cosmetics

Case Report

Computer-Assisted Reconstruction of an Orbital Trauma Case Treated with a Patient-Specific Titanium Prosthesis

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Abstract: Virtual planning is ideally suited for maxillofacial operations as it allows the surgeon to assess the bony and critical neurovascular structures and enables him to plan osteotomies and fracture reductions. This study aims to propose the use of titanium-based patient-specific implants (PSI), along with virtual surgical planning to assess the advantages and the complications in a case of orbital reconstruction. A three-dimensional model of the skull was generated using computed tomography (CT) data of a female patient using Mimics software (version 19, Materialize, Leuven, Belgium). Numerical PSI models were designed using 3-Matic software (version 13, Materialize, Leuven, Belgium) and the non-affected orbit as a template. Surgical virtual planning showed the suitability of the use of the numerical models in traumatic surgical rehabilitation. Moreover, the digital printing process enabled the trial of the designed PSIs on the patient's face before the surgery. Reconstruction Biomechanical studies are an essential part of understanding the limits of maxillofacial traumas. The surgical results confirmed the virtual predictions, and the orbital reconstruction seems to be more enhanced and facilitated.

Keywords: orbital reconstruction; virtual planning; titanium maxillofacial prosthesis

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1. Introduction

The use of modern methods in the treatment of maxillofacial injuries formed a qualitative transfer in the outcomes of treatments and reduced the need for subsequent surgical interventions [1]. It also greatly assisted in pre-surgery planning and predicting the treatment outcomes to facilitate effective communication between the surgeon and patient, and teamwork [2].

The presence of high-resolution computed tomography (CT) images, computer-aided design, and manufacturing (CAD/CAM) in combination with 3D titanium printing achieved these goals and gave excellent outcomes compared to traditional treatments that are usually used to treat such injuries by prefabricated titanium plates and meshes [3]. The zygomatic-orbital complex fractures are among the most common fractures of the face and jaw and are often caused by traffic accidents, assaults, and sports [4].

The challenge facing oral and maxillofacial surgeons is the ability to return the zygomatic compound to the three-dimensional position. Any defect in 3D positioning may lead to an erroneous measure of face width or a variation in the size of the orbital [5]. Moreover, the association of injuries of the zygomatic-orbital complex with a loss of bone complicates the treatment and reduces the chance of obtaining satisfactory results for the patient [6]. The complaint is repeated after treating such cases, describing an inability to re-anatomize the area to restore the cosmetic and functional aspect, and thus affects the health-related quality of life (HRQoL) and prevents the surgeon from obtaining patient satisfaction [7]. Computer-assisted design and manufacturing techniques contributed significantly to the reconstruction of the area anatomy using the healthy side or an old CT scan of the patient or of his relatives [8].

The objective of this study is to present a case of a zygomatic-orbital complex injury pertaining to a patient who underwent several consecutive operations to reach a satisfactory cosmetic and functional result. The most distinctive point was the use of virtual planning and the design of personalized titanium plates and meshes.

2. Case Presentation

2.1. Case Story

A patient in their fifth decade of life was referred to the Oral and Maxillofacial Hospital at Damascus University (Damascus, Syria) with a complaint of deformation on the left side of the face and around the eye. This injury was caused by a previous car accident and resulted in a comminuted fracture of the left zygomatic-orbital complex, a narrowing of the eye-opening, tear duct damage, infraorbital nerve injury and paralysis in the buccal branch of the facial nerve.

The patient underwent several surgeries to treat the injury without reaching a satisfactory result with the deformation remaining, and the patient had to wear large-sized sunglasses to hide the location of the injury. The car accident occurred ten years ago, leading to a comminuted fracture of the left zygomatic-orbital complex. This was initially treated with an open reduction procedure using a titanium plate and mesh. The result was a displacement of the zygomatic compound due to imprecise anatomical reduction. All of this led the patient to undergo several subsequent surgeries to reach a satisfactory cosmetic and functional result. Firstly, an autograft from the frontal bone was implanted in the infraorbital area to restore the zygomatic protrusion. However, the graft seemed to be placed in the wrong place, as it had to be placed more laterally. Secondly, cosmetic surgeries, including implanting pieces of silicone laterally to the orbital wall and under the lower edge of the orbit, were performed lately, but the results were not satisfactory, as it led to the inconsistency of the area and to the presence of many heterogeneous depressions and protrusions, as it is shown in Figure 1A,B.

