Mirror imaging and preshaped titanium plates in the treatment of unilateral malar and zygomatic arch fractures

Fan Feng, DDS, a Hang Wang, DMD, PhD, b Xiaoguang Guan, DDS, a Weidong Tian, DMD, PhD, c Wei Jing, DMD, d Jie Long, DMD, PhD, b Wei Tang, DMD, PhD, c and Lei Liu, DMD, PhD, c Chengdu, China
SICHUAN UNIVERSITY

Objective. The aim of this study is to discuss the application of mirror imaging and preshaped titanium plates in the treatment of unilateral malar and zygomatic arch fractures.

Study design. Four patients with unilateral malar and zygomatic arch fractures were included in this study. All patients underwent preoperative CT scan. CT data were processed with Surgicase. Two 3D skull models were reconstructed using a rapid prototyping device. The first model was the original model obtained from CT scanning; the other model was obtained by mirroring the unaffected side onto the fractured side. Simulation surgery was performed on the first model. For the second model, titanium plates were shaped in advance and a resinous guide plate was created to guide surgical reduction. When using the resinous guide plates, 4 patients’ fractures were reduced and fixed with preshaped titanium plates. The pre- and postoperative displacement of zygomatic markers were analyzed in Surgicase.

Results. According to the measurement of fracture displacements, the facial asymmetry of all 4 patients was greatly improved at the 1-month follow-up.


Fractures of the zygoma and zygomatic arch are common types of maxillofacial fractures in the midface region. These fractures are usually accompanied by adjacent bone fractures that lead to facial collapse and asymmetry, as well as restricted mouth opening. The changes in facial contour and occlusal function greatly affect the patients’ health and quality of life.1,2 Because of the involvement of adjacent anatomical structures of the zygomatic bone and the lack of occlusal guidance, the reduction of malar and zygomatic fractures is quite challenging to oral and maxillofacial surgeons. Traditional surgical methods largely depend on the surgeon’s experience; therefore, anatomical reduction is sometimes difficult to achieve.

This study included 4 patients with unilateral malar and zygomatic fractures. Their computed tomography (CT) data were processed with Surgicase. Seven marker points were chosen to measure the inward, backward, and downward fracture displacements pre- and postoperatively. Two head models of each patient were manufactured using a rapid prototyping (RP) device. The first model was the original model obtained from CT scanning; the second model was obtained by mirroring the unaffected side of the 3-dimensional (3D) CT data onto the fractured side. Surgical simulation was performed on the first resinous model. Titanium plates were preshaped on the second model and resinous guide plates were made to guide fracture reduction during the operation, thus increasing the accuracy of fracture reduction and recovering a symmetric facial contour.
May 2008 to April 2009. All patients were male, with a mean age of 33.0 years (range, 18 to 45 years). The cause of fracture for all patients was motor vehicle accident. All patients had unilateral malar and zygomatic arch fractures; the temporomandibular joint (TMJ) regions were unaffected. Surgical reductions were performed less than 1 month after injury.

Materials included the following: Philips Brilliance CT 64-slice (Philips, Amsterdam, Netherlands) Surgicase 4.0 (Materialise, Leuven, Belgium), self-solidifying denture acrylic and liquid (Shanghai Dental Instrument Factory, Shanghai, China), titanium plate and screw system (Osteomed, Addison, TX, USA), and rapid prototyping device (Union Technology, Co, Ltd, Shanghai, China).

Preoperative planning

Data collection and processing. For all 4 patients, transverse, coronal, and sagittal CT data of the craniofacial region were obtained by Brilliance CT 64 (Philips) scanning; slice thickness was 0.75 mm. CT data were then transferred into Surgicase for 3D modeling. Marker points were recorded for the left and right malar and zygomatic arch regions, and the distances between each marker point and the reference planes were measured (Fig. 1).

Establishing the reference planes in Surgicase. Four points were selected to establish the reference planes.

