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CASE REPORT

Craniofacial

Orbital Remodeling and 3-dimensional Printing in Delayed Orbital Floor Fracture Reconstructions

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Summary: The mechanism and physiology of orbital cavity remodeling after orbital fractures is not well described. This poses a challenge in the delayed operative treatment of orbital floor fractures due to variations from expected anatomy and may risk injury to critical structures during exploration as well as misguided reconstruction, causing persistent ocular dystopia. We report a case where significant orbital remodeling caused unexpected challenges to orbital floor reconstruction, highlighting the need for further research in this field. A 23-year-old previously healthy man was treated conservatively for a left orbital floor fracture sustained during a rugby match. At a 4-month follow-up, the patient was found to have significant ocular dystopia with vertical diplopia and cosmetically significant enophthalmos. A discrepancy of 4 mm was noted on exophthalmometry. Intraoperatively, the neo-floor was found to have fully healed but with significant downsloping angulation and clinically appreciable depression. Furthermore, no fracture ledges were able to be used to guide the height of the titanium reconstruction plate, posing a significant challenge. Therefore, a 3-dimensional printed model of the orbit using a recent computed tomography scan was used to conform the plate to the required dimensions. The patient made a good recovery without ocular symptoms. Fracture remodeling of the orbital cavity is poorly described and may not be considered in the delayed treatment of orbital fractures. Further research to describe the mechanism and pattern of how this occurs is necessary. Computer-assisted design with 3-dimensional printing is a useful tool that can help overcome technical challenges in complex maxillofacial cases. *(Plast Reconstr Surg Glob Open 2025;13:e6772; doi: 10.1097/GOX.0000000000006772; Published online 5 May 2025.)*

The dynamics of remodeling in orbital floor fractures, particularly in cases managed with delayed reconstruction, remains underexplored in the existing literature and merits a more in-depth investigation. The Laplace law states that wall stress is directly proportional to radius and inversely proportional to wall thickness. Thus, the orbital floor, being a thin, curved structure, is particularly susceptible to fractures.[1] The gold standard for diagnosing orbital trauma is noncontrast computed tomography facial bones (CTFB). Surgical indications are either acute or subacute. Acute indications include soft-tissue entrapment or large retro-orbital hematomas that elevate ocular pressure. Subacute indications aim to minimize long-term risks of enophthalmos or hypoglobus caused by large defects with herniated orbital contents.[2,3] Orbital fat, whether conal or extraconal, plays a key role in stabilizing the globe and preventing displacement. Fractures causing fat prolapse can exacerbate enophthalmos and diplopia. Orbital volumetry is vital in diagnosing dystopia and enophthalmos, helping assess fracture severity and degree of enophthalmos. However, in many

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The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding authors upon reasonable request. The data are located in a controlled access data storage at Liverpool Hospital. Access to medical records and software is provided by Liverpool Hospital as part of routine clinical practice.

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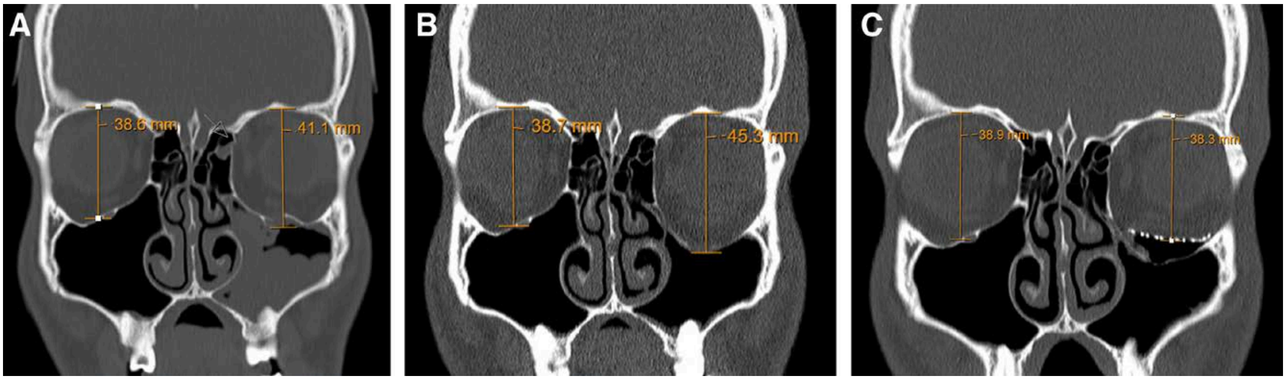