Clinical examination revealed left orbital asymmetry with the right orbit, the disappearance of the zygomatic protrusion, the presence of a protrusion under the lower edge of the orbit even though this area should be depressed, the presence of a protrusion under the left nasal wing, a depression at the lateral wall of the orbit, asymmetry of the lateral orbital contour, absence of facial contour, decrease in facial width, narrowing of the eye-opening, change in the medial and lateral anastomosis, and several scars resulting from the injury and previous surgeries (Figure 1C,D).

Radiological examination using a CT image and the three-dimensional structure of the skull showed, firstly, a presence of downward and medial displacements in the zygomatic compound. Secondly, a presence of a wire suture in the form of a knot was noticed at the zygomatic junction. Moreover, a titanium plate was attached to the frontal bone at the upper orbital margin, extending to form the lateral edge of the orbital, and then fixed to the integrity part of the zygomatic bone. Finally, a small titanium mesh adapted to form the orbital floor, an autograft bone fixed below the inferior edge of the orbit, and two pieces of silicone, one infraorbital and the other lateral to the zygofrontal suture (Figure 2).

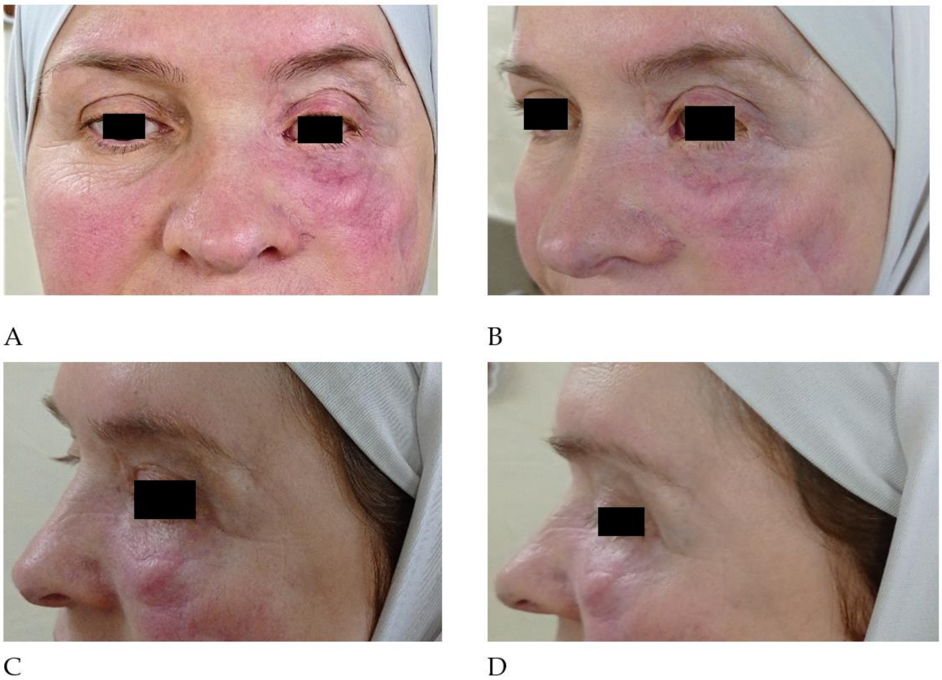


Figure 1. Patient appearance after several previous surgeries. (**A**): Frontal view, (**B**): lateral view showing a massive tissue protrusion. (**C**): Protrusion under infraorbital rime. (**D**): sagittal view showing the deformation of the orbital circumference.

