Virtual Planning and 3D Printing in the Management of Acute Orbital Fractures and Post-Traumatic Deformities

Basel Sharaf, MD, DDS, FACS[1] Daniel E. Leon, MD[1] Lilly Wagner, MD[2] Jonathan M. Morris, MD[3]
Cristina A. Salinas, BS[1]

[1] Division of Plastic Surgery, Mayo Clinic, Rochester, Minnesota
[2] Department of Ophthalmology, Mayo Clinic, Rochester, Minnesota
[3] Department of Radiology, Anatomic Modeling Unit, Mayo Clinic, Rochester, Minnesota

Address for correspondence Basel Sharaf, MD, DDS, FACS, Division of Plastic surgery, Department of Surgery, Mayo Clinic, 200 First Street SW, Rochester, MN 55905 (e-mail: sharaf.basel@mayo.edu).

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Abstract

Virtual surgical planning (VSP) and three-dimensional (3D) printing have advanced surgical reconstruction of orbital defects. Individualized 3D models of patients' orbital bony and soft tissues provide the surgeon with corrected orbital volume based on normalized anatomy, precise location of critical structures, and when needed a better visualization of the defect or altered anatomy that are paramount in preoperative planning. The use of 3D models preoperatively allows surgeons to improve the accuracy and safety of reconstruction, reduces intraoperative time, and most importantly lowers the rate of common postoperative complications, including over- or undercontouring of plates, orbital implant malposition, enophthalmos, and hypoglobus. As 3D printers and materials become more accessible and cheaper, the utility of printing patient-specific implants becomes more feasible. This article summarizes the traditional surgical management of orbital fractures and reviews advances in VSP and 3D printing in this field. It also discusses the use of in-house (point-of-care) VSP and 3D printing to further advance care of acute orbital trauma and posttraumatic deformities.

Keywords

- virtual surgical planning
- three-dimensional printing
- orbital fracture
- orbital reconstruction
- point-of-care

Virtual surgical planning (VSP) and three-dimensional (3D) printing have gained greater utility in the field of orbital reconstruction. Three-dimensional printing of customized models of patients' orbital anatomy provides the surgical team with an additional view of the defect and surrounding structures. The basic process includes converting medical images from various modalities (computed tomography [CT], magnetic resonance imaging, etc.) into digital files that can be printed on 3D printers. Both bone and soft tissue have been successfully printed from low-cost desktop 3D printers.[1] The main limitation in the process of 3D printing is outsourcing to third-party companies, making the process less efficient and less feasible in the setting of acute orbital fractures. Incorporating VSP and 3D printing at the point-of-care offers the advantage of having VSP and 3D printing expertise in proximity to the surgeons at the treating hospital. When expedited treatment is needed, the process from imaging to printing patient-specific models can be accomplished in 24 to 48 hours.[2]

Overview of the Traditional Approach to Acute Orbital Trauma

Types of Orbital Fracture and Indications for Surgery

Although there is no consensus classification system in use for trauma to the orbital skeleton, orbital traumas can be divided into pure and impure fractures. Pure orbital fractures involve a single wall of the bony orbit such as the medial wall

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or the floor. Impure orbital fractures involve segmental lower orbital rim and adjacent facial bones, such as nasomaxillary, zygomatic, maxillary, and nasoethmoid bones. Blowout fractures involve the medial wall or floor of the orbit, and often result in expansion of the orbital volume. Blow-in fractures are often caused by high impact damage to the lateral wall or roof and can decrease the orbital volume.[3] Indications for surgical repair of orbital fractures include trap door mechanism with soft tissue incarceration, ocular motility restriction, persistent diplopia, globe malposition, or significant enophthalmos. The goals of fracture repair are restoring orbital volume and unrestricted extraocular muscle function, maintaining symmetric globe position with the contralateral side, and preventing long-term sequalae and facial disfigurement.[4–7]

Surgical Approaches to the Orbit

Current techniques used to gain access to the orbit emphasize exposure while resulting in a more cosmetically concealed scar and preservation of normal eyelid function and position. The choice of orbitotomy incision type varies based on the specific fracture pattern, extent of exposure needed, and associated soft tissue injuries. Approaches to the lower eyelid include subciliary, subtarsal, and transconjunctival. For a subciliary approach, the incision is made below the lash line and can be skin only or skin and muscle. The transconjunctival approach is often preferred as it does not produce a visible scar, has low complication rates, and can be combined with a lateral canthotomy via either a retroseptal or preseptal approach for increased exposure. The medial wall is most commonly accessed by a transcaruncular approach, which can be combined with a transconjunctival approach. The orbital roof and lateral wall can be approached via an extended upper blepharoplasty excision. Each method of orbital exposure carries its own advantages and limitations which must be taken into consideration when choosing an incision. Regardless of the approach chosen, repair proceeds with exposure of the orbital rim and bony wall in a subperiosteal plane, identification and protection of neurovascular structures, reduction of herniated soft tissue, and visualization of the entire orbital defect[8] (**►Fig. 1**).

