Virtual Surgery Planning and Three-Dimensional Printing Template for Osteotomy of the Zygoma to Correct Untreated Zygomaticomaxillary Complex Fracture

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Abstract: Untreated zygomaticomaxillary complex fractures may lead to aesthetical and functional sequelae needing secondary surgical correction. A 31-year-old male was addressed to our department for right enophthalmos and loss of cheek projection 3 months after facial trauma. Restauration of facial symmetry can be achieved by repositioning of the zygomaticomaxillary complex by osteotomies. To achieve good functional and aesthetical results, the reduction needs to be accurate. This is the main difficulty in delayed cases as there are less anatomical landmarks due to initial trauma and bone remodeling. Nowadays, in France, thanks to good care access, very few patients are not treated within the first two weeks after trauma; thus, surgeons have little experience on secondary reduction. It has been reported that navigation-guided surgery and use of stereolithographic models improve results. In small centers, access to both technologies and induced over-cost may limit their use. With the ease to access a 3D printer, small centers have to develop innovative, simple ways to offer comparative results. In the case presented, surgery planning and plate modeling were achieved using an office-based three-dimensional printed model. To reduce the cost, free open source software has been used. In this case, facial symmetry has been restored and postoperative computed tomography scan shows good stability. This simple, cost effective technique, is applicable in most centers equipped with a 3D printer and ensures a good and reproductive result even when this surgery is not routinely done.

Key Words: 3D printing, midface asymmetry, ZMC fracture

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Fractures of the zygomaticomaxillary complex represent 17% of all facial fractures.[1] These fractures can lead to esthetical sequelae, such as flattened cheek and enophthalmos, as well as functional and sensitive impairment like diplopia, maxillary hypoesthesia, or impaired mandibular movements. The criteria for determining treatment are based on clinical signs, type of fracture, displacement, and degree of comminution in the aim to obtain facial symmetry with no functional sequelae.[2] In surgical cases, early reduction with or without osteosynthesis is recommended. However, in some situations, the early surgery cannot be realized, or the early reduction is not sufficient to optimally restore the facial symmetry. This could lead to remaining functional complications and/or esthetical sequelae.

In such cases and after bone consolidation, it is recommended to offer a delayed corrective procedure. Camouflage techniques can restore the contour symmetry, especially in cases with projection defect of the cheekbone without functional impairment. Correction of more complex zygomaticomaxillary complex (ZMC) fractures with both functional and esthetical sequelae can be achieved by repositioning of the ZMC by osteotomies with or without bone grafting.[3] The difficulty is to obtain a good reduction with less anatomical landmarks due to initial trauma and bone remodeling.

In the past few years, the use of computer-assisted technologies has increased in different fields of maxillofacial surgery including delayed treatment of ZMC fractures.[4,5] Navigation-guided surgery is reported to ensure good reduction, but not all centers are equipped. The use of stereolithographic (3D) model offers the possibility of surgery planning and osteosynthesis plate bending to help ZMC reduction improving results.[5] The main issue is the increased cost if performed by off-site vendors. The use of office-based 3-dimensional (3D) printing permits low-cost 3D planning in all centers even small ones.[6] We present a surgical technique using office-based 3D printing allowing preoperative osteotomies planning and plates modeling for delayed ZMC repositioning.

CLINICAL PRESENTATION

A 31-year-old white male was referred to our institution 3 months after facial trauma. He received a direct hit in the cheekbone and presented a right ZMC fracture. He reported initial diplopia, which recovered spontaneously. He did not seek immediate medical advice and so did not benefit from any acute surgical correction. The physical examination revealed esthetic and functional impairment with a severe right enophthalmos without diplopia, dental paresthesia in the territory of the right suborbital nerve, and a loss of projection of the zygomatic bone leading to facial contour asymmetry (Fig. 1A and B).

The computed tomography scan showed the stigma of ZMC fractures with signs of partial consolidation. The right ZMC was rotated in a varus position associated with inferior displacement with subsequent enlarged orbital volume compared to the opposite side (right orbital volume: 27.16 cm^3; left orbital volume: 22.12 cm^3) (Fig. 1D).

