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ORIGINAL ARTICLE
Reconstructive

Custom 3D-printed Titanium Implant for Reconstruction of a Composite Chest and Abdominal Wall Defect

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Background: Three-dimensional (3D) printing of implantable materials is a recent technological advance that is available for clinical application. The most common medical application of 3D printing in plastic surgery is in the field of craniomaxillofacial surgery. There have been few applications of this technology in other areas.
Methods: Here, we discuss a case of a large, symptomatic composite thoracic and abdominal defect resulting from the resection of a chondrosarcoma of the costal marginand sections of the abdominal wall, diaphragm, and sternum. The initial and second attempts at reconstruction failed, resulting in a massive hernia. Given the size of the defect, the contiguity with a large abdominal wall defect, and the high risk of recurrence, a rigid thoracic reconstruction was essential to durably repair the thoracic hernia and serve as a scaffold to which both the diaphragm and the abdominal mesh could be secured. A custom-made plate offered the most durable and anatomically accurate reconstruction in this particular clinical scenario. This technology was used in concert with a single section of coated mesh for reconstruction of the diaphragm, chest wall, and abdominal wall.
Results: There were no post-operative complications. The patient has improvement of his symptoms and increased functional capacity. There is no evidence of hernia recurrence 1.5 years after repair.
Conclusions: 3D printing technology proved to be a useful and effective application for reconstruction of this large thoracic defect involving the costal margin. It is an available technology that should be considered for reconstruction of rigid structures with defect-specific precision. *(Plast Reconstr Surg Glob Open 2021;9:e3885; doi: 10.1097/GOX.0000000000003885; Published online 30 November 2021.)*

INTRODUCTION

Three-dimensional (3D) printing has been adopted by many surgical disciplines to create contour models, guides, implantable prostheses, and splints, for the biocell printing of 3D tissues or organs, and to create scaffolds for tissue engineering. Within plastic surgery, craniomaxillofacial surgery was the first field to utilize this technology, most commonly in the fabrication of contour models for surgical planning.[1,2] The main advantages of 3D printing are increased precision and decreased surgical time.[3] Applications for its use are expanding as the technology becomes more available and affordable. We will discuss one such application of 3D printing: the manufacture of a large titanium plate, which was used to successfully reconstruct a composite thoracic and abdominal wall defect.

CASE DESCRIPTION

A 64-year-old man presented with a history of a right anterior chest wall chondrosarcoma, resected at another institution in March 2018 (**See figure 1, Supplemental Digital Content 1**, which displays the CT scan of chondrosarcoma before resection. **http://links.lww.com/PRSGO/B825**.)

Ribs 6–8, the distal third of the sternum, a portion of the diaphragm, and the superior aspect of the right hemi-abdominal musculature were resected. This

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composite chest/diaphragm/abdominal wall defect was reconstructed with a lightweight synthetic mesh and a free omental flap. A large, symptomatic ventral hernia was diagnosed 3 months postoperatively. The hernia was repaired with a mid-weight synthetic mesh 6 months after the index surgery. The hernia recurred 2 months after the initial hernia repair.

The patient then presented to our institution for reconstruction. In addition to an obvious bulge over his right anterior chest and abdominal wall, the patient reported pain and discomfort, positional dyspnea, and functional limitations such as inability to engage in vigorous physical activity (Fig. 1). Examination revealed a right subcostal incision and a large hernia at the right costal margin, extending from the right nipple–areolar complex to the umbilicus. Computed tomography revealed a full-thickness 41 × 40 cm defect of the musculofascial chest and abdominal wall and a hernia containing portions of the liver, large bowel, and small bowel (Fig. 2).

Given the size and location of the defect and the history of hernia recurrence, a rigid construct for the chest wall was critical to maximize the reconstruction's functionality and durability. The defect's large size, complex geometry, and unique dimensions supported the use of a custom chest wall implant.