Types of Orbital Implants

Several alloplastic materials are available for reconstructing simple, single wall defects, such as Medpor (Stryker, MI), polytetrafluoroethylene (PTFE), silicone, preshaped titanium plates (Synthes/DePuySynthes, KLS Martin, Stryker), titanium mesh, and resorbable materials such as polydioxanone sulfate membrane (Ethicon, Norderstedt, Germany).[8,9] Bone grafts were used in the past but have been associated with unpredictable resorption rates and increased donor site morbidity, thus limiting their current use in favor of alloplastic material.[10,11] Medpor is a nonresorbable, porous polyethylene implant that is easy to shape and has had similar results as bone tissue with fewer infection rates.[9] Titanium mesh implants have been used since 1992 to correct orbital wall fractures of moderate to large size and have the advantage of being radio-opaque and radiologically visible. The main complication of titanium mesh is difficult removal in cases of infection due to tissue growing within the gaps of the mesh. PTFE and silicone are not commonly used because of risk of extrusion that can occur up to 21 years after placement. Resorbable materials are used for pediatric patients due to their low immune reactivity and high biocompatibility. Patient-specific implants (PSIs) are particularly useful in complex orbital fractures and provide a precise implant based on the contralateral orbit. While these alloplastic materials offer biocompatibility, stability, and safety, one disadvantage they all share is cost, which will be discussed later.[8,12,13]

Advantages of PSIs

PSIs are used for apical, skull base fractures, defects that are too large or complex for prefabricated implants, and when additional bulk is needed to correct orbital volume or globe position. The normal orbital cavity is virtually planned by mirroring the normal side onto the fracture side. After normal orbital volumes are calculated and the contour and thickness of the implant are designed, the implant can be 3D printed. PSIs can be made using various materials, including titanium, Medpor, and polyetheretherketone (PEEK). PEEKs are highly biocompatible, durable, and fatigue resistant, but only a few studies have reported their use in orbital implant reconstruction.[14] The efficiency of PEEK PSIs was compared with that of prebent titanium implants in the reconstruction of posttraumatic orbital wall fractures. Postoperative diplopia was seen in 17.9% of patients treated with PEEK PSIs and 29.4% of patients with prebent implants. Intraoperative time was shorter in the PEEK PSI group, with an average of 54.25 minutes, compared with 82.9 minutes in the prebent implant group. Finally, the average difference in orbital volume between the fractured and normal orbits was 0.74 cm^3 in the PEEK PSI group, which was lower than 1.9 cm^3 in the control group.[15] PSIs are also used in pediatric cases. Akiki et al described the case of a 7-year-old girl who was in a motor vehicle collision and experienced an orbital blowout fracture involving the medial wall and floor of the orbit. A 3D model was used as the defect was large and provided the surgeons with a better understanding of the space it would have to fill. Resorbable material was used for this case because she had not reached skeletal maturity. At the 18 months' follow-up, the authors reported no complications and normal eye projection.[16]

Three-dimensionally printed PSIs and models have been shown to be anatomically accurate. Schön et al demonstrated that PSIs were accurate within a 1-mm range on postoperative CT scan.[17] In this study, the accuracy of the 3D orbital reconstruction was determined via image fusion of the postoperative CT and the preoperative virtual plan, and measuring the absolute maximal distances in the axial, coronal, and sagittal planes.[17] Blumer et al found a mean difference of 0.6 mm between the virtual and surgical reconstructions, with a mean maximal distance of 3.4 mm. In this study, the accuracy of the reconstruction was determined by superimposing the postoperative 3D image onto the preoperative virtual reconstruction.[18] These two studies

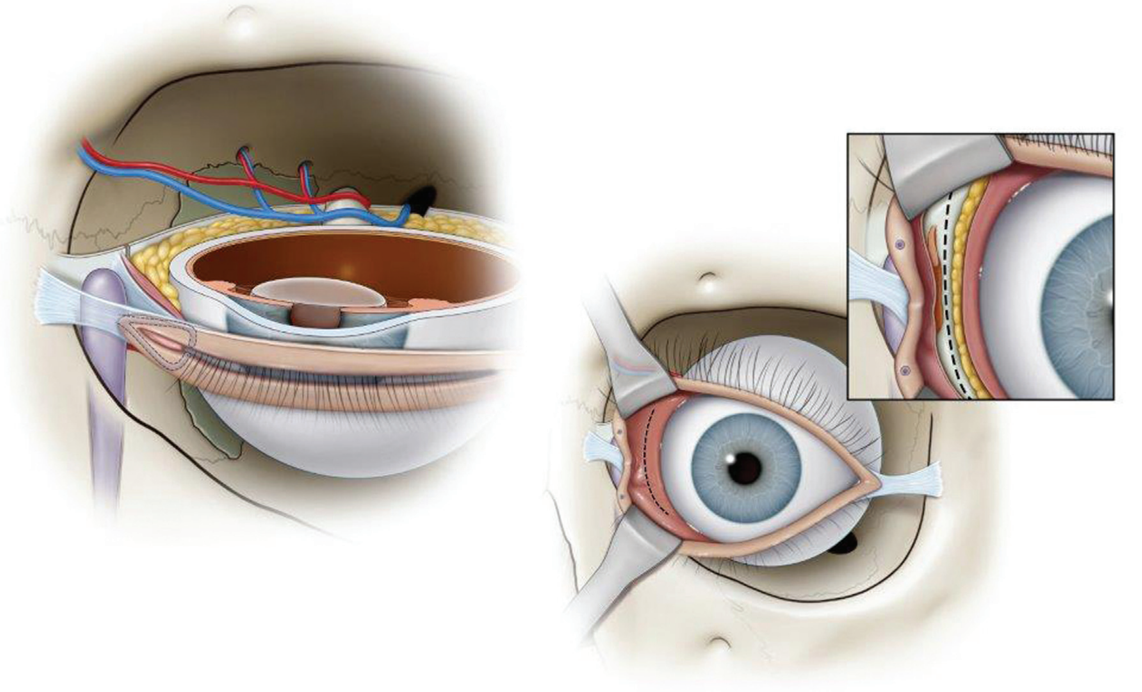
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Fig. 1 Transcaruncular approach to the medial orbit may be necessary to access the medial wall and can be combined with a transconjunctival lower eyelid incision to access the floor when necessary.

