Trauma Case Reports 26 (2020) 100291

Contents lists available at ScienceDirect

Trauma Case Reports

journal homepage: www.elsevier.com/locate/tcr

Case Report

Case report: The use of three-dimensional biomodels for surgical planning of rib fixation

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ARTICLE INFO

Keywords:
Rib fracture fixation
Surgical models
Titanium

ABSTRACT

Background: Prosthetic titanium plates are frequently used in the stabilization of rib fractures and are typically contoured to the patient's anatomy at the time of implant in the operating room. Smith et al. [17] described the use of a 3D prototype biomodel of his patient's skeletal anatomy for preoperative customization of standard titanium plates for rib fractures. This process facilitated the preoperative planning and provided implants appropriate for a patient's unique anatomy. Further, the approach facilitated repair of complex fractures and may decrease operating time. Besides that, it provides idealized conditions for plate shaping and may facilitate implantation.

Methods: We performed rib fixation combined with 3D biomodels for surgical planning for the first time in Brazil, achieving reduced operating time with a good outcome for our patient.

Results: Surgical planning was conducted one day before the surgery using a 3D printer to make a patient-specific model. The printing time of the model was 16 h. The 3D biomodel was used for simulating the surgical procedure, pre-molding the titanium plates, and measuring the screw sizes that would be used in the procedure. All five fractures were fixed on the 3D biomodel and the total simulation time was 58 min. We used four pre-contoured titanium plates of 1.5 mm thickness and one straight 1.5 mm thickness titanium plate. We used the printed model to measure screw size, as we would do in the surgery. After planning, the material was processed and sterilized according to the hospital standards to be implanted in the patient the following day.

Conclusion: This is the second reported case of surgical stabilization of rib fractures using a 3D model. Both cases demonstrated the advantages of this approach. More studies are needed to validate the safety and benefits for the patient, as well as the impact on cost savings.

Introduction

Rib fractures are painful injuries seen in about 10% of all trauma admissions and occurring in up to 39% of patients who have sustained blunt chest trauma [1]. The mainstays of nonoperative management of rib fractures include conventional pain control methods (analgesia, intercostal blocks), aggressive pulmonary toilet, and mechanical ventilation [2,3]. However, 82% of the patients

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https://doi.org/10.1016/j.tcr.2020.100291
Accepted 17 February 2020
Available online 22 February 2020
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with flail chest injuries treated without surgical intervention required intensive care unit (ICU) admission and 59% required mechanical ventilation, due to the compromised respiratory function and inability to clear pulmonary secretions [4]. Further, 27–70% of these patients develop pneumonia and have a mortality rate of 25–51% [5].

The surgical treatment of rib fractures is becoming a treatment option for patients with flail chests. Several authors have shown the benefits of rib fixation in this specific group of patients, including decreases in intensive care stay, mechanical ventilation time, and complications from prolonged ventilation [6–8]. The ideal timing of surgical stabilization of rib fractures (SSRF) is unknown. Trials of SSRF have performed fixation within 1 week of injury. Tissue inflammation peaks between post-injury days 3 and 5, which would exacerbate intraoperative hemorrhage if repair is undertaken during this time. Furthermore, after this period, substantial callous formation would occur, further complicating the repair. Finally, unlike for most other bones, it is nearly impossible to effectively immobilize rib fractures nonoperatively. Continual movement during respiration exacerbates pain, which may ultimately lead to preventable respiratory failure. We thus strive to perform SSRF as soon as possible and within 72 h of admission. Resuscitated, hemodynamically stable patients without either intracranial hypertension or competing operative priorities are transported from the trauma bay to the operating room for immediate SSRF [9].

The system for generating three-dimensional (3D) objects was created in 1986 by Charles Hull [10]. 3D printers were first adopted by the aerospace and automobile industries, to create prototypes for testing their products. Over the years, its use has expanded to other sectors. Today, 3D models allow physicians to teach trainees, create custom prosthetics and implants, and perform preoperative planning of complex surgeries [11]. The number of 3D printers in the medical field has increased rapidly in recent years, and many hospitals now have access to internal 3D printers [12,13].