A. Center point of the left condyle.
B. Center point of the right condyle.
C. Prenasal.
D. Midpoint between A and B.

Three reference planes were established to evaluate fracture displacement:

- Sagittal plane (SP): the plane through D and perpendicular to AB
- Coronal plane (CP): the plane through D and perpendicular to CD
- Horizontal plane (HP): the plane through A, B, and C

Defining the marker points. Seven marker points were defined to measure the fracture displacement pre- and postoperatively (Fig. 1):

- OZ: the intersection point of the zygomaticomaxillary suture and the infraorbital margin
- ZM: the most inferior point of the zygomaticomaxillary suture
- MP: the most anterior point of the zygoma
- JU: the vertex of the angle between the vertical margin posterior to the frontosphenoidal process of the zygoma and the horizontal margin superior to the temporal process of the zygoma
- TP: the intersection point of the zygomatic process of temporal bone and the body of temporal bone
- ZTL: the most inferior point of the temporoorozygomatic suture
- FMT: the most lateral point of the frontozygomatic suture

Measuring fracture displacement. Distances between each marker point and the reference planes were recorded in Surgicase. Fracture displacements in 3 directions (inward: distance between marker point and SP; backward: distance between marker point and CP; downward: distance between marker point and HP) were measured by comparing the distances between each marker point and reference planes of the unaffected side and the fractured side (Fig. 1).

Design and manufacture of the RP model. Using Surgicase, 3D CT data of the unaffected side were mirrored through the midsagittal plane to build a symmetric counterpart. In this way, a bilaterally symmetric 3D head model was reconstructed (Fig. 2).

Using a computer-assisted manufacturing technique, the 3D head models of all 4 patients were manufactured through radiofrequency CO₂ laser sintering using polystyrene powder (engineering plastic; particle diameter is smaller than 0.1 mm); the process took about 20 hours. The RP models were then sprayed with epoxy resin and treated for 45 minutes with ultraviolet radiation for solidification.

Model surgery. Model surgery was performed on the original head model (Fig. 2) before the operation. The osteotomy, reduction and fixation, displacement of the fractured segment, and reconstruction of the facial contour were all simulated to ensure a better surgical outcome. For all 4 patients with unilateral malar and zygomatic arch fractures, titanium plates were placed across the zygomaticomaxillary suture, the zygomaticofrontal suture, and the temporoorozygomatic suture (across the zygomatic arch). Rigid fixation can be achieved using this 3-point fixation technique.

Preshaping of titanium plates. The preshaping of titanium plates on the mirror-imaged head models is presented in Fig. 2. Titanium plates were placed across the fractured ends and shaped carefully according to the contour of the fractured ends. In addition, a resinous guide plate was made to guide the reduction during the operation (Fig. 2). The guide plate was made using self-solidifying denture acrylic and liquid. A separation agent was smeared at the point of titanium plate insertion. The completed resinous guide plate was 5 mm in width and 2 mm in thickness; all margins were...
smoothed after solidification. Intraoperatively, the guide plate was used to guide the reduction and positioning of the fixation plates.

**Operation method**

The preshaped titanium plates were sterilized using a high-pressure steam sterilizer. The resinous guide plates were immersed in povidone iodine solution for 30 minutes for sterilization. Operations were performed through hemi-coronal, oral vestibular groove, or facial scar approaches. After fully exposing the fractured bony segments, the resinous guide plate was placed near the surgical area. Using the guide plate, surgeons could clearly observe the reduction of the bony segments and the positioning of the fixation plates by comparing the shape and position of the guide plate to the shape and position of the reduced bony segments and the fixation plates. It is not necessary to place the guide plate next to the reduced bony segments, thus excessive soft tissue stripping is avoided. Intraopera-

---

**Fig. 1. Establishment of marker points and measurement of fracture displacement.**

A and B, Marker points on the fractured side and the unaffected side in Surgicase. C, The distance between JU’ (JU on the unaffected side) and SP is 53.67 mm. D, The distance between ZTL and SP was 61.36 mm. The distance between ZTL’ (ZTL on the unaffected side) and SP was 64.39 mm. The inward displacement of ZTL can be measured by subtracting 61.36 mm from 64.39 mm. In this case, ZTL moved –3.03 mm inwardly after the fracture.
Fig. 2. Treatment of unilateral malar and zygomatic arch fractures using mirror imaging and preshaped titanium plates. 

A, Preoperative 3D CT data for 1 patient with unilateral malar and zygomatic fractures.

B, CT data were imported into Surgicase for 3D modeling.