calculated surgical error using different techniques and so cannot be directly compared, but both demonstrated that PSIs are able to obtain precise results. In another study, the accuracy of the 3D models and two-dimensional CT images was compared and found to have a difference of < 1 mm that was not statistically significant.[19] The accuracy of these models translates into fewer postoperative complications. Other advantages to custom 3D-printed implants are shortened intraoperative times, reduced length of anesthesia, and greater precision in restoration of orbital volume to match the unaffected orbit.[9] In addition, the revision rates of orbital reconstruction using 3D-printed models and PSI were lower compared with reconstruction with standard implants.[20]

One of the challenges to using PSIs has been cost. The cost of standard implants depends on the material used. Medpor Titan Mesh (Stryker) prices ranged from $20,000 to $29,000, 3D preformed implants (Stryker) ranged from $42,000 to $50,000, MatrixORBITAL (Synthes, PA) ranged from $33,000 to $40,000, and RapidSORB (Synthes) ranged from $35,000 to $39,000.[21] While no systemic review has directly compared the cost of PSIs and preformed standard orbital implants, several studies point to the increased cost of PSIs as a limitation.[22–24] However, 3D printing technology is becoming more widespread and low-cost 3D printers have been shown to be reliable. PSIs can cost between $2,000 and $14,000, but their accuracy and low revision rates must also be taken into account when considering long-term costs.[25]

Posttraumatic Orbital Deformities

Posttraumatic orbital anatomy can be altered due to scar tissue, atrophy of orbital fat, and bony remodeling of fractures, making exposure of orbital wall defects challenging. Inadequate visualization of the orbital wall defect and important landmarks may result in overcontouring or malpositioning of implants.[11,20] Long-term complications can result from orbital fractures as well as orbital reconstruction because of inaccurate reduction of fractures, orbital volume enlargement, or hardware malposition. Diplopia can develop due to extraocular muscle restriction, scarring, or plate malposition. Eyelid retraction, ectropion, entropion, and enophthalmos are common indications for secondary reconstruction of posttraumatic deformities.[4,20] Vision loss can occur due to optic nerve compression during orbital fracture reconstruction or from postoperative retrobulbar hemorrhage. While retrobulbar hemorrhage is a rare complication, it presents the patient and the surgeon with an emergency. In a review of orbital wall repair cases from 1983 to 1994, retrobulbar hemorrhage was reported in 0.32% of 1,240 cases, with 50% of those cases resulting in permanent vision loss.[26] In a later review, retrobulbar hemorrhage was seen in 0.17% of 1,180 cases from 2006 to 2011, with 50% of those cases also resulting in permanent blindess.[27] More recently, retrobulbar hemorrhage was encountered in 1.15% of 261 cases from 2011 to 2019. Of those cases, 33% had permanent vision loss.[28]

Timing of Orbital Fracture Repair

Timing of repair of orbital fractures is also an important factor when discussing potential postoperative complications because delaying repair can lead to permanent damage.[29] The Burnstine criteria have been used to determine optimal timing of orbital fracture repair. Immediate intervention is recommended for early enophthalmos (> 2 mm) or hypoglobus causing facial asymmetry, diplopia with CT evidence of entrapped muscle or periorbital tissue associated with a nonresolving oculocardiac reflex, or a "white-eyed blowout fracture" in pediatric patients. Intervention is often delayed in patients with orbital floor fractures to allow for resolution of initial edema. Surgical intervention within 2 weeks is recommended if more than 50% of the orbital floor is depressed, causing latent enophthalmos or globe ptosis, or if there is progressive infraorbital hypesthesia. In cases with minimal diplopia or enophthalmos and good ocular motility, observation is preferred.[30] However, there are other factors besides the size of orbital floor involvement that deserve consideration when evaluating whether to intervene surgically. Alinasab et al proposed a new algorithm based on herniated orbital volume and other CT scan findings for the prediction of late visible deformities, such as superior sulcus deformity, hypoglobus, and enophthalmos. This algorithm had 83% accuracy, which increased to 91.5% if patients were followed up at interval times. Based on the new criteria, patients have high risk of late visible deformity in an inferior blowout fracture with < 1 mL herniation and a ratio between fracture area and orbital wall area of > 42%, or a fracture area of > 2.3 cm^2; inferior blowout fracture with > 1 mL herniation and > 3 cm distance from inferior orbital rim to posterior edge of the fracture; or inferomedial wall fracture with > 0.9 mL of herniation.[31] A recent review also found five factors that contribute to the development of delayed enophthalmos, including linear measurements of the fracture, involvement of specific intraorbital structures, rounding of the inferior rectus muscle, orbital fracture area, and orbital volumetric changes.[32]

Enophthalmos

Enophthalmos occurs when there is inadequate restoration of orbital volume, resulting in a discrepancy between orbital soft tissue volume and volume of the affected bony orbital cavity. This may result from soft tissue herniation into a paranasal sinus, muscular or periorbital atrophy, fat tissue necrosis, and orbital implant malposition.[4,10,11] Medial orbital wall and combined medial-inferior orbital wall fractures have the highest association with enophthalmos. He et al reported that out of 71 patients with enophthalmos, 76% had medial wall fractures and 53% had a combined medial-inferior wall fracture.[33] In surgical correction of enophthalmos, the goal is to restore orbital anatomy, volume, function, and aesthetic appearance.[10]