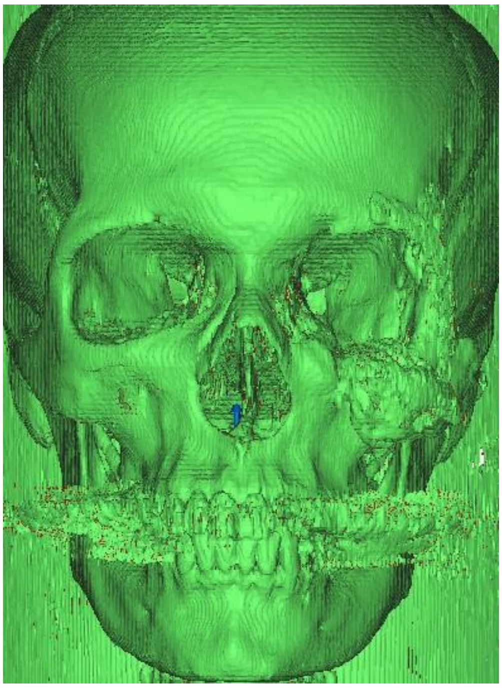


Figure 2. Examination of the 3D model with previous plates and definition of landmarks.

2.2. Design of PSI and Virtual Planning

DICOM files were used from the patient's CT image and transferred to Mimics® software (version 19, Materialize NV, Leuven, Belgium). A skull mask was created using segmentation tools, as shown in Figure 3, and modified so that virtually all materials used for treatment were deleted (titanium plate, mesh, bone graft, silicone, fixation wire, fixation screws) to the patient's bone.

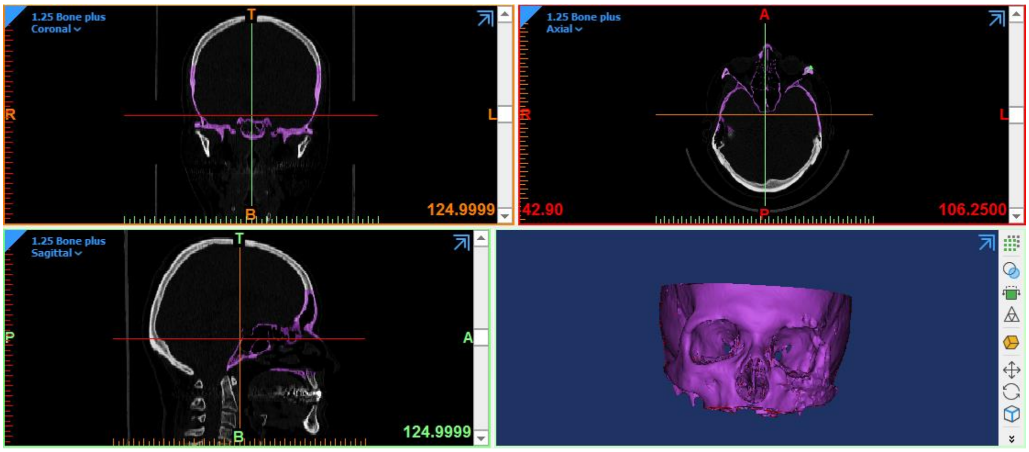


Figure 3. Overview of computed images on the three planes with a display of a 3D model built from the defined mask, where the colored lines indicate the position of the cursor point placed on the 3D model on the three planes (coronal, sagittal, and axial).

In consultation with the work team, the work plan was developed virtually, as it was agreed on the length of the allocated implant, its thickness, and the locations of the fixation screws, and provided that the implant would be in two parts to facilitate its surgical placement (Figure 4).

