyping for the correction of fractures in the middle third of the face. Oliveira et al. (2008)\(^4\) described the use of 3D biomodelling for mandibular fractures. The authors demonstrated the importance of biomodels for the correct determination of volume, length, angles, and the general morphology of the grafts used. Regarding middle third fractures, Kozakiewciz et al. (2009)\(^3\) used prototyping in a planning study for orbital fractures, finding an improvement in patients who received the pre-molded screen, especially in terms of the correction of diplopia and dystopia.

Prototypes provide a faithful anatomic copy of the patient. Nizam et al. (2016)\(^8\) proved that the error in the creation of prototypes is minimal and does not interfere with clinical applications when used for the planning of oral-maxillofacial surgeries.

The method used in the present study to determine the success of fracture correction surgery through tomographic measurements of three parameters proved useful. Moreno et al. (2012)\(^1\) report similar results in a study conducted to compare and determine the best treatment to be used for zygomatic fractures.

In the present investigation, a statistically significant difference was found in the comparison of the difference in means of the sides in the preoperative and postoperative periods (\(p < 0.05\)) regarding the anteroposterior projection of the zygoma, showing that it was possible to improve the projection of the zygomatic bone with the aid of planning with biomodels. Improvements were found for the other parameters in the comparison of the preoperative and postoperative periods, but the differences did not achieve statistical significance. This was likely due to the fact that the difference between sides for the ocular globe and lateral wall of the orbit were not large in the preoperative period and the improvement after treatment was therefore small. For the anteroposterior projection of the zygoma, the differences between sides were large at the preoperative period in most patients. Thus, it was possible to find a statistically significant improvement in this variable.

Due to the instability of fractures of the zygomatic-orbital complex, it may be necessary to alter the planning during the course of the surgery. Indeed, there was a need to install a titanium screen in three patients in the present study that was not foreseen in the planning of the surgery.
Silva et al. (2017)\textsuperscript{2,10,11} used prototyping for the planning of the treatment of sequelae of a zygomatic fracture with the pre-molding of titanium screens on prototypes and achieved an excellent result. Thus, stable fractures, such as sequelae, ensure the success of treatment planned using biomodels. A more stable, firmer bone with no comminution make the planning more predictable, without the need for intraoperative changes.

According to Brito et al. (2016)\textsuperscript{8,9}, the use of prototyping is restricted in countries such as Brazil due to the high cost. Thus, prototypes should be left for more complex surgeries, in which their use would be essential to successful surgery, such as ZOC fractures.

5 CONCLUSION

In the present study, a significant difference was found in the comparison of sides in the preoperative and postoperative periods regarding the anteroposterior projection of the zygoma, showing that it is possible to improve the projection of the zygomatic bone through planning with biomodels. However, it is necessary to determine the benefits and limitations of this planning method. The type of fracture is also an important point to consider in the decision-making process regarding the use of biomodels. For a more comminuted fracture of the zygomatic bone, it is possible that not all traits are faithfully reproduced by computed tomography, which could exert an influence of the planning of surgery, requiring the surgeon to alter the plan during the course of the surgery.

Further studies are needed to compare interventions with and without the use of prototypes and determine whether significant differences are found, enabling a more definitive conclusion regarding the benefit of this method for the planning of fractures of the zygomatic-orbital complex.
REFERENCES