VSP and 3D Printing in Management of Posttraumatic Enophthalmos

In a study by Dvoracek et al, 9 patients with acute orbital floor or wall fractures were seen at the Children's Hospital of Pittsburg, with 7 patients presenting with preoperative enophthalmos. CT scans were obtained and reconstructed using Mimics Medical v21.0 and 3-Matic Medical v13.0 (Materialise, Leuven, Belgium). Three-dimensional models of the affected side and mirrored unaffected side were printed from an in-house Formlabs Form 2 stereolithography printer (Formlabs, Somerville, MA), using 0.05-mm layer thickness and Dental SG Resin. The models served as templates for titanium plates that were to be used for reconstruction. An average of 10.4 hours was spent preparing the model and 60 seconds in plate bending.[34] This is compared with obtaining models from third-party companies and having a delivery delay of 2 to 3 days.[35] Maximum material costs were $21 per patient. Intraoperative time was decreased by approximately 50%. Of the 7 patients who started out with enophthalmos, 6 had resolution and 1 had persistent enophthalmos at 4 months of follow-up. The difference in orbital volume postoperatively between the affected and unaffected eye was insignificant.[34]

Implant Malposition

The most common indication for revision orbital surgery is implant malposition with an associated clinical symptom, such as globe malposition, vision changes, ocular motility restriction, or diplopia.[35] In a retrospective study of patients who underwent reconstruction of orbital fractures, 6.5% of 232 reconstructions required revisional surgery. The need for revision was highest in more complex fractures, such as midfacial fractures that involved the rim, and was associated with implant malposition. The study also analyzed how the implant material affected the scoring of implant position after reconstruction (good, acceptable, poor). Materials used were patient-specific milled titanium implant (PSIs) (Planmeca Ltd), bioactive glass (BAGS53P4 BonAlive Biomaterials Ltd), polylactide acid and/or polyglycolic acid polymer (PLA/PGA) (Synthes, Stryker), manually bent titanium mesh (Synthes/DePuySynthes, Stryker), and preformed 3D titanium plates (Synthes/DePuySynthes, KLS Martin, Stryker). Eighty-four and seven percent of the PSIs received a score of "good," and 100% of both the bioactive glass and PLA and/or PGA received a score of "good." This is compared with the 77.2% of the manually bent titanium mesh and 50% of the preformed 3D titanium plates that received a score of "good." Patients that underwent reconstruction with PSIs had a revision rate of 3.4%, compared with 12.9% with the preformed 3D titanium plates. PSIs and resorbable materials resulted in better positioning and lower revision rates compared with other materials.[20]

Case 1: VSP and 3D Printing in Management of Bilateral Enophthalmos and Globe Malposition

A 27-year-old male presented to our institution after multiple prior facial surgeries following an all-terrain vehicle accident 4 years prior. He continued to suffer from diplopia and enophthalmos despite previous orbital reconstruction with Medpor wedge implants bilaterally, which had both migrated anteriorly at time of presentation. He underwent CT imaging with 3D reconstruction, which was used to calculate intraorbital volumes. Previous studies have shown

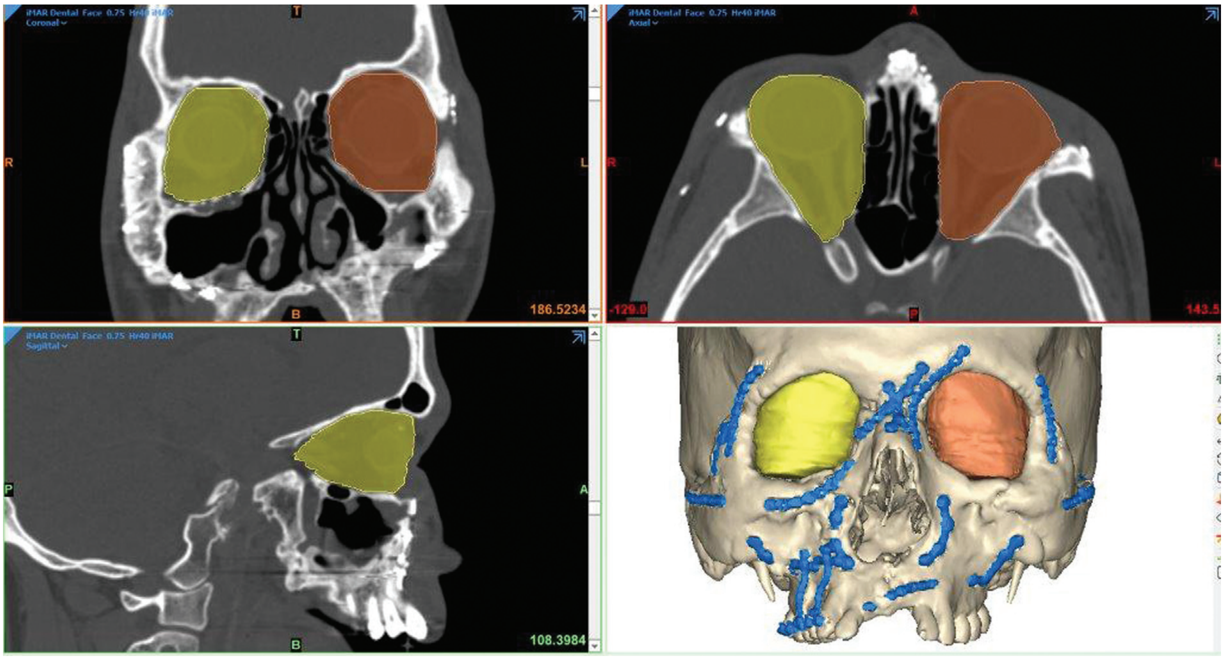

Fig. 2 Virtual measurement of intraorbital volumes prior to surgical management of enophthalmos, globe malposition, and diplopia. The calculated left orbital volume was 31.4 mL, and the right orbital volume was 30.8 mL, both significantly larger than the average male orbital volume (see text).

the average orbital volume of the male patient to be 24.9 mL.[36] The left orbital volume in this patient was found to be 31.4 mL, whereas the right orbital volume was found to be 30.8 mL, explaining the patient's enophthalmos and diplopia. The CT scans were imported into Mimics software (Materialise, Belgium). The bones of the face were segmented and transferred to 3-Matic (Materialise, Belgium). A STL file was made and transferred into Pro-plan (Materialise, Belgium). The models were printed in-house using material jetting on an Objet 500 (Stratasys, MN). The patient underwent removal of prior implants with placement of new PSIs bilaterally, resulting in significant improvement of enophthalmos and diplopia after surgery (►**Fig. 2**).