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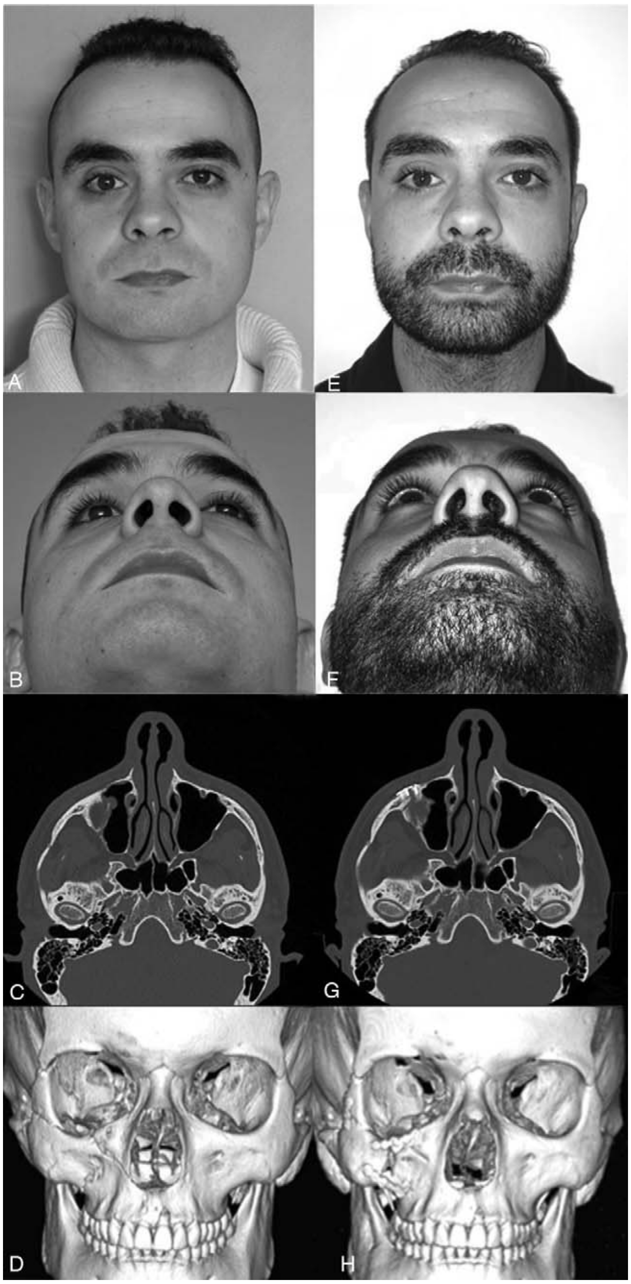

FIGURES 1. A, Preoperative photo of the patient (front view). B, Preoperative photo of the patient from worm's eye view. C, Preoperative axial view of computed tomography (CT) scan at zygoma level. D, 3D reconstruction of preoperative CT scan. E, Postoperative photo of the patient (front view). F, Postoperative photo of the patient from Worm's eye view. G, Postoperative axial view of CT scan at zygoma level. H, 3D reconstruction of postoperative CT scan.

Planification and Surgical Procedure

Before surgery, a 3D planification was made using free open-source software. We used 3D Slicer (3D Slicer 4.0; Surgical Planning Laboratory, Harvard University, Boston, MA) for image segmentation and generation of STL (stereolithographic) file from DICOM (Digital Imaging and Communications in Medicine) data and Meshmixer (Autodesk Inc, Mill Vallay, CA) for image mirroring. These 2 softwares are free and easy to use. We finally use Z-Suite (Zortrax, Olsztyn, Poland) to prepare for printing with slicing and to add support pillars. This software is sold with the 3D printer. The Z-code data are transferred to 3D printer Zortrax M200 (Zortrax).

Two 3D models of the median third of the face were printed: one in the actual state and one after mirroring of the unaffected side. To realize the valgization of the zygomatic bone, 2 osteotomies and a greenstick-oriented fracture were proposed and applied on the first model, following the initial site of fractures. An osteotomy was made from the zygomaticomaxillary buttress to the inferior orbital rim lateral to the infraorbital foramen. The second one was located at the base of the frontal process of the zygomatic bone. Finally, the anterior part of the zygomatic arch was fractured using a unicortical osteotomy. Movements of the separated fragments were planned by overlying native and mirrored computed tomography (CT) scans to measure the lack of projection, width and the amount of orbital floor lowering that need to be corrected (projection 2 mm, width: 2.5 mm). These movements were reported on the model and stabilized using wax. Osteosynthesis plates were bended on the mirrored model and then tried on the "native" model on which the osteotomies were performed: 1 plate on inferior orbital rim, 1 on the zygomaticomaxillary buttress, and 1 at the level of the frontal process osteotomy. The osteosynthesis plates were then sterilized (Fig. 2).

Incision was made on vestibular free mucosae and the subperiosteal dissection was made on the zygomaticomaxillary buttress and the frontal face of the zygomatic bone up to the inferior orbital rim after identification of the infraorbital foramen and zygomaticomaxillary foramen. Subciliary incision was performed. After a short subcutaneous dissection, the orbicularis oris muscle was crossed in the muscle fibers direction to join the infraorbital rim permitting the periosteal incision. The subperiosteal dissection was realized on the inferior orbital wall, downward to join the inferior approach and laterally to expose the frontal process and the anterior part of the zygomatic arch. The osteotomies were performed using a piezoelectric instrument following the planification. Concerning osteotomy of the zygomatic arch, the fracture was initiated by piezoelectric instrument permitting mobilization of the osteotomized fragment.