Takeaways

Question: What are the considerations in repair of composite chest and abdominal wall defects and how do they guide the reconstructive options and techniques?

Findings: Durable repair of a large hernia involving both the chest and abdominal wall was achieved with a patient-specific 3D-printed titanium plate and a medium weight synthetic mesh.

Meaning: Rigid chest wall reconstruction can be achieved with 3D-printed plates. The repair of a composite defect including the abdominal wall can be integrated into the reconstruction using the techniques described in this case report.

Construct Design

A 3D-printed, titanium rib-sternum plate (Synthes, Solothurn, Switzerland), based on a 3D reconstruction of a recent computed tomography scan, was designed using virtual surgical planning and computer-assisted design/computer-assisted manufacturing technology. Multiple fenestrations were incorporated into the plate design to allow for suspension of the reconstructed diaphragm and abdominal wall from the titanium neo-ribs. (**See figure 2, Supplemental Digital Content 2,** which displays 3D-printed titanium plate. **http://links.lww.com/PRSGO/B826**.)

Surgical Technique

Access to the chest and abdominal cavities was obtained through the prior subcostal incision, and the defect was recreated. (**See figure 3, Supplemental Digital Content 3**, which displays defects of the chest and abdominal wall. **http://links.lww.com/PRSGO/B827**.)

The 3D construct was fixated to the sternum medially and to the remaining free edges of ribs 6–8 with 20 titanium locking screws (10–18 mm) (Fig. 3A). Ventralite ST mesh (Becton Dickinson and Company, East Rutherford, N.J.) was secured to the underside of the diaphragm with 10-cm underlay. The native diaphragm and underlying mesh were secured to the superior two struts of the 3D construct with multiple #1 polypropylene sutures (Fig. 3B). The abdominal defect was approximately 15 × 20 cm. Advancing the resected abdominal wall musculature superiorly by securing it to the mesh with a wide underlay decreased the bridged defect surface area by 66%, to 10 × 10 cm (Fig. 3C, D). The 3D-printed titanium plate was covered by rotating and advancing the prior omental flap and a serratus muscle flap. The skin was reapproximated primarily. The patient's postoperative course was uneventful.

At 1.5 years postoperatively, the patient's reconstruction remains intact, with no hernia recurrence on examination or imaging (Fig. 4). He is practicing yoga and doing light weight training and martial arts with a custom-made chest protector. He takes no narcotic pain medication and his dyspnea has resolved.

DISCUSSION

The following are generally accepted indications for chest wall reconstruction[4–6]:

- Anterior or lateral defects involving more than two adjacent ribs
- Anterior or lateral defects greater than 5 cm in diameter
- Posterior defects in which scapular entrapment is a risk
- Posterior defects greater than 5 cm

Large anterior and lateral defects are appropriate indications for rigid repair, which has been proven safe.[7,8]

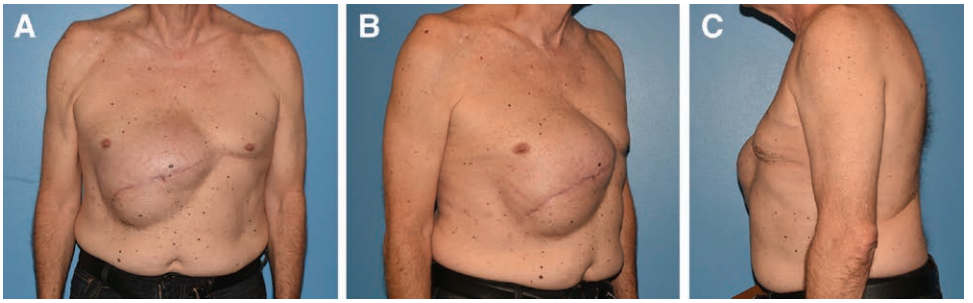

Fig. 1. A 64-year-old man presented with a complex hernia involving the chest wall and the abdomen. A, Anteroposterior view. B, Oblique view from right. C, Lateral view from left.