One of the oldest and most established uses of 3D printing in surgical planning has been in maxillary and craniofacial reconstructions [14,15]. During those surgeries, a significant amount of time is spent in plate contouring to reconstruct the mandible, while the patient is under anesthesia. When a 3D model is created, it assists in contouring of plates before surgery, thus reducing operating time [15–17]. As a result, this technology provides patients with a decreased time under general anesthesia, decreased blood loss, and shorter wound exposure time [15,17]. This concept has been applied to many orthopedic surgeries, including rib fixations [17]. Jeong et al. [18] described a minimally invasive plate osteosynthesis technique for midshaft fractures of the clavicle using intramedullary indirect reduction and prebent plates with 3D printing models. They needed only 20 dollars and 3 h to print the 3D models for a pair of clavicles after CT scan, and 3 h to bend and sterilize the plate. Thus, the 3D printing procedure was inexpensive and required only a short time to produce the model. They are optimistic that almost all patients can afford the cost and time for this technique.

Prosthetic titanium plates are frequently used in the stabilization of rib fractures, and are typically contoured to the patient's anatomy at the time of implant in the operating room. Smith et al. [17] described the use of a 3D prototype biomodel of his patient's skeletal anatomy for the preoperative customization of standard titanium plates for fixation of rib fractures. This process facilitated the preoperative planning and provided implants appropriate for a patient's unique anatomy. They found that this approach can facilitate the repair of complex fractures and may decrease operating time. Besides that, it provides idealized conditions for plate shaping and may facilitate implantation.

We performed rib fixation combined with 3D biomodels for surgical planning for the first time in Brazil, achieving a reduction in operating time with a good outcome for our patient.

Case presentation

A 65-year-old man presented to the Emergency Department of our hospital in April 2015 after sustaining a severe chest wall contusion in a motorcycle accident. The thorax X-ray showed six broken ribs (from the 4th to the 9th left costal arches) without hemothorax. The patient was admitted for pain control. After 4 days, the patient was asymptomatic and was discharged. He returned to the Emergency Department after 14 days complaining of fever and thoracic pain on the same side. A new thorax X-ray scan and computed tomography (CT) scan were performed. The CT scan of his chest showed a moderate hemothorax and five displaced ribs. A video assisted thoracoscopic surgery was performed to clean the pleural cavity and retained hemothorax. Due to suspected infection of the retained hemothorax, the surgical team decided that the ribs should not be fixed as that could cause infection of the titanium plates. The patient was discharged after 14 days of antibiotic administration without signs of hemothorax and with pain well controlled. Four months after the trauma, the patient returned with new complaints of chest pain. A new CT scan of his chest showed fractures of the left 4th to 9th ribs. While one rib had healed, the other five (5th to 9th) showed signs of malunion or no union. No clinical signs of infection were detected; therefore, surgical fixation of the ribs was indicated.

Surgical planning was conducted one day prior to the surgery using a 3D printer to make a patient-specific model. A 120 kVp chest CT scan with 1 mm slice thickness was performed with Siemens equipment Materialise Mimics Software (Materialise Software, Leuven, Belgium) for segmentation of the images, a process that separates different kinds of tissue and identifies regions of interest (ROI). This software reads the CT DICOM images and converts them to a stereolithography (STL) three-dimensional object file. In this case, the fracture region was isolated as the ROI. The STL file was sent to a 3D printer (Connex3 260) and was printed with VeroWhite opaque polyjet resin (Sculpteo, Villejuif, France) and SUP706 soluble support material (Stratasys, Eden Prairie, MN, USA). The final model was cleaned through the waterjet machine (Fig. 1A–C). The printing time of the model was 16 h.

The 3D biomodel was used for simulating the surgical procedure, pre-molding the titanium plates, and measuring the screw sizes that would be used in the procedure. All five fractures were fixed on the 3D biomodel, and the total simulation time was 58 min (Fig. 2). We used four pre-contoured titanium plates of 1.5 mm thickness and one straight 1.5 mm thickness titanium plate (The Depuy Synthes CMF MatrixRib® Fixation System, West Chester, PA, USA). Each plate was fixed on the model with only one bicortical