VSP and 3D Printing in Reconstruction of Orbital Fractures

The anatomy of the orbit is complex, and reconstruction can be difficult as visualization of the surgical field is limited. Noncustom implants often require shaping and trimming by the surgeon at the time of reconstruction to fit the patient's orbital anatomy, as well as repeated placement and removal to confirm correct size and shape. This extends the operative time and may increase the risk of infection.[37] VSP and 3D printing has allowed surgeons to plan corrected orbital volumes of the fracture side based on normalized anatomy. A 3D-printed model of the normalized side can be used to contour various types of orbital plates to reestablish accurate orbital anatomy and volume. Patient-specific 3D-printed models allow surgeons to visualize the deformity and bend titanium implants or do mock surgery in complex cases beforehand. The accuracy of the models also ensures correct contouring and positioning of the implant, and so decreases the risk of revisional surgery due to malpositioning.[38]

In a case series of three patients with enophthalmos due to medial orbital wall fractures, 3D reconstruction of the CT images of the defect created precise models that were used as a template for the creation of an iliac crest bone graft. Benefits were both immediate, by decreasing case complexity and operative time, and long-term, by minimizing the need for future corrections. All reported patients had correction of their enophthalmos and good postoperative outcomes.[39]

Point-of-Care (In-House) VSP and 3D Printing

Three-dimensional printing at the point-of-care offers the advantage of team learning, increased efficiency, and an expedited process of VSP and 3D printing. Hatz et al compared the accuracy of a low-cost desktop 3D printer with a professional-grade 3D printer and found that the mandible models that were created were comparable in accuracy. There are many techniques for 3D printing anatomical models, with the most common being fused filament fabrication (FFF) and selective laser sintering (SLS). While SLS technology has shorter printing times and higher printer resolution, which makes it better at printing fine anatomical structures, they are more expensive. FFF technology is cheaper, costing less than $3,000 USD, and was shown to produce suitable and accurate anatomical models requiring only minimal adjustment intraoperatively. One difference noted is that models from FFF printers are made with material that cannot be steam sterilized and so required special sterilization before use in surgery. Models printed with SLS printers can undergo steam sterilization and do not require further sterilization before use in the operating room.[35] At our institution, Ultimaker 3D printers are used, with cost ranging from $3,000 to $5,000 for a reliable model.

Printing PSIs in-house has been shown to be more cost effective than outsourcing to third parties to print. The average cost of industry-printed PSI was $1,678, whereas the average cost of printing PSIs in-house averaged $236. The cost breakdown of printing in-house came out to be $34.50 for software and disposable fees, $43.80 for segmentation, $11 for materials, $65.60 for print time fees, and $20.50 for production.[40] Thus, printing at the point-of-care can further decrease the cost of PSIs and increase their availability to patients.

Case 2: Point-of-Care VSP and 3D Printing in Acute Orbital Trauma with Inferior Rim Comminution and Floor Blowout Fracture

A 17-year-old male presented with a left orbital blowout fracture and comminuted anterior maxillary fractures after sustaining a hit by a golf ball. Symptoms included diplopia, and physical exam was notable for enophthalmos and contour depression of the left inferior orbital rim and maxilla. After a maxillofacial CT was performed (►**Fig. 3**) VSP was completed using similar methods described in case 1. Two 3D printed models were created, one being a model of the patient's skeletal deformity (►**Fig. 4A**) and the other a reconstruction of the left orbital floor, inferior rim, and anterior maxilla using a mirror image of the normal right orbital and maxillary anatomy (►**Fig. 4B**). The process of VSP and 3D printing of the two models was accomplished at the point-of-care. The surgical procedure was completed through a combined transconjunctival and transoral approach. The 3D printed model was utilized intraoperatively to contour the orbital floor implant (►**Fig. 4C**). The 3D printed model was used to contour

