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Computer aided and 3D printing in pre-operative planning of orbital reconstruction surgery

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Abstract:

This article describes the example of a computer aided and 3D print of a patient's fractured orbital preoperational reconstruction surgery planning.

On basis of a medical visualization a triangular model of the facial part of the skull with the fractured orbital has been developed. Using the haptic voxel modeling tools the model has been improved and next the model of the reconstructed orbital has been made. This model served to build a physical model. Using the physical model of the orbital the reconstruction mesh has been made which was then implanted into the patient's skull. The entire surgery was completed with no complications and the patient regained proper sight.

KEYWORDS: **computer aided**, **reconstruction of the orbit**, **virtual model**, **haptic modeling**, **3D printing**

1. Introduction

Nowadays the CA – Computer Aided notion is no longer limited to engineering and designing with constructing processes in particular. This CA is more and more frequently used in other fields e.g. medicine.

There are a number of CA software used by doctors in various aspects of their work. An example of such an aid is computer processing of data obtained in CT scanning or magnetic resonance [2]. The target effect of processing such data is a virtual 3D model of an isolated tissue (e.g. a bone tissue) [2, 4].

This article describes the case of reconstructing an orbital using CA and 3D printing in preoperational surgery planning.

2. Materials and methods

2.1. Medical case

A 52-year-old female, underwent a multi-organ injury being hit by a car in an accident. She came to the outpatient Department of Craniomaxillofacial Surgery Oral Surgery and Implantology Medical University of Warsaw three months after the accident. It was very late!

The patient underwent a preoperational ophthalmologic and orthoptic examination. The examination revealed diplopia (double vision), enophthalmos, ocular motility and collapse of one eye ball could also be observed (fig. 1). All the disorder hampered her normal daily activities. On the basis of clinical and imaging examination (CBCT - Cone Beam Computed Tomography) the patient was qualified for surgical reconstruction of the orbital floor.

Fig. 1 Left side up-gaze restricted (before treatment)

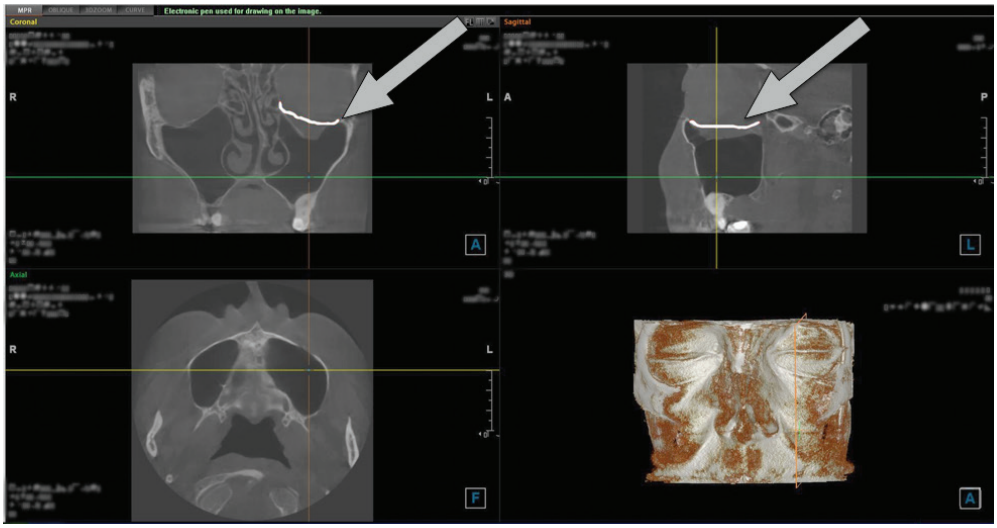

Fig. 2. Fracture of the bottom wall of the orbit – visible on standard CT images viewer

2.2. Medical imaging

To obtain the virtual model of the skull facial part (including the orbitals: both the sound and the injured one) the CT with the cone beam radiation (CBCT) was used. This solution is widely used in various medical disciplines to mention only such as dentistry and facial and jaw surgery [6, 9, 10].