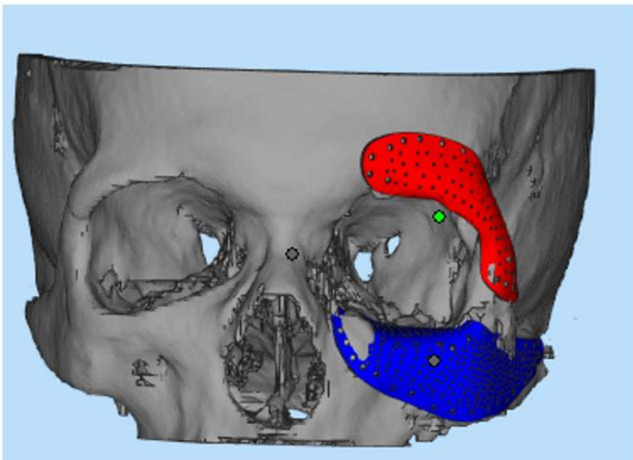


Figure 4. Virtual planning of the surgical intervention, where the implant was separated into two parts: upper (figured in red) and lower (figured in blue), and the placement of the two implants was checked and verified before the surgery. The places of screws were also verified such as to prevent any interference with nerves or vessels in the region.

We moved then to the design stage using 3-Matic software (version 13, Materialize NV, Leuven, Belgium). A 3D reconstruction of the affected orbit was performed by using mirroring of the nonaffected orbit. The 3D object was improved to wrap and smooth the surface. The extents of PSI models were lined superiorly and inferiorly to the orbital fissure (Figure 4). The anatomical mesh implant with a screw hole fixation at the frontal and zygomatic bones was then created of plastic and then titanium. Plate thickness was 0.5 mm, and the screw hole diameter was 1.7 mm, whereas the diameter of hole texture was 0.5 mm.

2.3. Trial of 3D PSI

The designed PSI was first manufactured from Polylactic acid (PLA) using a 3D printer (Longer LK4, Longer, China) based on Fused Deposition Modeling (FDM), and the prostheses were tried exteriorly on the face of the patient, and the shape and the borders were checked (Figure 5A,C). Secondly, the models were sent as STL files to a private laboratory to be printed with the Ti-6Al-4V alloy (periodic structure) using selective laser melting (SLM) technology (Riton D-150, Guangzhou Riton Additive Technology Co., Ltd., Guangzhou, China) with an intended porosity of 85%. This was assessed by the laboratory and depended on the sequencing of printing steps and the defined temperatures. The powder layer thickness was 20 microns, and the printing accuracy was ±0.2% (Figure 5B). Smoothing and final polishing steps by a sanding machine were performed before sterilization and surgical use (Figure 5D).