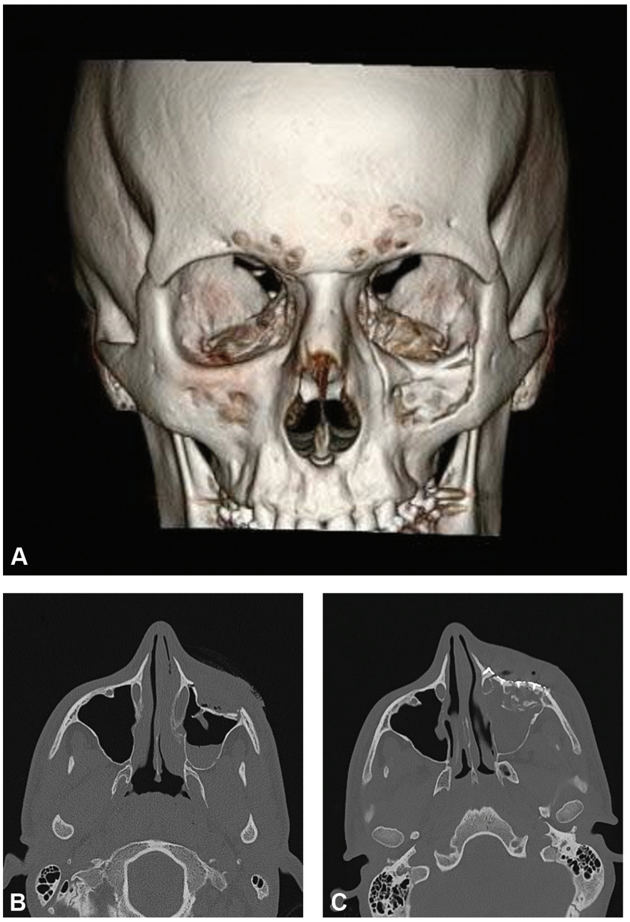

Fig. 3 (**A**) Maxillofacial CT with 3D reconstruction demonstrating the comminuted nature and contour deformity of the left inferior orbital rim and anterior maxilla. (**B**) and (**C**) demonstrate the contour deformity of the left rim and anterior maxilla prior to and after open reduction and internal fixation of fractures using VSP and 3D printing.

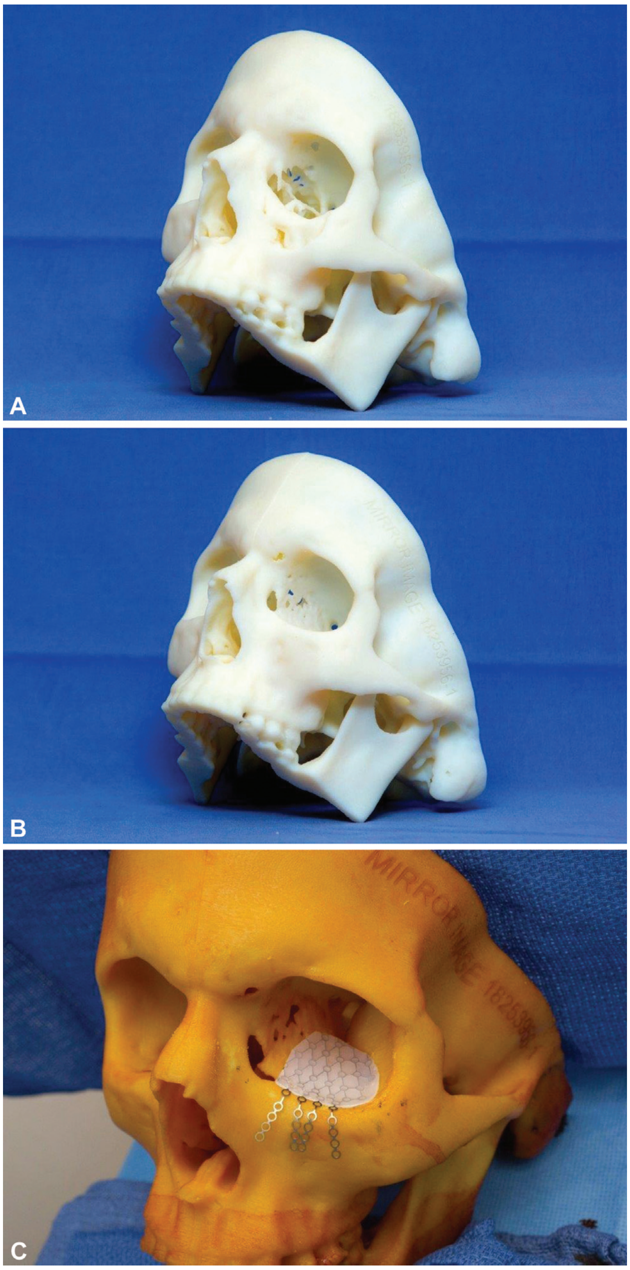

Fig. 4 (**A**) Printed 3D model of the traumatized facial skeleton showing left orbital floor blowout fracture with inferior rim comminution. (**B**) Printed 3D model at the point-of-care after VSP with left orbito-maxillary anatomy created by mirroring the normal right side onto the left side. (**C**) 3D printed model used intraoperatively to contour the orbital floor implant.

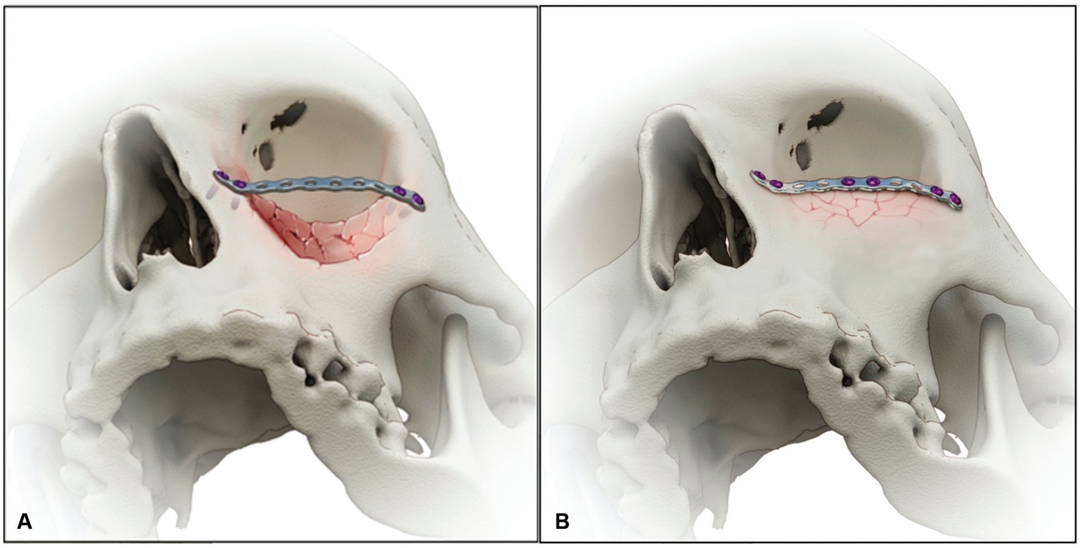

Fig. 5 An illustration of VSP using a precontoured plate based on perfected anatomy. (**A**) Plate fixated medially and laterally on unaffected bone prior to reduction of rim fractures. The plate was used as a guide to reestablish accurate symmetry and contour with the right side. (**B**) After reduction and fixation of the inferior rim fractures.

the inferior orbital rim plate pre-operatively. The pre-contoured plate to the perfected anatomy (►**Fig. 5A**) was sterilized and used intraoperatively as a guide to help reduce and fixate the bony fragments (►**Fig. 5B**). The patient had a successful outcome with restoration of globe and bony symmetry at 13 months follow-up.