Fig. 1. Coronal CTFB scans with vertical mid-orbital measurements (mm), taken posttrauma at 2 weeks (L: 41.1 mm; R: 38.6 mm) (A); 4 months (L: 45.3 mm; R: 38.7 mm) (B); and postoperatively at 5 months (L: 38.3 mm; R: 38.9 mm) (C). L, left; R, right.

cases, the risk of globe malposition is not immediately evident. Remodeling can occur weeks or months posttrauma, altering the orbital anatomy and complicating treatment decisions. We present a 23-year-old man with orbital floor remodeling, initially managed conservatively, and our approach to delayed reconstruction using 3-dimensional (3D) printing. To our knowledge, such a case has not been previously documented.

CASE PRESENTATION

A 23-year-old man presented with vertical gaze diplopia and ocular pain 2 weeks post left orbital floor fracture, sustained playing rugby. Examination showed minor bruising, slight enophthalmos, and normal ocular movements, with no neurological deficits. Initial CTFB (Fig. 1A) revealed a left-inferior orbital wall fracture with infraorbital canal involvement, prolapse of the inferior rectus muscle and orbital fat, and additional nondisplaced medial and lateral wall fractures. The Hertel exophthalmometry readings were symmetrical (left: 19 mm; right: 19 mm), and conservative management was advised.

At 4 months, the patient reported worsening diplopia, blurry vision, and vertical dystopia. Examination showed worsening enophthalmos (left: 15 mm; right: 19 mm). Repeated CTFB (Fig. 1B) revealed significant inferior bowing of the orbital floor and herniation of soft tissue. Intraoperatively, a solid and stable orbital floor was noted in the anterior 19 mm before dipping into a large floor defect. After examining the 3D model and computed tomography, it became clear that the "solid" anterior orbital floor was remodeled after the fracture and did not reflect the true level of the original floor. Moreover, no fracture ledges were able to be used to guide the height of the Medpor Titan plate, complicating positioning.

A 3D-printed model tailored to the original defect allowed for plate conformation to the required dimensions. (**See appendix, Supplemental Digital Content 1**, which displays a 3D model software workflow, **http://links.lww.com/PRSGO/E20**.) Postoperative recovery was uneventful, with complete resolution of diplopia, satisfactory cosmesis, and significant improvement in enophthalmos (left: 16 mm; right: 17 mm) at 3 months (Fig. 1C).

DISCUSSION

A conservative approach with clinical follow-ups and repeated exophthalmometry is often used in cases of small or equivocal orbital floor fractures. Surgical intervention is considered if enophthalmos develops.[4] This case demonstrates that significant remodeling can occur even with fractures that initially appear minor on CTFB. The orbital floor varies anatomically, often sloping upward from the orbital rim with a variable dip behind the infraorbital rim. Surgeons must consider individual anatomical variations, as a remodeled floor can deceptively resemble the normal one, potentially leading to undercorrection and persistent enophthalmos.

The stages of bone healing involving inflammation, reparation, hard callus formation, and remodeling inherently influence reconstruction. (**See appendix, Supplemental Digital Content 2**, which displays the physiology of orbital remodeling, **http://links.lww.com/PRSGO/E21**.) If treated nonsurgically, the orbital floor fracture heals in its new position via fibrous union, involving the laying down of scar tissue that is later subject to shrinkage. Such a phenomenon of cicatricial anchorage could be purported to result in inferiorly displaced healing of the orbital floor.[5] In unilateral fractures, comparing the injured side to the uninjured side is crucial for assessing remodeling. A well-healed remodeled floor may be mistaken for the true floor, but 3D models can help prevent this.