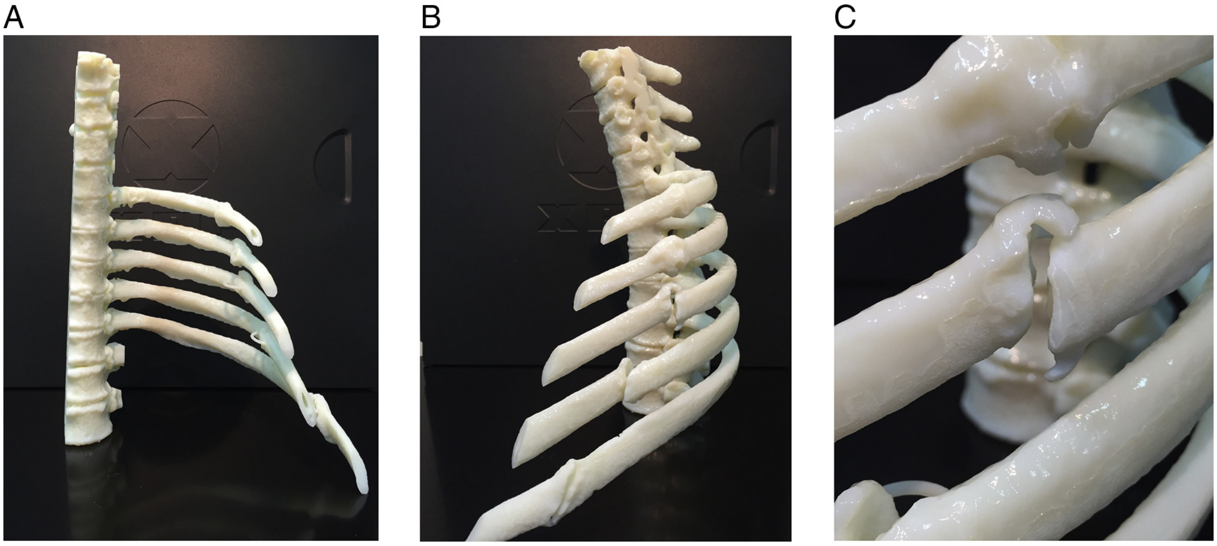

Fig. 1. 3D biomodel.
1A: Internal view.
1B: External view.
1C: Fracture close-up.

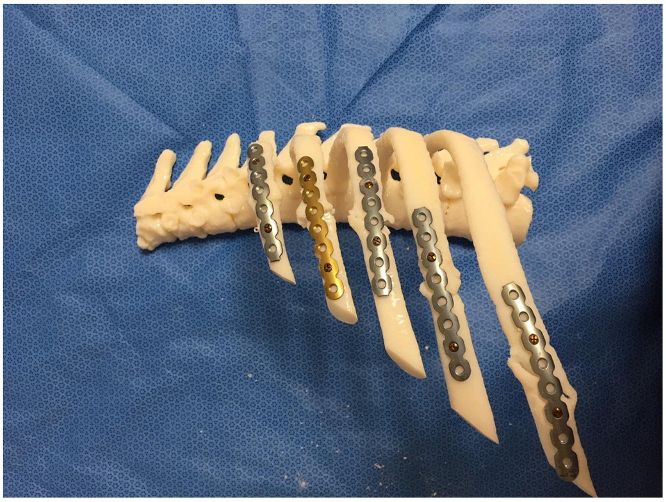

Fig. 2. 3D biomodel fixed with measured plates.

screw on each side of the fractures. We used the printed model to measure the screw size as we would do in the surgery on the next day. The screws used in the planning were discarded due to increased risk of failure with reuse. After planning, the material to be implanted in the patient on the following day was processed and sterilized according to the hospital standards (Sterrad® 100S, Advanced Sterilisation Products, Irvine, CA, USA).

With the patient under general venous anesthesia, we made a 12-cm vertical incision on the left mid-axial line, allowing access to all the fractures seen on the 3D prototype and CT scan. We were able to resect the nonunion segments and reduce the fracture exactly as we had in the simulated procedure. Moreover, there was an approximate 40% reduction of costs as we used only three plates instead of five as initially predicted. Review of the CT scan suggested one plate would be needed for each rib. However, during the simulation, using the 3D prototype, we were able to test different plate sizes without the concern of prolonging operating time and were ultimately able to cut two plates into different sizes to fix four costal arches. Each titanium plate in Brazil costs US$3000, and each screw costs US$300; thus, the total reduction in cost was approximately US$6000. We believe that a further cost reduction as well as a clinical benefit to the patient resulted as anesthesia time was reduced. The patient had an uneventful postoperative course. He was sent to the ICU the day after the surgery and was discharged to the ward with a normal X-ray one day later (Fig. 3). The chest tube was withdrawn on postoperative day 3, and he was discharged home on postoperative day 6. The patient had no signs of hemothorax and no pain at the last follow-up 1 year after the procedure.