3D Printing for Resident Education on Orbital Anatomy

Three-dimensionally printing models offer an additional platform in resident surgical education. These models serve as reusable visual teaching aids to enhance hands-on learn-

Fig. 6 Three-dimensional (3D) printed models enhance resident education. The surgical anatomy is reviewed and when necessary, plates are bent preoperatively or mock surgery can be performed ahead of surgery in complex cases.

ing experiences, such as live surgeries and cadaver dissections. They have been shown to enhance visual-spatial skills by providing immediate feedback, improve memory of procedures, and allow for preparation with a realistic model prior to the day of surgery.[41] The use of 3D-printed models in the teaching of orbital anatomy is especially helpful as orbital anatomy is complex and there is a restricted field of view during surgery that makes intraoperative teaching difficult. Vatankhah et al performed a study in which 24 ophthalmology residents in years 1 and 2 at Mashhad University of Medical Sciences in Iran were randomized into two groups of learning. One group trained with traditional methods and the other group with 3D-printed models of fractures and congenital abnormalities. Pretest and posttest scores were compared with measure knowledge enhancement 3 and 14 days later. The posttest scores of students who learned with 3D-printed models were higher than the scores of students in the traditional learning group. Interestingly, the use of 3D models in teaching was more effective in year 1 residents than year 2 residents, as evidenced by their posttest scores.[41] Three-dimensional models for resident education have been shown to improve residents' learning in a concrete way by improving test scores but also stimulate interest and curiosity in their field of study (►**Fig. 6**).

Conclusion

VSP and 3D printing have advanced the field of orbital fracture reconstruction by providing surgeons with precise anatomical models for preoperative planning and decreasing postoperative complications. Integrating VSP and 3D printing at the treating hospital has further cut down time to operation by eliminating third-party outsourcing and decreased the overall cost. Low-cost desktop 3D printers were shown to be comparable in accuracy with more expensive professional-grade 3D printers. As VSP and 3D printing become more widely used and accessible, the treatment and outcome of acute complex orbital fractures will be elevated as a new gold standard emerges.

Conflict of Interest
None declared.

References

1 Shui W, Zhou M, Chen S, et al. The production of digital and printed resources from multiple modalities using visualization and three-dimensional printing techniques. Int J CARS 2017;12 (01):13–23

2 Sharaf B, Kuruoglu D, Cantwell SR, Alexander AE, Dickens HJ, Morris JM. EPPOCRATIS: expedited preoperative point-of-care reduction of fractures to normalized anatomy and three-dimensional printing to improve surgical outcomes. Plast Reconstr Surg 2022;149(03):695–699

3 Holmes S. Primary orbital fracture repair. Atlas Oral Maxillofac Surg Clin North Am 2021;29(01):51–77

4 Grob S, Yonkers M, Tao J. Orbital fracture repair. Semin Plast Surg 2017;31(01):31–39

5 Alinasab B, Beckman MO, Pansell T, Abdi S, Westermark AH, Stjärne P. Relative difference in orbital volume as an indication for surgical reconstruction in isolated orbital floor fractures. Craniomaxillofac Trauma Reconstr 2011;4(04): 203–212

6 Bianchi F, De Haller R, Steffen H, Courvoisier DS, Scolozzi P. Does vertical incomitance predict the diplopia outcome in orbital fracture patients? A prospective study of 188 patients. J Craniomaxillofac Surg 2019;47(02):305–310

7 Dal Canto AJ, Linberg JV. Comparison of orbital fracture repair performed within 14 days versus 15 to 29 days after trauma. Ophthal Plast Reconstr Surg 2008;24(06):437–443

8 Boyette JR, Pemberton JD, Bonilla-Velez J. Management of orbital fractures: challenges and solutions. Clin Ophthalmol 2015; 9:2127–2137

9 Vasile VA, Istrate S, Iancu RC, et al. Biocompatible materials for orbital wall reconstruction-an overview. Materials (Basel) 2022; 15(06):2183

10 Ellis E III, Tan Y. Assessment of internal orbital reconstructions for pure blowout fractures: cranial bone grafts versus titanium mesh. J Oral Maxillofac Surg 2003;61(04):442–453

11 Hammer B, Prein J. Correction of post-traumatic orbital deformities: operative techniques and review of 26 patients. J Craniomaxillofac Surg 1995;23(02):81–90

12 Gear AJ, Lokeh A, Aldridge JH, Migliori MR, Benjamin CI, Schubert W. Safety of titanium mesh for orbital reconstruction. Ann Plast Surg 2002;48(01):1–7, discussion 7–9

13 Sugar AW, Kuriakose M, Walshaw ND. Titanium mesh in orbital wall reconstruction. Int J Oral Maxillofac Surg 1992;21(03): 140–144

14 Sharma N, Welker D, Aghlmandi S, et al. A multi-criteria assessment strategy for 3D printed porous polyetheretherketone (PEEK) patient-specific implants for orbital wall reconstruction. J Clin Med 2021;10(16):3563