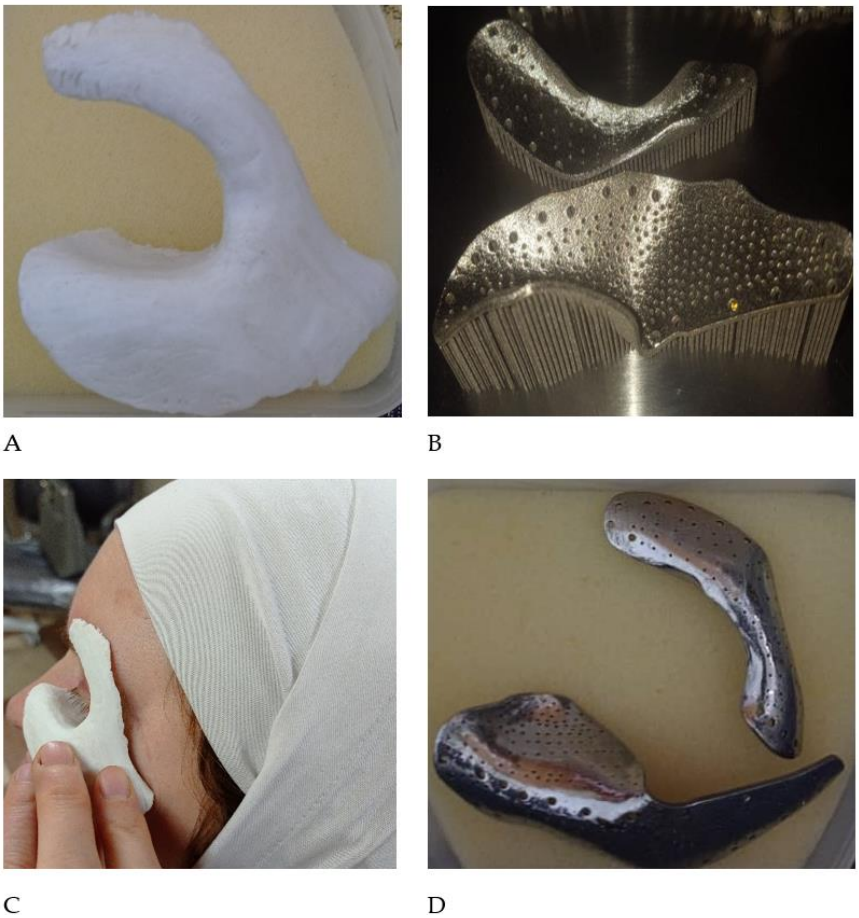


Figure 5. Physical printing of the designed PSI parts. (**A**): plastic prototype, (**B**): Metallic Titanium PSIs, (**C**): patient's communication, (**D**): PSIs after removing the supports, sanding and smoothing.

2.4. Surgical Procedure

Under general anesthesia and after sterilization and draping the patient, the surgical approach was planned in proportion to the allocated implant. An infraorbital incision was made, and an incision was made through the eyebrow, and they were connected to facilitate the surgical work and increase accessibility (Figure 6A).

The dissection was carried out in layers down to the periosteum; then, the periosteum was elevated, and the hemostasis of the bleeding blood vessels was obtained to clear the working area. All materials used in the previous treatments (silicone pieces, titanium plate, mesh, autograft bone, fixation screws, and fixation wire) were initially removed (Figure 6B), and then scraped bone protrusion was trimmed in proportion to the virtual planning to prepare the place to receive the PSIs (Figure 6C). After confirming the anatomical fit of the implants and placing them in the programmed places, they were fixed using ready-made screws (Figure 6D). Then suturing was performed in layers with the appropriate dressing, and antibiotics, analgesics, and anti-edema were prescribed.