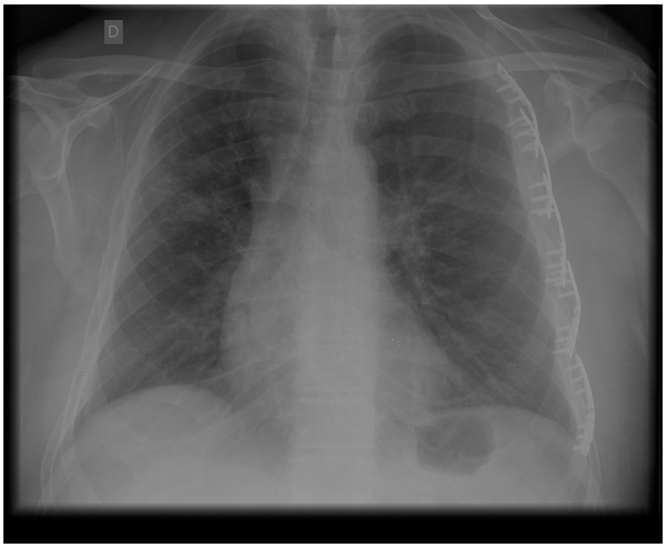

Fig. 3. Postoperative posterior-anterior X-ray shows the ribs fixed.

Discussion

SSRF with a 3D prototype is a new approach with increasing acceptance. This type of surgery can help patients with broken ribs to have a safer, faster, and less traumatic surgical procedure [19]. In our case, the surgical staff felt that operating time was shorter, since the localization of the fractures and the positioning of the incision was determined in advance. In comparison, cases without 3D planning sometimes require longer operating time to determine the best incision location and may result in larger incisions. The ability to mold the plates before the procedure also reduces operating time. In this case, the molding time was 1 h. This was a particularly challenging case as it dealt with malunion rib fractures, and the affected segments would have to be resected prior to fixing the ribs with the titanium plates. The 3D model allowed us to resect the nonunion segments and reduce the fracture exactly as we planned. Besides that, we used only three plates instead of five as first predicted, reducing costs by about 40%. The opportunity to rehearse with the 3D prototype gave the surgical team more confidence and increased predictability of the surgery on the next day, contributing to greater patient safety.

Lin et al. [19] reported another case of preoperative 3D printing for SSRF. The advantages they found were very similar: an easy way to localize the fracture site of the ribs and to predict the incision size; shorter operating time; and easy explanation of the SSRF surgery to the patient and family. They also pointed out a key limitation of this approach in SSRF: 3D printing is time-consuming, and it is not recommended for emergency conditions. Lin et al. produced a simpler model that only took 5 h to print. Our model was more complex as it included the backbone and a larger number of ribs compared to theirs. We believe this detailed model made the simulated procedure much closer to the real one, and also aided in planning the incision, as it was possible to compare the model to the patient's anatomy during the surgery. Our procedure was not urgent; thus, the 16-hour printing of the model was done overnight and did not delay the procedure.

Lin et al. further noted that the procedure had extra cost because of the machines and the materials they used. We noted similar costs. More studies are needed to determine if the cost of producing the model could be offset by the possible cost savings it could provide. Possible savings may include reduction in operating time and operating room occupancy, as well as potential reductions to the amount of implanted material required.

This is the second reported case of SSRF using a 3D model [20]. Both cases demonstrate the advantages of this approach. More studies are needed to validate the safety and benefits for the patient, as well as the impact on cost savings.

At present, the cost of 3D printing remains substantial, but given the improved planning in complex cases, this cost may be recaptured in the reduction of operating time and improved outcomes with reduced re-operation rates [21]. Within the orthopedic and traumatology field, 3D printing also enables advance testing of the surgical procedure; this possibility can lead to a better intervention outcome and a reduction in operating time [22].

Recent advances in segmentation algorithms along with growing availability of low-cost 3D printers have reduced the barrier to the production of 3D anatomical models. The continued advancement of technology and the explosive growth in this field suggest that within only a few years, the cost will be reduced to a point where 3D printing may be achievable in all routine cases where complex 3D geometry is visualized. We believe that the early adoption of this technology by surgeons can help improve surgical quality and provide more individualized patient care. Centers should pursue the integration of 3D printed models into their practice and active collaborations between surgeons and modeling experts should be sought at every available opportunity [21].

Declaration of patient consent

The patient provided informed consent for the study and has given consent for publication of his images and other clinical information.

Funding

The 3D models were donated by BioArchitecs Brasil.

Declaration of competing interest

The authors have no conflicts of interest to declare.