C, Bony structure of the unaffected side was mirrored through the midsagittal plane onto the fractured side.

D, Original head model of the patient, manufactured using a RP device.

E, Mirror-imaged head model of the same patient.

F, Titanium plates were shaped before surgery on the mirror-imaged model.

G, A resinous guide plate was made on the mirror-imaged model to guide intraoperative fracture reduction and fixation.

H, 3D CT reconstruction 1 month after surgical reduction. CT data were then imported to Surgicase for measuring postoperative fracture displacement.

I, Preoperative view of the patient in Fig. 1.

J, Postoperative view of the patient in Fig. 1 during 7-day follow-up.
tively, the preshaped titanium plates were matched well with the fractured ends. Surgery was successful in all patients.

**Postoperative data processing**

All 4 patients underwent CT scan 1 month postoperatively. The 3D CT data were transferred to Suricase, which allowed comparison of the displacement of zygoma and zygomatic arches pre- and postoperatively as a way to evaluate the surgical outcome.

**RESULTS**

**Postoperative examination**

One-month follow-up was uneventful for all patients; no infection or plate exposure was observed. All 4 patients regained a normal degree of maximal interincisonal opening (MIO) and occlusion. Facial contour was recovered successfully in all 4 patients. Postoperative CT examination revealed that fracture reduction was successful; bilateral zygoma and zygomatic arch contours were symmetric.

**Comparison between pre- and postoperative fracture displacement data**

The mean values of pre- and postoperative displacement data for each marker point are shown in Table I. Postoperatively, the displacement of each marker point in any of the 3 directions was shortened significantly, especially the displacement of MP, which is of greatest importance to the patient’s facial projection. The results indicated that the facial contour of all 4 patients recovered satisfactorily.

**DISCUSSION**

Malar and zygomatic arch fractures are common midface fractures caused by road accidents, violence, and other forces. The symptoms include dysfunctions, such as restricted mouth opening, diplopia, and injury to the infraorbital nerve, as well as zygomatic and facial collapse and enophthalmos. Therefore, malar and zygomatic arch fractures can severely affect the patient’s physical and mental health and social rehabilitation.

The treatment goal in the context of malar and zygomatic arch fractures must focus on both facial contour and function.\textsuperscript{1,2} The restoration of function can be objectively judged by markers, such as degree of MIO and occlusion. On the other hand, the restoration of facial contour depends largely on the extent of the surgeon’s experience. The zygoma and zygomatic arch have complex anatomical relationships with adjacent facial bones. In contrast to maxillary and mandibular fractures, reduction of the zygoma and zygomatic arch does not prevent occlusion. The accuracy of facial contour restoration is sometimes difficult to maintain or evaluate. In this study, the mirror-imaging technique was applied in the surgical planning of unilateral malar and zygomatic arch fractures. The resins guide plate and preshaped titanium plates were also used to guide the reduction and fixation during surgery. The results suggested that the combined use of these techniques can increase the accuracy of reduction and restore facial contour.

**Application of mirror imaging in oral and maxillofacial surgery**

The mirror-imaging technique was used here to reconstruct a symmetric head model for shaping the titanium plates in advance. Previous research efforts have suggested that the application of the mirror-imaging technique can improve treatment outcome after craniofacial surgery.\textsuperscript{3-7} Zhou et al.\textsuperscript{4} used mirror imaging and RP technique to treat a patient with unilateral hemifacial microsomia using a customized mandibular implant. Positive outcomes were observed at 6-year follow-up. Singare et al. applied 3D mirror imaging and an RP technique to design and manufacture custom titanium implants for reconstructing mandibular defects. The facial contour and occlusal function of the patient recovered soundly.\textsuperscript{5} The mirror-imaging technique is also widely applied in the design and manufacture of facial prostheses, such as artificial ears.\textsuperscript{6,7} With this technique, the design of prostheses can be simplified by mirroring the healthy side to obtain an anatomically symmetric counterpart. In this study of unilateral malar and zygomatic

