J Med Sci 2018;38(1):46-48
DOI: 10.4103/jmedsci.jmedsci_77_17

CASE REPORT

Preoperative Three-dimensional Printing for Surgical Stabilization of Rib Fractures

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Pulmonary trauma is a significant cause of morbidity and mortality in patients with major trauma. Chest wall contusion with rib fracture is very common. Surgical stabilization of rib fracture (SSRF) has traditionally required an exploratory thoracotomy for adequate exposure. Minimally invasive approaches for SSRF are now being developed. However, preoperative localization of rib fractures and intraoperative designing of titanium plates require additional time. We present a novel technique involving three-dimensional printing for promoting SSRF with a minimally invasive approach that is efficient and provides good patient outcomes.

Key words: Surgical stabilization of rib fracture, three-dimensional printing, titanium plates

INTRODUCTION

Pulmonary trauma is a significant cause of morbidity and mortality in patients with major trauma. Major trauma represented the sixth highest medical cost in men and the eighth highest in women among 10 leading catastrophic illnesses in 2014 according to the Taiwan National Health Insurance. Rib fractures are noted in 10% of all trauma patients and about 30% of patients with significant chest trauma.[1] Surgical stabilization of rib fractures (SSRF) has traditionally required an exploratory thoracotomy for adequate exposure; however, the degree of chest wall instability was determined by palpation, and the planned approach for surgery was fine-tuned on the basis of direct vision of rib fracture location during surgery.

Recently, minimally invasive approaches are being developed. Schots *et al*.[2] mentioned that video-assisted thoracoscopic surgery (VATS) is effective and safe and can be of additional value by providing the possibility to adjust the planned incision for SSRF and decrease the area of muscle destruction. However, an extended duration for the preoperative preparation of VATS and single-lung ventilation is expected, and at least one more assistant for controlling the process of thoracoscopy is necessary. Therefore, we used a three-dimensional (3D) reconstruction computed tomographic images for simulating a patient's rib cage to determine the length and curve of titanium plates before surgery to decrease the size of incisions, identify the precise location of fracture sites, and easily measure the rib thickness using a caliper for proper screw length. 3D printing is a form of rapid prototyping technology, which has led to innovative new applications in biomedicine. Baskaran, *et al*.[3] presents the findings of a literature review of the Pubmed and Web of Science databases investigating the applications of 3D printing in anatomy and surgical education and neurosurgery. A number of applications within these fields were found, with many significantly improving the quality of anatomy and surgical education, and the practice of neurosurgery.

We applied this novel technique using a minimally invasive approach with the application of 3D printing, which allowed a reduction in operation time and resumption of daily activities. No cases have been reported in such technique before. Our patient is the first case and was followed at our outpatient department for more than 6 months without any complaints.

CASE REPORT

A 64-year-old male fell down from a height of 4 meters and got left chest wall contusion with a fracture of 3^{rd}–6^{th} and

Received: July 12, 2017; Revised: September 27, 2017; Accepted: October 20, 2017
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How to cite this article: Lin WC, Lin KH, Huang HK, Huang TW, Chen YY. Preoperative three-dimensional printing for surgical stabilization of Rib fractures. J Med Sci 2018;38:46-8.

10th ribs. He only had hypertension before under regular medication control. Then, he was referred to our hospital for further evaluation and management. Under initial medical treatment with adequate pain control (combined nonsteroid anti-inflammatory drugs and opioids), he still felt chest pain, especially in deep breathing and coughing during admission. We followed the chest plain film in posttrauma day 3 showed left-sided hemothorax [Figure 1a], and the patient complained exertional dyspnea. After discussion with the patient and his family, they all agreed on surgical fixation of ribs and VATS with the evacuation of blood clots.

We created 3D-computed tomographic reconstructions of the chest wall [Figure 2a and b] and used the UP-BOX 3D printer with acrylonitrile butadiene styrene as the raw material to produce a 3D-printed model of the rib cage. The MatrixRIB system (DePuy Synthes, Amersfoort, The Netherlands) was used, providing anatomically contoured titanium angular stable plates for posterior or retroscapular fractures. The titanium plates were cut to a suitable length and bent to fit the curve of the patient's rib cage [Figure 1b]. The rib thickness was measured using a caliper. The plate was fixed with a minimum of three locking screws on each fracture side to ensure proper fixation. After completion of titanium plate designing for rib fixation, the screws and titanium plates were sent for autoclave sterilization.

We created the incision length with only 6.5 cm [Figure 1c] alone the fracture line at left lateral chest wall. Dissection of skin and muscle layers and exposure of the surface of ribs and intercostal muscles were done. Fractured ribs were repositioned, and the designed titanium plates were easily inserted and fixed. The postoperative chest plain film revealed well reduction and fixation of ribs [Figure 1d]. The patient was discharged to home in 1-week later and followed up at our outpatient department.