15 Chepurnyi Y, Chernogorskyi D, Kopchak A, Petrenko O. Clinical efficacy of peek patient-specific implants in orbital reconstruction. J Oral Biol Craniofac Res 2020;10(02): 49–53

16 Akiki RK, Jehle CC, Crozier J, Woo AS. Using 3D printing and mirror image modeling in orbital floor reconstruction. J Craniofac Surg 2021;32(07):2465–2467

17 Schön R, Metzger MC, Zizelmann C, Weyer N, Schmelzeisen R. Individually preformed titanium mesh implants for a true-to-original repair of orbital fractures. Int J Oral Maxillofac Surg 2006; 35(11):990–995

18 Blumer M, Essig H, Steigmiller K, Wagner ME, Gander T. Surgical outcomes of orbital fracture reconstruction using patient-specific implants. J Oral Maxillofac Surg 2021;79 (06):1302–1312

19 Ma CY, Wang TH, Yu WC, et al. Accuracy of the application of 3-dimensional printing models in orbital blowout fractures-a preliminary study. Ann Plast Surg 2022;88(1s, Suppl 1) S33–S38

20 Nikunen M, Rajantie H, Marttila E, Snäll J. Implant malposition and revision surgery in primary orbital fracture reconstructions. J Craniomaxillofac Surg 2021;49(09):837–844

21 Mims MM, Wang EW. Cost analysis of implants in the surgical repair of orbital floor fractures. Ann Otol Rhinol Laryngol 2020; 129(05):456–461

22 Schlittler F, Vig N, Burkhard JP, Lieger O, Michel C, Holmes S. What are the limitations of the non-patient-specific implant in titanium reconstruction of the orbit? Br J Oral Maxillofac Surg 2020;58 (09):e80–e85

23 Kitabata R, Uno K, Sakamoto Y. Reconstruction of combined orbital floor and medial wall fractures using custom-made titanium alloy implant. J Craniofac Surg 2021;32(04): e388–e389

24 Chae MP, Rozen WM, McMenamin PG, Findlay MW, Spychal RT, Hunter-Smith DJ. Emerging applications of bedside 3D printing in plastic surgery. Front Surg 2015;2:25

25 Callahan AB, Campbell AA, Petris C, Kazim M. Low-cost 3D printing orbital implant templates in secondary orbital reconstructions. Ophthal Plast Reconstr Surg 2017;33(05):376–380

26 Girotto JA, Gamble WB, Robertson B, et al. Blindness after reduction of facial fractures. Plast Reconstr Surg 1998;102(06):1821–1834

27 Cheon JS, Seo BN, Yang JY, Son KM. Retrobulbar hematoma in blow-out fracture after open reduction. Arch Plast Surg 2013;40(04):445–449

28 Kim JM. Retrobulbar hematoma following the repair of an orbital wall fracture: a case series. Maxillofac Plast Reconstr Surg 2021;43(01):8

29 Putterman AM, Stevens T, Urist MJ. Nonsurgical management of blow-out fractures of the orbital floor. Am J Ophthalmol 1974;77(02):232–239

30 Burnstine MA. Clinical recommendations for repair of isolated orbital floor fractures: an evidence-based analysis. Ophthalmology 2002;109(07):1207–1210, discussion 1210–1211, quiz 1212–1213

31 Alinasab B, Borstedt KJ, Rudström R, et al. New algorithm for the management of orbital blowout fracture based on prospective study. Craniomaxillofac Trauma Reconstr 2018;11(04):285–295

32 Choi A, Sisson A, Olson K, Sivam S. Predictors of delayed enophthalmos after orbital fractures: a systematic review. Facial Plast Surg Aesthet Med 2022;24(05):397–403

33 He Y, Zhang Y, An JG. Correlation of types of orbital fracture and occurrence of enophthalmos. J Craniofac Surg 2012;23(04):1050–1053

34 Dvoracek LA, Lee JY, Unadkat JV, et al. Low-cost, three-dimensionally-printed, anatomical models for optimization of orbital wall reconstruction. Plast Reconstr Surg 2021;147(01):162–166

35 Hatz CR, Msallem B, Aghlmandi S, Brantner P, Thieringer FM. Can an entry-level 3D printer create high-quality anatomical models? Accuracy assessment of mandibular models printed by a desktop 3D printer and a professional device. Int J Oral Maxillofac Surg 2020;49(01):143–148

36 Andrades P, Cuevas P, Hernández R, Danilla S, Villalobos R. Characterization of the orbital volume in normal population. J Craniomaxillofac Surg 2018;46(04):594–599

37 Gosau M, Schöneich M, Draenert FG, Ettl T, Driemel O, Reichert TE. Retrospective analysis of orbital floor fractures–complications, outcome, and review of literature. Clin Oral Investig 2011;15(03):305–313

38 Oh TS, Jeong WS, Chang TJ, Koh KS, Choi JW. Customized orbital wall reconstruction using three-dimensionally printed rapid prototype model in patients with orbital wall fracture. J Craniofac Surg 2016;27(08):2020–2024

39 Jadhav C, Cunneen S. Three-dimensional printing technology for medial orbital wall fractures. J Craniofac Surg 2015;26(08):e799–e800

40 Lor LS, Massary DA, Chung SA, Brown PJ, Runyan CM. Cost analysis for in-house versus industry-printed skull models for acute midfacial fractures. Plast Reconstr Surg Glob Open 2020;8(05):e2831

41 Vatankhah R, Emadzadeh A, Nekooei S, et al. 3D printed models for teaching orbital anatomy, anomalies and fractures. J Ophthalmic Vis Res 2021;16(04):611–619