After zygomatic bone mobilization, the osteosynthesis was performed using the prefolded 1.25 plates with 5-mm screws. The bone gap between medial and lateral part of the zygomatic bone was filled with 2 bone grafts harvested on the right mandibular ramus and placed under the plates in order to stabilize the

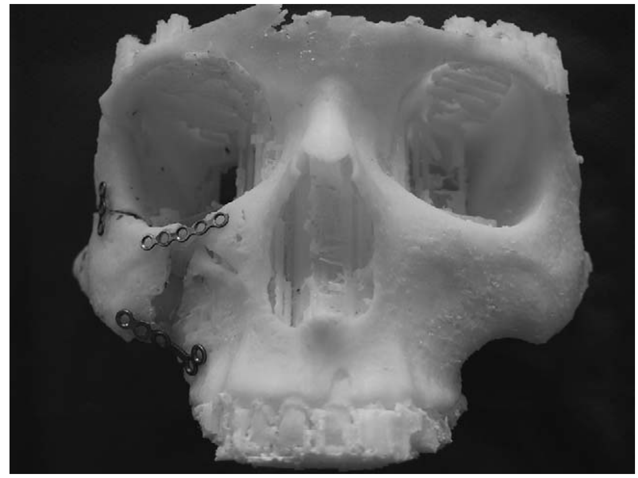

FIGURE 2. Prebended plates on innate stereolithographic model after ZMC repositioning. ZMC, zygomaticomaxillary complex.

osteosynthesis, to keep the space opened and to induce osteogenesis for bone consolidation. The movement was insufficient to correct the orbital floor lowering and orbital floor defect was enlarged. Thus, to make sure to correct enophthalmos, the orbital floor defect was restored using a 0.25 PDS plate.

The patient was discharged the day after surgery. He presented no signs of complications (hematoma, infection, poor healing). The V2 hypoesthesia stayed stable. Six months postoperatively, the physical examination showed restoration of the facial symmetry with replacement of the lower eyelid and symmetrical projection of the ZMC (Fig. 1E–H). Orbital volume was calculated again and was significatively reduced as planned even if a slight difference persisted between both sides (right orbital volume post operatively: 24.21 cm^3, left orbital volume: 22.12 cm^3).

DISCUSSION

The symmetry of the middle third of the face relies on a good projection of both zygomatic bones. After facial trauma, fractures of the ZMC can alter this symmetry and cause functional and esthetical consequences mainly by setback of the cheekbone and widening of the face.[2,7] The setback of the cheekbone is known in the aging process due to both fat tissue migration and negative bone remodeling process. This phenomenon induces an older and depressed profile appearance. Furthermore, functional consequences of the displacement of the ZMC can be defined by an enophthalmos with or without diplopia and interfere with normal range of mandibular movements by conflict with the coronoid process. Thus, it appears mandatory for functional and aesthetic reasons, to restore the facial symmetry of the middle third even months after a trauma. Thanks to the ease of care access, most of the ZMC fractures needing surgery referred to our center are treated as recommended, in the first two weeks after trauma. This explains the difficulty to realize bigger trials.

Depending on the type of fracture, degree of displacement and comminution of the ZMC, different surgical techniques may be discussed. For esthetical sequelae, present in displaced fractures without functional impairment, facial contour restoration techniques could be sufficient.[8] Apposition techniques have been described to reproject the flattened cheek using bone graft either, autogenous or allogenic bones, and alloplastic implants. These techniques are efficient but have been associated with different complications and limits including resorption, infection, and implant exposure, which can all alter the final result.[9] Other camouflage techniques can include autologous fat graft or fillers injection for minimal displacement of the ZMC and especially for cheekbone projection insufficiency.

In case of significant orbital volume change and important abnormal zygomatic bone position with functional impairment, these techniques are not sufficient. Some techniques solely correct orbital dystopia by trying to restore the orbital volume. These include orbital wall bone grafting or orbital implants.[10,11] They can be combined with camouflage techniques to correct both esthetical impairment and enophthalmos.

In the setting of severely displaced and noncommunitive fractures of the ZMC that were untreated or undertreated, the surgeon should reposition the whole zygomatic complex using osteotomies. The aim of this surgical procedure is to restore ocular correct position, normal range of mandibular movement as well as facial symmetry. Several techniques have been described and osteotomies can be achieved at different locations depending on initial fracture sites.[12,13] In communitive fractures, there is often no complete bone consolidation but fibrous tissue formation in which osteotomies and osteosynthesis are hardly feasible. For these cases, camouflage technique may be preferable especially if no functional impairments are identified. In the case presented here, there were CT scan signs of consolidation allowing us to perform a replacement osteotomy of the ZMC complex.