Current materials for orbital floor reconstructions include autologous calvarial bone grafts, titanium mesh, Medpor, and Medpor Titan.[6] Surgeons typically shape premanufactured implants by referencing the injured orbital floor, but this method risks undercorrection if unaware of remodeled neo-floors. Routine CTFB scans to identify such changes are not standard practice due to cost, yield, and irradiation concerns.[7] To reduce undercorrection, surgeons can use 3D-printed models designed from CTFB data, which allow the shaping of implants both pre- and intraoperatively (Fig. 2). These models also aid in patient education and communication.[8] Revision surgery due to undercorrection can be costly, often reaching $2000 per hour, excluding implants, with additional time lost for the patient, family, and surgeon. In contrast, 3D modeling

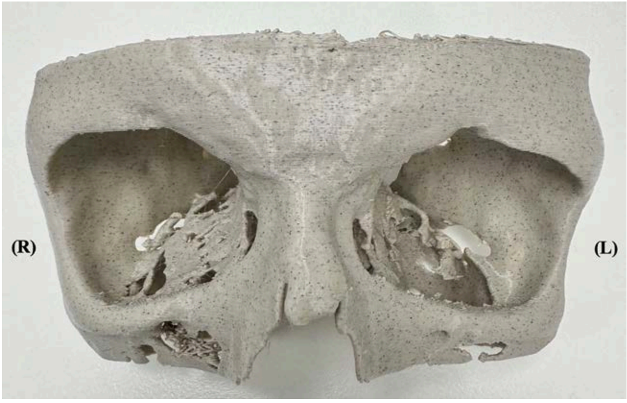

Fig. 2. 3D-printed model of the orbital floor based on preoperative CTFB scans at 4 months. Our 3D model was constructed using digital imaging and communications in medicine data from CTFB with 2 mm layer thickness and 512 × 512 resolution, processed with 3D Slicer and Meshmixer software (30–60 min). See Supplemental Digital Content 1 (**http://links.lww.com/PRSGO/E20**) for further details on workflow. Using a Prusa-3D MKS3+ printer (10 h) and sterilization with V-Pro gaseous H_2O_2 (3 h), the model costs A$15–25 and is ready within 2–3 days. Preoperatively, a surgical team member studies the model, comparing both orbits. A titanium mesh is shaped ex vivo to restore orbital volume, considering insertion ease and anchoring points. Once molded satisfactorily, it undergoes heat sterilization. Intraoperatively, the premolded mesh is trialed on the model before insertion. If trimming is needed, the mesh is removed, adjusted, and checked against the 3D model before reinsertion. This ensures precise reconstruction while minimizing intraoperative adjustments for optimal orbital restoration. L, left; R, right.

typically costs less than $100, providing a cost-effective alternative to reoperation.

To improve precision, symmetry, and operating time, a mirroring technique can be used. By using CTFB data from the uninjured side, a mirrored 3D skull is printed, and the implant is shaped around it. Computer-aided design/computer-aided manufacturing also allows for the printing of a patient-specific implant. The mirrored implant can be inserted with minimal reshaping, reducing implant fatigue, soft-tissue edema, and operative time.[9] This contrasts with traditional methods, which require repeated reshaping, withdrawals, and retrimming. However, patient-specific implants are around US $3000 versus US $300 for standard implants.[10]

This case highlights how an orbital floor fracture initially deemed minimally displaced by the treating clinician may remodel over time and require future surgery. With resource limitations and/or a desire to avoid unnecessary radiation exposure, patients typically have an initial CTFB to assess the fracture but may not have follow-up CTFB. Instead, follow-up assessment is with exophthalmometry and clinical examination. Surgery is considered if significant enophthalmos ensues but not necessarily with repeated CTFB. It would be assumed that soft-tissue prolapse/herniation has increased over time, leading to loss of globe support posteriorly. In such a situation, the traditional approach involves the operating surgeon exposing the orbital floor of the injured side and inserting a manually molded mesh using the remnant solid stable bony floor as reference point(s). This case highlights a pitfall in this approach where the unaware surgeon may not necessarily recognize that the "intact" floor remnant is not in the correct anatomical position due to remodeling of the orbital floor postinjury. An orbital floor displacement of even 1 mm can shift volume by over 1 cm^3, depending on implant size. Further research to describe the mechanism of how this occurs is necessary, potentially requiring more routine pre-/postoperative CTFB, the practicality/cost-benefit of this remaining open to further debate. Computer-aided design with 3D printing is a useful tool that can help overcome technical challenges in complex maxillofacial cases.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

PATIENT CONSENT

Written informed consent for publication of their clinical details and/or clinical images/scans was obtained from the patient. A copy of the written consent is available for review by the editor-in-chief of this journal on request.

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