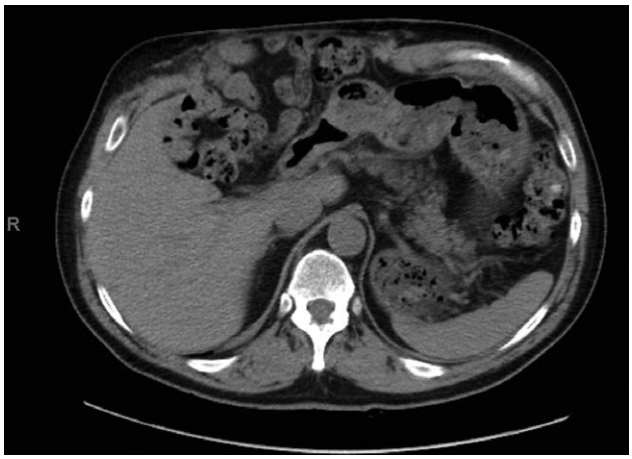

Fig. 2. Computed tomography scan upon presentation to our department, demonstrating hernia of the abdomen, which was contiguous with the chest wall.

There are two major advantages of a custom plate over the more commonly used methylmethacrylate cement and synthetic mesh reconstruction: anatomic precision and reduced operative time. Secondary advantages include no toxic fumes or exothermic chemical reaction, ease of use, and a more biocompatible modulus of elasticity.[3,9] Disadvantages of a 3D-printed plate include cost, manufacturing time, inability to alter the design intraoperatively, and lack of widespread accessibility to the planning technology.

Although 3D-printed plates have been employed in chest wall/sternal defects previously (see **Supplemental Digital Content 4** for a comprehensive list of related case reports. **http://links.lww.com/PRSGO/B884**.), our case is unique owing to the defect's extensiveness, involving major resections of three distinct anatomic structures: the chest wall, diaphragm, and abdominal wall. Composite defects such as these are particularly well-suited for patient-specific rigid reconstruction for a number of reasons. The large