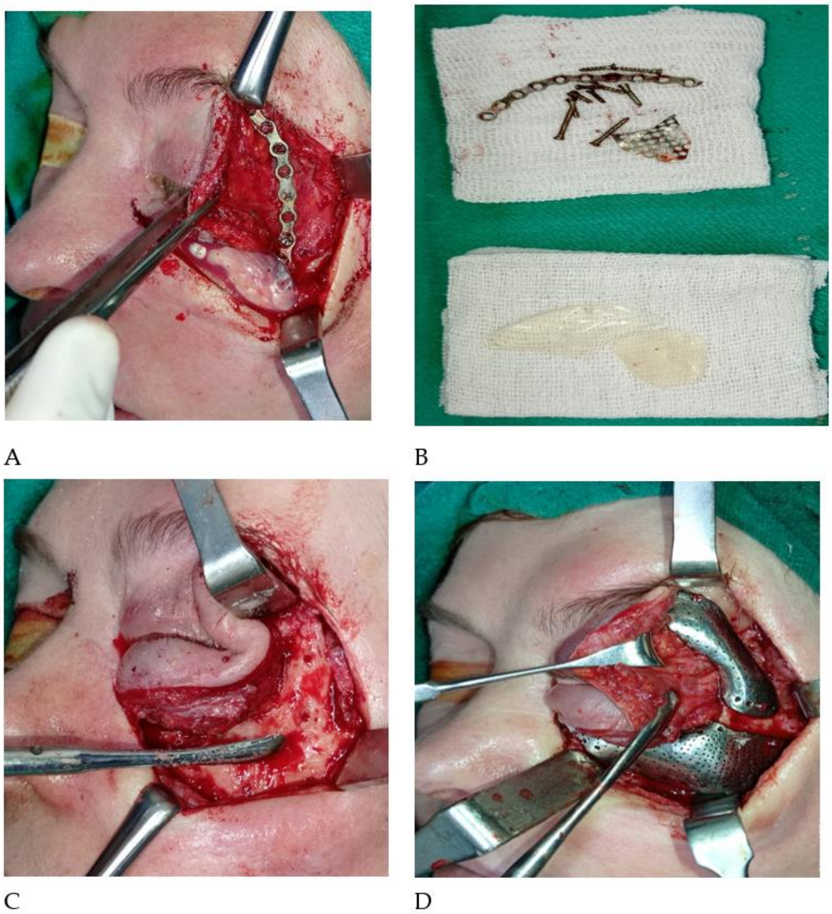


Figure 6. Surgical procedure. (**A**): surgical approach, (**B**): removal of old plates and silicon fillers, (**C**): Preparing the bone to receive the PSIs, (**D**): PSIs fixation.

2.5. Assessment and Follow-Up

The patient was followed up, and the suture was removed after 10 days (Figure 7A,B), and a CT image was requested to ensure the accuracy of the PSI (Figure 8A,B). The first surgical result was the correct positioning of the zygomatic compound, resulting in a correction of the appearance and in a reduction of the protrusion. Secondly, the PSIs seemed to fit well in their anatomical places with good integration with the surrounding region.

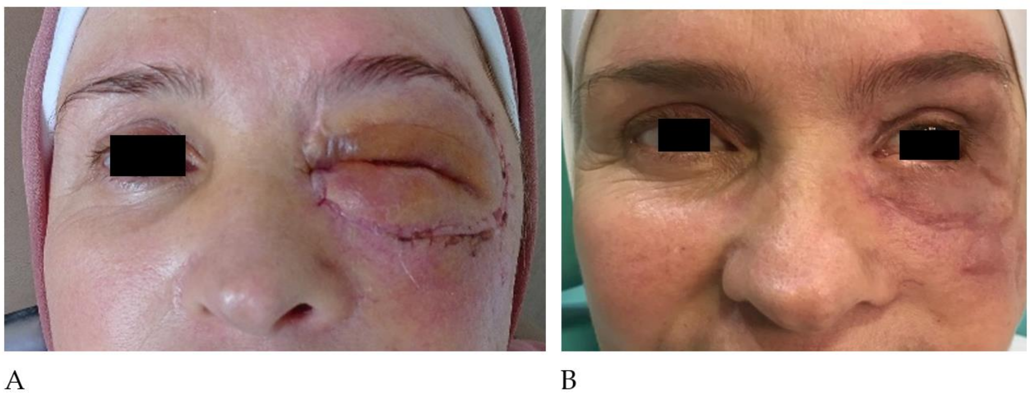
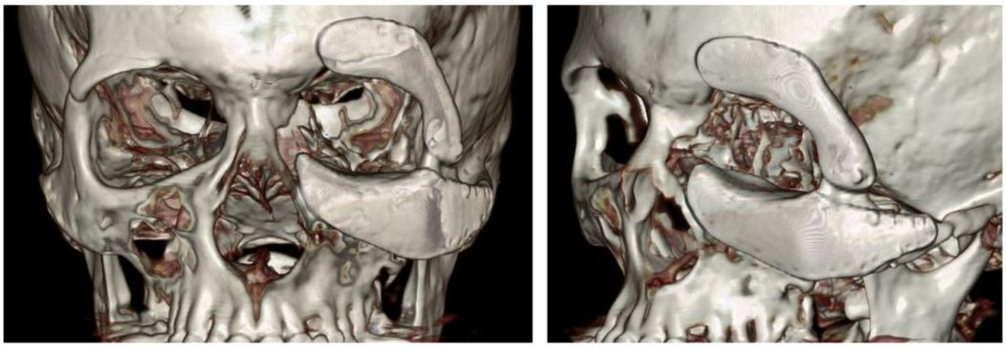


Figure 7. Post-surgical follow up. (**A**): sutures removal, (**B**): general examination and testing of orbital reconstruction and eyeball position and protrusion disappearance after 3 months.



A B

Figure 8. (**A**): Radiologic examination of prosthetic positioning and integration, (**B**): inclined view to assess plates' bone osteointegration.