The main advantages of such CTs are lower doses of radiation and several times shorter time of the examination since the required result is already obtained after a single rotation of the lamp around the patient. Images obtained in such a way are of very high resolution with a high density of sections (cross cuts).

CTs and magnetic resonance also provide images presented in the DICOM (Digital Imaging and Communications in Medicine) format [2]. Images recorded in the DICOM standard include not only graphic data – images but also information concerning the patient and the parameters of the surgery. If the examination is done in high resolution with a high density of sections (cross cuts) the images may be used to provide a virtual model to be used in reconstruction of the examined organ.

The DICOM images are imported to specialized computer systems (e.g. Mimics [5], Osirix [8], Invesalius [4] etc.) which enable digital processing. After inputting the data the two dimensional sections can be visualized in 3 planes: coronal, transverse and sagittal. The so called masks with appropriate Hounsfield's scale (quantitative scale describing the radiological density reflecting the X ray absorption by a given organ) representing the bone tissue density are generated in these images.

Using this method the facial part of the skull has been initially segmented in the model. Next, many processes of the images were done to generate a 3D model of the facial part of the skull with the fractured orbital (fig. 3). This model was saved in the form of a triangle mesh.

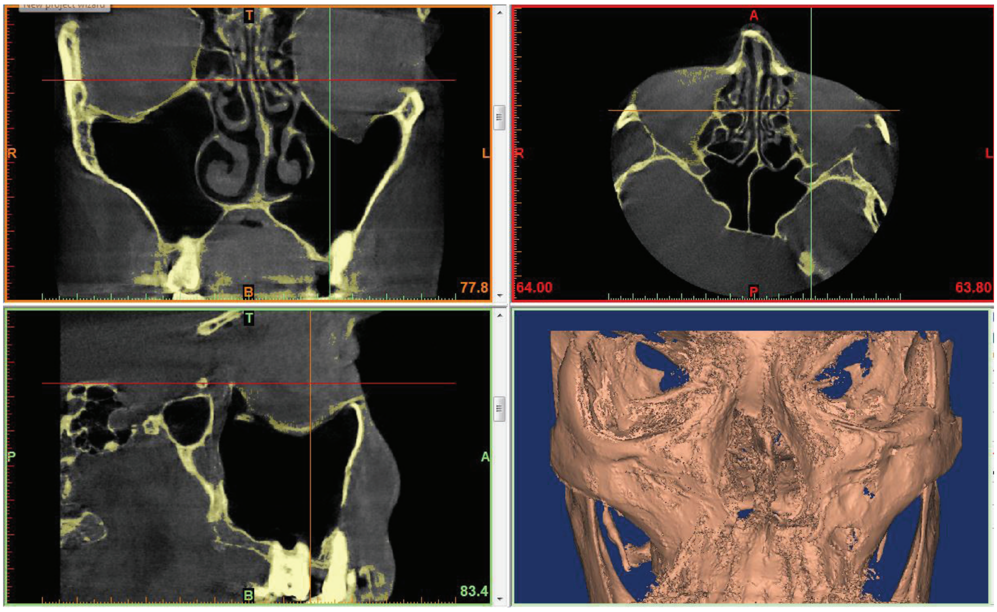

Fig. 3. Fracture of the floor wall of the orbit – visible in the Mimics system

Because of the necessity of reconstructing the left orbital, the area of the facial part of the skull has been significantly limited by removing fragments of the triangle mesh (fig. 4).

However, the obtained triangular model of the facial part of the skull included many needless artifacts (resulting from the examination technique) and the reconstructed area of the bone of the sound right orbital was uneven and contained many nonadjacents resulting from a very thin malar bone. To reconstruct the left orbital it was necessary to improve the skull facial part model first.

This improvement and the reconstruction of the orbital was made using the haptic voxel modeling [1, 7]. This kind of modeling enables a human – computer interaction not only via the sense of sight but also via the sense of touch. This is possible by means of a special haptic device (alias: modeling arm, fig. 5) through which the human physically feels the resistance of the virtual matter of the shaped model.