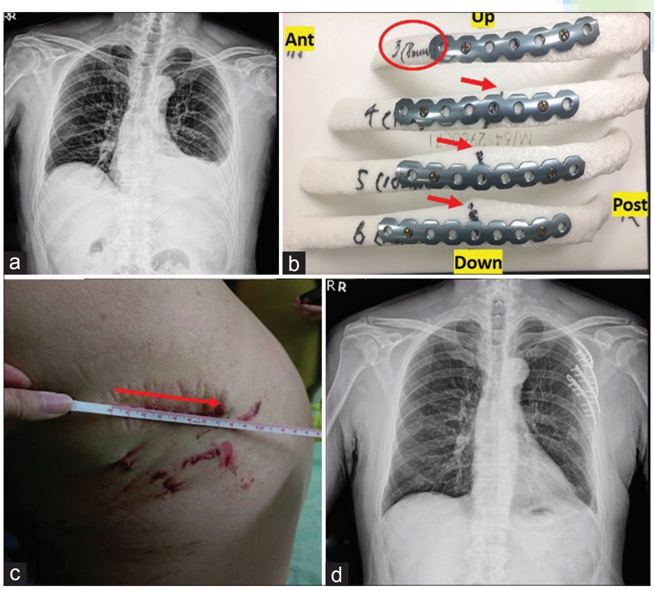

Figure 1: A 64-year-old male fell down from a height of 4 meters. He had chest wall contusion with fractures of the 3rd–6th and 10th ribs and left costophrenic angle blunting. (a) The initial plain chest film. (b) The arrows indicate the fracture line, and the circle indicates the thickness of the 3rd rib (8 mm). The designed plates (3rd–6th) are fixed on the model with locking screws. (c) The incision (6.5 cm) at the left 5th intercostal space. (d) The postoperative plain chest film

DISCUSSION

Fracture of multiple ribs in more than one location can lead to flail chest or other associated thoracic injuries significantly compromising respiratory function.[4] Over 30% of patients with severe chest trauma will have some long-term disability and often do not return to full-time employment.[5] In addition, this results in social and economic costs, both to the US health care system and to individuals in the form of lost productivity and decreased quality of life (QOL).[6] Bhatnagar *et al*.[7] presented a model that looks specifically at long-term outcomes and QOL after SSRF in patients treated in North American trauma centers, and this Markov decision model was designed to compare the cost-effectiveness of nonoperative management versus SSRF of a flail chest. Nickerson *et al*.[8] mentioned that the surgical reach for rib fracture stabilization can be extended with the use of a 90° drill and screwdriver and that high fractures under the scapula where access is technically challenging can be stabilized without prolonged operative times.

3D printing has opened new avenues for the manufacturing of objects across a number of fields. 3D printing techniques offer advantages over existing methods of anatomical modeling, which include cadaveric dissection, plastic models, and plastinated cadaver specimens.[9] 3D printing can produce accurate simulations of patient-specific anatomy and pathology, which can then be used for preoperative planning and skill acquisition. These models are based on real patient data, are reproducible, represent actual pathology and human

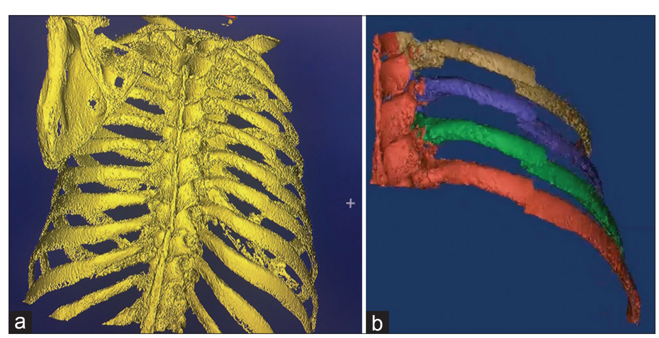

Figure 2: Preoperative three-dimensional computed tomographic reconstruction for fractures of ribs. (a) Posterior view. (b) Regional posterior view

variation, and are constructed with multiple materials designed to replicate real human tissue.[9-11]

The preoperative 3D printing approach has the following three advantages for SSRF:

1. Easy to localize the fracture site of ribs and to predict the incision size
2. Shortening operation time
   We used personalized titanium plates with preoperative design of the appropriate length and curve. The screw length could be confirmed with the 3D-printed model before surgery.
3. Good to explain the surgical steps of SSRF to the patient and family.

The approach has the following limitations in SSRF:

i. Presence of other cardiothoracic injuries
   If a patient has other cardiothoracic injuries, thoracotomy with extended exploration might be necessary to check bleeding. Thus, a 3D-printed model for SSRF would be superfluous.
ii. Time-consuming of 3D printing (at least 5 h)
   This new technique is not suitable for emergency conditions.
iii. Extra cost.
   The cost is an additional limitation, with the rapid prototyping machines costing in one to two hundred of dollars, including the cost of the plastic- and resin-based materials.

In our case, the operation time was 130 min, including four rib fixations and hemothorax evacuation. Prospective multi-institutional studies are needed to validate the feasibility and safety of 3D printing in SSRF. Further studies on clinical information may provide more valuable results for patient outcomes.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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