Authors agree that the complexity relies on the difficulty to reposition the zygomatic bone due to partial bone consolidation, presence of fibrous tissue, and disappearance of accurate reduction criteria by bone remodeling added to the limited access to the region. Freihofer et al and Cohen et al replaced the mobilized zygoma based on self-appreciation of good positioning. The result may be uncertain especially for surgeons with little experience.[3,14]

The use of computer-assisted navigation and stereolithographic models have been reported and developed to cope with this difficulty. Computer-assisted navigation may be helpful if used by a trained team. This technique requires preoperative planning and intraoperative triangulation of the navigation system using markers (bone screws, tooth splints, anatomic landmarks or skin adhesives). If any step is done improperly, it can alter the result. The surgeon and his team must be experienced to allow good results with reasonable surgical time.[4,15] Although it permits a good positioning of ZMC,the difficulty to keep the reduction during osteosynthesis plates bending and screwing remains.[15] In addition, many centers are not equipped because of the elevated cost. Furthermore, it has been shown that fixed registration points, with bone screws or tooth splints, is the best recording system for navigation-assisted craniomaxillofacial surgery.[16] It requires a 3D-CT scan before surgery with navigation markers well positioned. 3D models are increasingly used in oral and maxillofacial surgery. Its use in delayed ZMC repositioning has been shown to improve surgical results.[5,17] Printing is usually done by off-site vendors with the disadvantage of an elevated cost. Elegbede et al[6] reported the principles of office based 3D workflow, which offers an affordable and efficient tool facilitating accurate reduction in acute facial trauma. In addition to the 3D diagnosis and its educational interest, the use of stereolithographic models allows surgery planning of osteotomies and appreciation of quantity of bone displacement. The use of mirrored model permits to easily bend the osteosynthesis plates preoperatively; when this is done peroperatively, the surgeon often faces exposure trouble related to soft tissue. Using wax, the different fragments of the "native" model are held in the desired position to confirm the restoration of good symmetry, and to test the bended plates. The prebended osteosynthesis plates can be sterilized and used for the surgery facilitating the osteosynthesis step and reducing the operative time. The free software available is easy to use and generates correct models. Klug et al[15] reported a technique based on a combination of computer-assisted navigation and stereolithographic model leading to accurate results at the cost of increased pre and per operative time. This full-combined technique may not necessarily be used.

Concerning the orbital volume, orbital floor was reconstructed using a PDS plate because the defect was not important, and we first thought that zygoma mobilization would be sufficient to restore the orbital floor lowering. In future cases, it will be preferable to use a titanium plate that can be preoperatively bent on the mirrored model to ensure a perfect restoration of the orbital volume. Measures and calculation of orbital volumes, on Osirix, uses bone edges. However, PDS plate is above the orbital floor; thus, the orbital content volume tends to be overestimated compared to the contralateral side. Moreover, the patient presented a fracture of the right medial orbital wall that has not been corrected. This explains the imperfection in volume restoration calculated even if clinically, enophthalmos was completely corrected.

Bone resorption is one of the main issues in contour restoration techniques.[3] In our case, the result is stable at 6 months, with CT scans signs of consolidation and preserved bone density.

Another issue that needs to be addressed is the surgical approach.[2] In the above-mentioned case, a combined intra-oral and sub ciliary approach was decided. Some authors add an eyebrow or upper eyelid incision to access the frontozygomatic suture. The aim is always to reduce the scar burden. An enlarged sub ciliary incision allows good exposure of both infraorbital and latero-orbital rim but leading to a visible scar and a risk of ectropion, which did not occur in our case. Sharma et al[18] recently described a single retroseptal transconjunctival approach with lateral canthotomy and inferior cantholysis using a Y-modification allowing exposure of both regions with limited scar issue. This surgical approach could improve our technique. In contrast, the use of coronal incision has been described to expose the frontozygomatic suture and zygomatic arch.[19] Except in cases of zygomatic arch comminution, this approach seems hardly acceptable for patients in the actual dynamism of innovations in maxillofacial surgery to attempt precise and predictable results being minimally invasive.

CONCLUSIONS

We described a simple, cost-effective technique using office based three-dimensional printed models without need of computer assisted navigation system. Thanks to free open-source software, this technique is applicable in most centers equipped with a 3D printer and ensures a good result even when this surgery is not routinely done. The preoperative bending of the osteosynthesis plates reduces the time of surgery with limited preoperative preparation. This technique is simple, inexpensive, and seems reproductible. Study of subsequent similar cases may be interesting.

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