In order to continue modeling the triangular model had to be transformed into the voxel form what enabled further edition using the haptic ClayTools system [3]. Since this method is not very popular it is presented in a more detailed way.

Fig. 4. Target facial model as a triangle mesh (periorbital fragment only)

2.3. Haptic modeling

Haptic modeling gives a lot of - unprecedented in the other engineering 3D CAx systems - possibilities to shape virtual models. Haptic modeling software tools used to shape virtual models so-called "virtual clay" (popular name of the voxel volumetric model). Haptic modeling allows speeding up the modeling process of very complex shapes (especially with no typical geometric shapes) in comparison to the other mentioned modeling systems. They allow us to perform even operations completely inaccessible in these systems, e.g. CAx systems. For example: we can shape the virtual model like as real piece of clay, using special programing functions cooperating with the special haptic device - modeling arm - PHANTOM Omni (fig. 5) [3, 7].

Fig. 5. The PHANTOM Omni haptic device

The haptic ClayTool modeling system was used to repair the sound right orbital first. Initially the needless artifacts were removed (fig. 6) using ball tool for virtual sculpting.

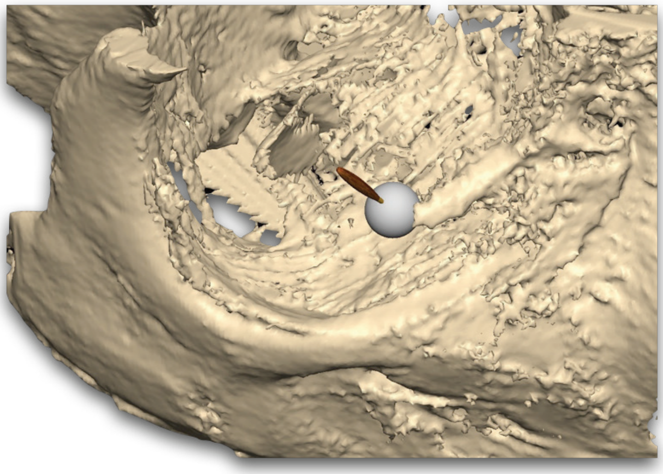

Fig. 6. Use of the „carve with ball" tool

Next, all the surfaces surrounding the orbital were primarily smoothed (fig. 7) using the free smoothing tool.

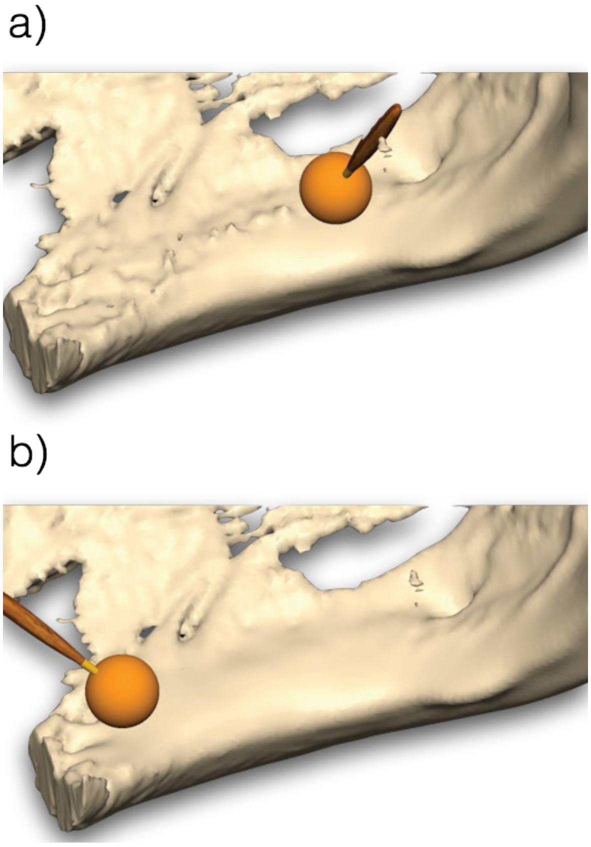

Fig. 7. Use of the „interactive smooth" tool: a) surface before smoothing b) the same surface area after smoothing

The existing intermittencies and those appeared during the smoothing process were completed using new fragments of virtual clay (fig. 8).