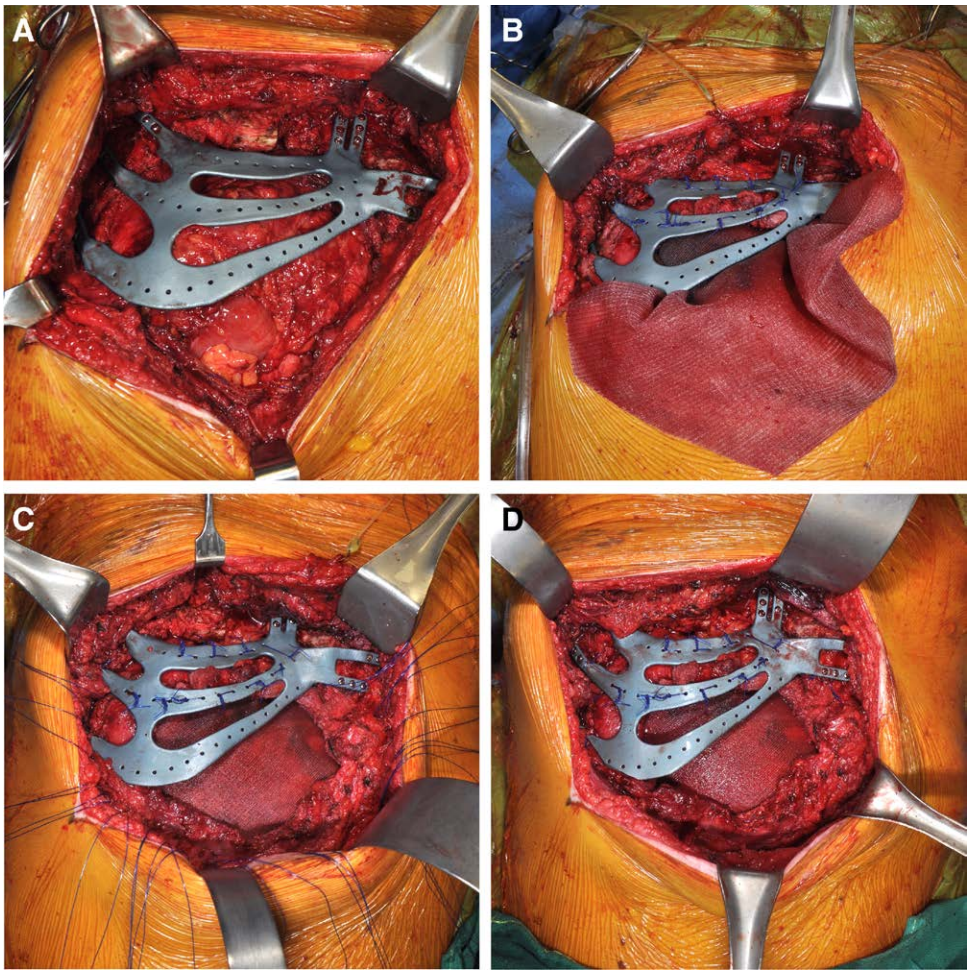

Fig. 3. Intra-operative photographs demonstrate the sequence of steps in reconstruction of the composite defect. A, The titanium plate was first secured to the sternum and to the remaining segments of ribs 4–6. B, The mesh was secured to the underside of the diaphragm. The native diaphragm and underlying mesh were secured to the superior two struts of the 3D construct. C, Sutures were placed between the mesh and the advanced abdominal wall in the underlay position and tagged to ensure optimal spacing and tension. D, Sutures were tied.

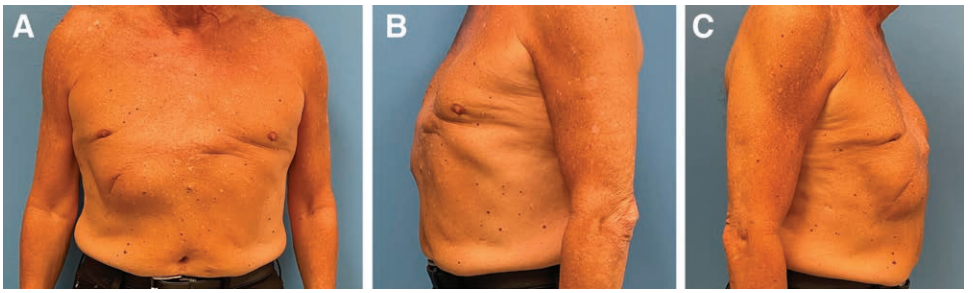

Fig. 4. At 1 year postoperative, there is no evidence of hernia recurrence and the patient enjoys an active lifestyle free from pain. A, Anteroposterior view. B, Lateral view from left. C, Lateral view from right.

resectional surface area is biomechanically destabilizing to both the abdominal wall and chest wall, predisposing the patient to reduced ventilatory capacity, paradoxical chest wall motion, and reduced core strength.[7,10] An isolated chest wall defect of this size could be reconstructed using standard titanium spanning rib plates; however, because the defect also included the inferior sternum, there was no anterior fixation point for the rib plates. Therefore, a custom prosthesis addressing both the resected ribs and the sternum was necessary. This patient-specific implant also made it possible to incorporate multiple fenestrations into the design without compromising the rigidity or structural integrity of the prosthesis; this allowed suspension of the diaphragm, mesh, and abdominal wall for a truly customized reconstruction.

3D printing can facilitate the creation of patient-specific, durable reconstructions of rigid structures. This is the first reported use of this technology for chest wall reconstruction in the United States and for the reconstruction of a composite defect. Although the low incidence of this type of defect precludes a case series, it is useful to document the successful application of this technology for other surgeons and centers that might be confronted with a similarly challenging case in the future.

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