### Table I. Mean values of fracture displacement pre- and postoperatively, for 4 patients

<table>
<thead>
<tr>
<th>Marker points</th>
<th>Preoperative displacement, mm</th>
<th>Postoperative displacement, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inward</td>
<td>Backward</td>
</tr>
<tr>
<td>OZ</td>
<td>–2.77</td>
<td>2.86</td>
</tr>
<tr>
<td>ZM</td>
<td>0.01</td>
<td>3.02</td>
</tr>
<tr>
<td>MP</td>
<td>–0.86</td>
<td>4.85</td>
</tr>
<tr>
<td>JU</td>
<td>–0.35</td>
<td>1.45</td>
</tr>
<tr>
<td>TP</td>
<td>0.87</td>
<td>–0.02</td>
</tr>
<tr>
<td>ZTL</td>
<td>–1.18</td>
<td>–2.05</td>
</tr>
<tr>
<td>FMT</td>
<td>1.18</td>
<td>0.40</td>
</tr>
</tbody>
</table>
arch fractures, mirroring the bony structures of the unaffected healthy side onto the fractured side and shaping the titanium plates in advance was not difficult and achieved good esthetic outcomes. Facial asymmetry was greatly improved in all 4 patients.

**Application of RP in oral and maxillofacial surgery**

The zygoma has unique dimensions and complex anatomical relationships to adjacent bones. The displacement of the zygoma and zygomatic arch after fracture has a strong influence on the projection of the midface. Simulated surgery on RP models based on 3D CT scanning can be a feasible solution for guiding the reduction of malar and zygomatic arch fractures. Rapid prototyping refers to a wide range of related technologies used to manufacture physical objects directly from computer-aided design data sources. Facilitated by improvements in medical imaging technology and up-to-date computer hardware, 3D image-processing software, and various engineering methods, RP has developed dramatically in recent decades. Three-dimensional head models can be manufactured rapidly through the RP technique and used for quantitative measurement of the osteotomy, virtual simulation of the operation, and design of custom implants. D’Urso et al. analyzed 45 patients with craniofacial, maxillofacial, and skull base deformities. Their study suggested that the combined use of 3D CT imaging and RP improved craniofacial operative planning and diagnoses by 82.2% and 95.2%, respectively. Since first described in the 1990s, the RP technique has now been applied in a wide range of medical specialties, including orthopedics and maxillofacial surgery.

Stereolithography (SL) is one of the RP techniques most commonly used in the field of oral and maxillofacial reconstruction. According to a recent study on the SL technique, the accuracy of SL models is considered sufficient for preoperative planning in craniofacial surgery. Performing model surgery on the RP models is an ideal way for surgeons to more clearly observe the anatomical structures of the skull, which in turn facilitates planning the surgery in advance. In this study, SL is used in the manufacture of resinous head models for model surgery, as well as in the preshaping of titanium plates for unilateral malar and zygomatic arch fractures.

In this study, 4 patients with unilateral malar and zygomatic arch fractures were treated with mirror imaging and preshaped titanium plates. Resinous guide plates were made on the mirror-imaged model to guide reduction and fixation during surgery. The displacement of zygomatic marker points pre- and postoperatively was analyzed with Surgicase software. One-month follow-up showed that facial contour and the restriction of mouth opening were improved in all patients.

**CONCLUSIONS**

Fracture displacement can be quantitatively measured in Surgicase using selected marker points and their distances from the reference planes. The outcome of surgical reduction of malar and zygomatic arch fractures can be objectively evaluated by comparing pre- and postoperative fracture displacement. The mirror-imaging technique, preshaped titanium plates and resinous guide plates are viable choices for the treatment of unilateral malar and zygomatic arch fractures. Surgeons can more clearly observe bony structures before the operation and shape the titanium plates in advance. Combined use of these techniques can increase the accuracy of the surgical procedure and improve facial symmetry. The authors also believe that the mirror-imaging technique and preshaped titanium plates are of great practical value of measuring and surgically treating other unilateral facial fractures (e.g., unilateral fracture of the superior and lateral orbital margins or the temporal region). Further studies on the indications of this technique and long-term functional and esthetic follow-up would be worthwhile.

The authors would like to extend special thanks to the Materialise Group for providing the trial version of the Surgicase software.

**REFERENCES**


Reprint requests:
Lei Liu, DMD, PhD
Department of Oral & Maxillofacial Surgery
West China Hospital of Stomatology
Sichuan University
Chengdu 610041, P. R. China,
drlulu@163.com