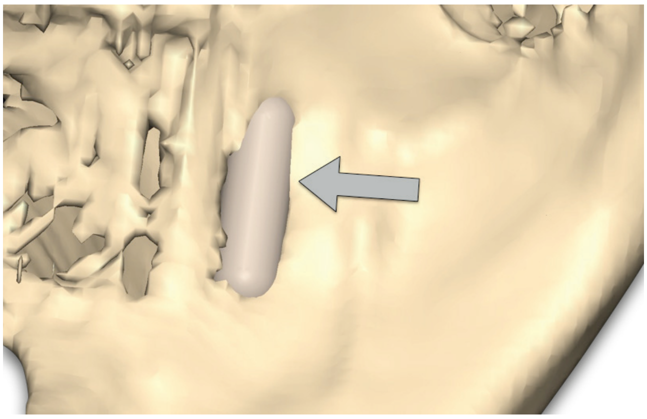

Fig. 8. Use of the „add clay" tool

In the end of this process the fragments were thoroughly smoothed, this time using the tool to average the irregularity of the model within the marked area of the model (fig. 9).

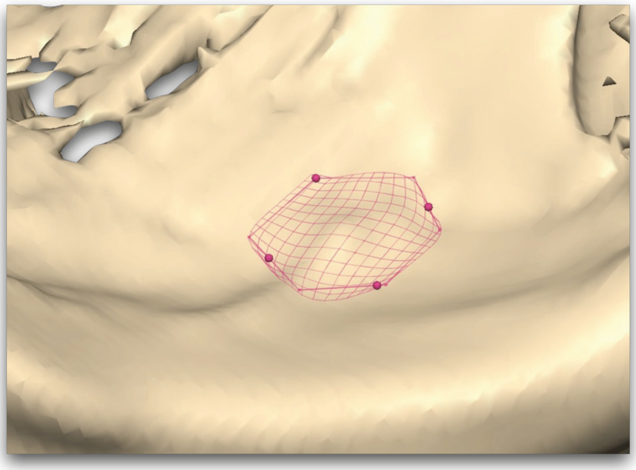

Fig. 9 Use of a the „smooth area" tool

The smoothed and improved fragment of the orbital was used to carry out the reconstruction of the fractured orbital. This was done by symmetrical reflection of the sound orbital model in relation to the sagittal plane. The copy of the sound orbital was put (as a test) in place of the fractured orbital (fig. 10).

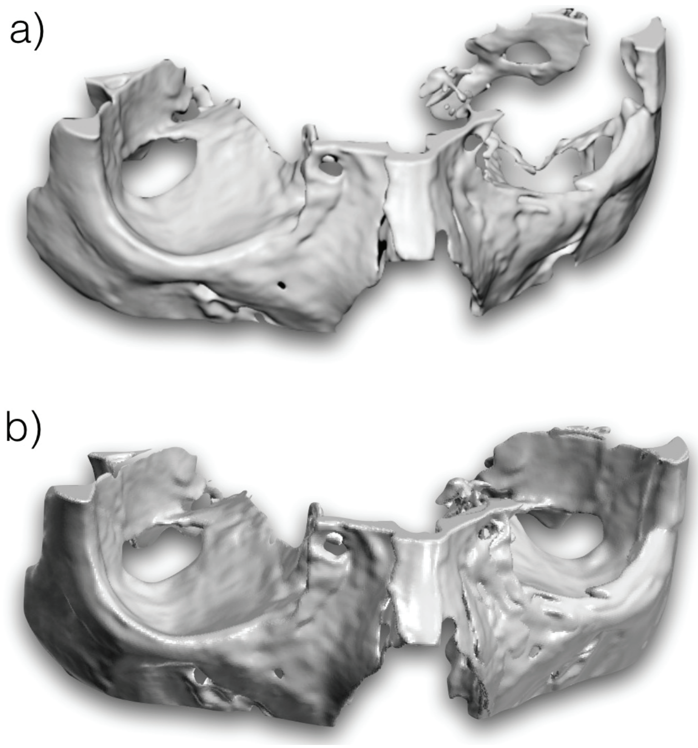

Fig. 10. The reconstructed facial virtual model as a „virtual clay" (periorbital fragment only): a) before mirroring the right orbit, b) after mirroring the right orbit

The main objective of the modeling process was to obtain the reconstructed orbital which would serve to develop the physical model using the generative – 3D technology. Therefore the model had to be cut (limited) to the fragment with the orbital floor only (fig. 11).