3. Discussion

We presented a case of a female patient in her fifties who had been in a traffic accident ten years ago, leading to an orbital injury. This was treated with a series of several failed interventions without a satisfactory cosmetic and functional result.

The treatment was carried out by several methods, starting with prefabricated titanium plates and meshes that were adapted in the operating room, which have proven their worth in treating such cases over decades but the problem was in the ability to adapt them appropriately and the ability to approach the anatomical shape of the affected area [9].

Autograft bone was then applied, as it is currently considered the gold standard. However, this technique is associated with numerous problems as it is difficult to form the graft in the appropriate anatomical shape, as well as the insufficient quantity of the graft sometimes, and the problems related to the absorption of the graft led to the disappearance of this technique [10].

Kanno et al. discussed the use of composite sheets and silicone pieces to restore the shape of the injury. Unfortunately, these treatments did not seem to achieve the desired goal, as they are not able to reconstruct the shape of the anatomical area [11–13].

When studying the case to make a treatment plan, we found that there was a displacement in the position of the zygomatic compound and that the main problem was recognized as the first treatment was carried out wrong, and the zygomatic bone was not placed correctly. This influenced the appearance of all adjacent anatomical elements and caused a problem on the lateral wall of the orbit, the lower edge of the orbit, and the emergence of the lateral nose.

Since the injury was very old, breaking and restoring the bone was representing a great challenge [14], so the treatment plan was decided based on removing all the previous materials and even the bone graft, causing a protrusion under the orbital edge instead of being to the lateral of it.

Podolosky et al. demonstrated a novel method to more precisely reconstruct the orbital fractures using patient-specific implants (PSI), leading to a better re-approximation of the shape and excellent stability properties [15].

Replacing all of this with printed titanium PSIs, which are characterized by the possibility of designing them virtually with an inner surface similar to the area on which it will be fixated and an outer surface with anatomical details that recreate the exact anatomy of the affected area [16].

Sukegawa et al. proposed a navigation system to help in guiding safer and more accurate interventions in oral and maxillofacial surgery. This system seemed to be promoting the orbital trauma reconstruction [17].

The use of bio acceptable titanium, which is known for its good biomechanical properties, greatly contributes to the increase in the demand for this type of treatment [18].

The planning and virtual design enhances the established treatment plan and gives us a prediction of the obstacles that may be faced during the surgery, and effectively reduces the time of the surgical work [19].

3D printing, whether in its initial form using plastic materials or in its final form using titanium, facilitates the process of communication with the patient and the work team and helps with explanation and education [20].

All these advantages do not prevent the existence of constant concern about the existence of any virtual error related to the accuracy of the x-ray images used in designing the case and the possibility of it being different from reality or the non-applicability of the PSI to the place of reception [21].

Reconstructing the area in an anatomically accurate way contributes in a large extent to restoring the function well and returning the cosmetic aspect. Even in the event of problems in the soft tissues, cosmetic treatments will not give the desired results without adequate support below them [22]. The ability to restore the area to what it was before the injury occurred, helps to restore the patient's self-confidence and improve the quality of life related to health, and thus the practice of social and functional activities well and effectively [23].

Through this case, a comparison was made between several treatment options that were used for the same case at different stages of time, despite the effectiveness of these treatments in specific cases, and how they failed in achieving the requested result.

4. Conclusions

Treatment with Titanium PSIs, designed and manufactured with the aid of computers, seems to enable a precise reconstruction of complex orbital fractures with rim involvement. Implants that are designed to fit in the exact anatomical position of the orbit yielded excellent outcomes. The time spent on a case and pre-surgery planning was all reduced thanks to computerized programs and manufacturing machines, especially in the case of the integrity of the opposite side used in PSI design.

More studies on the alloys' mechanical properties and the influence of pore sizes and porosity rate in changing the osteointegration and plates' stability should be performed in the nearest future.

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Informed Consent Statement: The patient provided an informed consent statement.

Data Availability Statement: Data are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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