References

[1] E.M. Gauger, B.W. Hill, P.M. Lafferty, et al., Outcomes after operative management of symptomatic rib nonunion, J. Orthop. Trauma 29 (2015) 283–289.
[2] S. Marasco, P. Saxena, Surgical rib fixation - technical aspects, Injury 46 (2015) 929–932, https://doi.org/10.1016/j.injury.2014.12.021.
[3] P.M. Lafferty, J. Anavian, R.E. Will, et al., Operative treatment of chest wall injuries: indications, technique, and outcomes, J. Bone Joint Surg. 93 (2011) 97–110 [Internet]. Available from http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00004623-201101050-00013.
[4] N. Dehghan, C. De Mestral, M.D. McKee, et al., Flail chest injuries: a review of outcomes and treatment practices from the national trauma data bank, J. Trauma Acute Care Surg. 76 (2014) 462–468.
[5] M.B. de Jong, M.C. Kokke, F. Hietbrink, et al., Surgical management of rib fractures: strategies and literature review, Scand. J. Surg. 103 (2014) 120–125.
[6] A. Unsworth, K. Curtis, S. Asha, Treatments for blunt chest trauma and their impact on patient outcomes and health service delivery, Scand. J. Trauma Resusc. Emerg. Med. 23 (2015) 17 [Internet]. Available from http://www.sjtrem.com/content/23/1/17.
[7] A. Granetzny, M. Abd El-Aal, E. Emam, et al., Surgical versus conservative treatment of flail chest. Evaluation of the pulmonary status, Interact. Cardiovasc. Thorac. Surg. 4 (2005) 583–587, https://doi.org/10.1510/icvts.2005.111807 Internet.
[8] S.F. Marasco, A.R. Davies, J. Cooper, et al., Prospective randomized controlled trial of operative rib fixation in traumatic flail chest, J. Am. Coll. Surg. 216 (2013) 924–932, https://doi.org/10.1016/j.jamcollsurg.2012.12.024 Internet.
[9] F. Pieracci, M. Rodil, R. Stovall, et al., Surgical stabilization of severe rib fractures, J. Trauma Acute Care Surg. 78 (4) (2015) 883–887.
[10] Hull CW, inventor; UVP Inc, assignee. Apparatus for production of three-dimensional objects by stereolithography. United States Patent 4,575,330. 1986.
[11] A. Marro, T. Bandukwala, W. Mak, Three-dimensional printing and medical imaging: a review of the methods and applications, Curr. Probl. Diagn. Radiol. 45 (2016) 2–9.
[12] Nicklaus Children's Hospital acquires 3D printer to support pediatric surgical planning and research, [Internet]. [cited 2019 Jun 21]. Available from Miami Children's Hospital, http://www.mch.com/press/EN/484/Nicklaus-Children-s-Hospital-Acquires-3D-Printer-to-Support-Pediatric-Surgical-Planning-and-Research.aspx, (2015).
[13] 12 Hospitals in the UK are using stratasys 3d printers for the creation of surgical models prior to surgery [Internet]. 3DPrint.com, [cited 2019 Jun 21]. Available from, 2015. http://3dprint.com/13033/stratasys-3d-printers-surgery/.
[14] S. Singare, L. Dichen, L. Bingheng, et al., Customized design and manufacturing of chin implant based on rapid prototyping, Rapid Prototyp. J. 11 (2005) 113–118.
[15] A. Cohen, A. Laviv, P. Berman, et al., Mandibular reconstruction using stereolithographic 3-dimensional printing modeling technology, Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 108 (2009) 661–666.
[16] Y. Liu, L. Xu, H. Zhu, et al., Technical procedures for template-guided surgery for mandibular reconstruction based on digital design and manufacturing, Biomed. Eng. Online 13 (2014) 63.
[17] J.A. Smith, V.P. Ho, C.W. Towe, Using 3-dimensional modeling to customize titanium plates for repair of chest wall trauma, Surg. Innov. 25 (2018) 115–120.
[18] H. Jeong, K. Park, K. Kil, et al., Minimally invasive plate osteosynthesis using 3D printing for shaft fractures of clavicles: technical note, Arch. Orthop. Trauma Surg. 134 (11) (2014) 1551–1555.
[19] W.C. Lin, K.H. Lin, H.K. Huang, et al., Preoperative three-dimensional printing for surgical stabilization of rib fractures, J. Med. Sci. 38 (2018) 46–48.
[20] Y. Chen, K. Lin, H. Huang, et al., The beneficial application of preoperative 3D printing for surgical stabilization of rib fractures, PLoS One 13 (2018) e0204652.
[21] J. Bergquist, J. Morris, J. Matsumoto, et al., 3D printed modeling contributes to reconstruction of complex chest wall instability, Trauma Case Rep. 22 (2019) 100218.
[22] F. Auricchio, S. Marconi, 3D printing: clinical applications in orthopaedics and traumatology, EFORT Open Rev. 1 (5) (2016) 121–127.