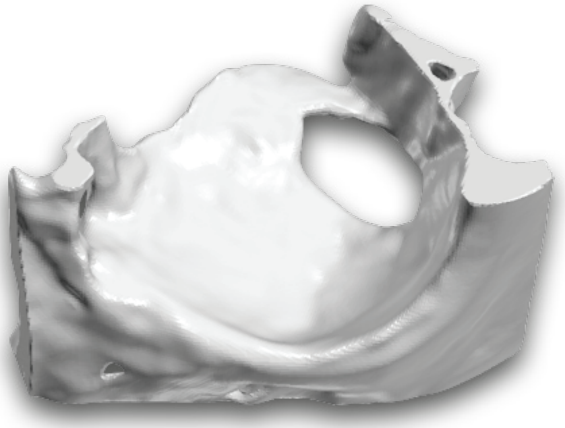

Fig. 11. The virtual model of digitally reconstructed orbit

2.4. Generative production (3D printing)

A 3D printer working in the FDM (Fused Deposition Modeling) technology was used to make the physical model (fig. 12). Generally the FDM technology is based on stratified laying of the base and the modeling material by two extruders (nozzle heads). The numerically controlled twin nozzle extruder enables laying the main model material (and if necessary, the base material stabilizing the model during printing as well) onto a mobile platform. Once one layer is laid the platform is lowered by the value of the layer thickness. This way the finished model, reinforced by base material in selected places, is obtained. All the reinforcements (supports) are removed once the model is ready. This may be done either mechanically detaching the extra material or by flushing it out using either a pressure or ultrasound washer.

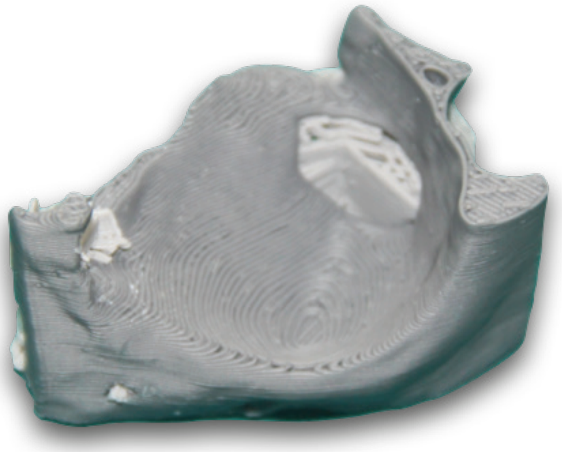

Fig. 12. The real orbit model as printed in 3D

All the previous processes served to obtain a preoperational titan reconstruction mesh (fig. 13) respective to the anatomical shape of the orbital. This shortens the time of the entire reconstruction and makes the surgery much easier.

Fig. 13. The real orbit model and precisely matched titanium mesh

3. Results

As mentioned above the main objective of all the processes was to reconstruct the fractured orbital floor. The surgery was potentially dangerous due to the time that elapsed from the accident to the patients arriving at the clinic, during which scars and adhesions developed in the orbital. Therefore the results of the surgical intervention were not fully predictable.

The orbital floor was approached using a standard subcilliary incision and a stepped blunt dissection to the infra orbital rim. The orbital floor was explored and the orbital fat and any involved muscles were removed from the maxillary sinus by blunt dissection. Then, for the reconstruction of the orbital floor a titanium plate previously formed on the model printed in 3D technology was used. A collagen membrane for isolating the soft tissue was placed on the titanium plate (fig. 14).

The postoperational examination showed regression of double vision and improved her ocular movements in all directions. The collapse of left eye ball was stopped (both eyes are on the one horizontal line, fig. 15). She is now leading a normal life.

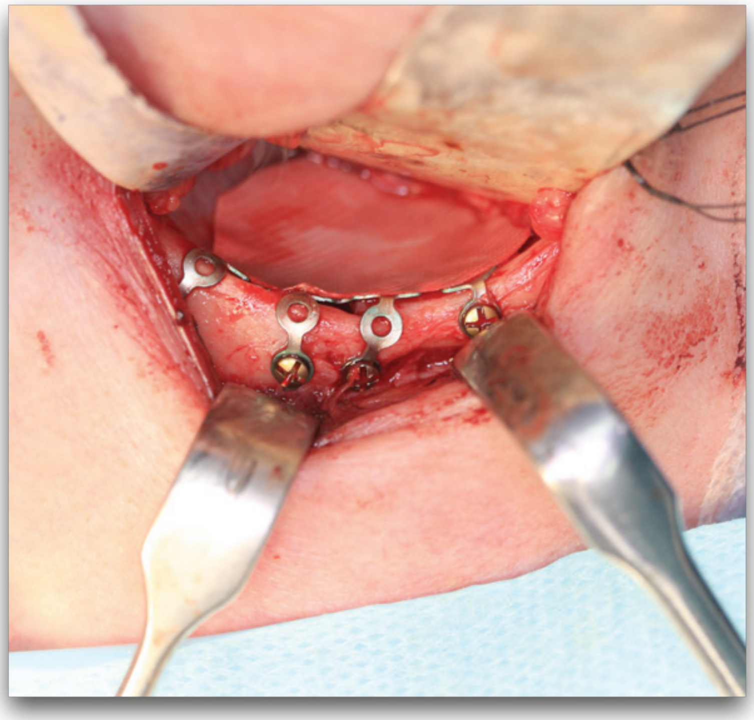

Fig. 14. During the surgery (visible titanium mesh, collagen membrane and placement screws)

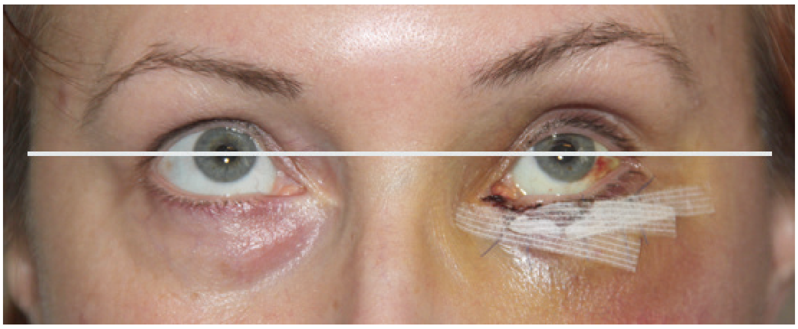

Fig. 15. Symetric up-gaze (one day after the surgery)

4. Discussion

Modern methods of medical imaging and modern methods of virtual modeling enable obtaining precise 3D models of anatomical structures. The compliance of the 3D models with the original structures depends on the quality (class) of the software and on the human skills and experience. The correctly made 3D model of a given structure – in this case the orbital- enables careful planning of the surgery. The virtual model provides the doctor with information on the condition of a given structure what enables faster decisions concerning the treating methods. While the physical model – of the same structure – enables individual matching of the preoperationally implanted reconstruction plates/mesh. The operation with adequately matched object to be implanted is much faster and the probability of correct shaping of the implanted object is much higher than in the case of manual shaping during the surgery.

Unfortunately, the preoperational planning of surgeries using virtual and physical models has not yet become a standard. This is due to the necessity of either having access to very specialized software, equipment and highly qualified staff (e.g. biomedical engineers) or cooperating with specialized external entities.

Both generate higher costs (the problem of refunding such additional costs). However both contribute to improving the quality of the surgery, shorter time of the surgery itself and recovery time for the patient thus eventually lowering the unit cost of a surgery. Therefore, it is important to take all such factors into account and calculate whether such preoperational planning does not, in the end, pay back.

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