

Three-Dimensional Custom-Made Titanium Ribs for Reconstruction of a Large Chest Wall Defect

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Eur J Pediatr Surg Rep 2016;4:26–30.

Abstract

Reconstruction of large chest wall defects always demand surgeons of having lots of means available (both materials and resourceful) to apply a cover to chest wall defects which can range from a few centimeters to the lack of a few entire ribs. In this study, we present the case of a teenager who suffered from a complete resection of three ribs because of Ewing sarcoma dependent on the sixth rib. Given the size of the defect, a multidisciplinary approach was chosen to provide rigid and soft tissue coverage and minimal functional and aesthetic impact. Custom-made titanium implants were designed based on three-dimensional computed tomography scan reconstruction. The surgical specimen via a left lateral thoracotomy (fifth, sixth, and seventh entire ribs) was resected, leaving a defect of 35 × 12 × 6 cm. A Gore-Tex patch (W. L. Gore & Associates, Arizona, United States) was placed and, after that, the implants were anchored to the posterior fragment of the healthy ribs and to the costal cartilage anteriorly. Finally, the surgical site was covered with a latissimus dorsi flap. The postoperative course was uneventful. After 9 months of follow-up, the patient has full mobility. This case shows that the implant of custom-made ribs, combined with other techniques, is a good surgical choice for reconstruction of large chest wall defects. The implant of custom-made ribs, combined with other techniques, is a good surgical choice for reconstruction of large chest wall defects.

Keywords

- ▶ chest wall reconstruction
- ▶ chest wall resection
- ▶ chest wall deficiency
- ▶ chest wall prosthesis
- ▶ 3D titanium-printed technology

Introduction

Chest wall defects are relatively uncommon problems among the pediatric population. Different etiologies, from congenital (Poland syndrome) to acquired (malignant tumors) may lead to a deficiency.¹

There is a wide range of materials and options to reconstruct chest wall defects, from muscle flaps to prosthetic materials (both absorbable and nonabsorbable, both synthetic and bio-

logical: meshes, plates, bars, screws). There is no consensus on the optimal surgical approach. In any case, all of them have always the same goal: restore skeletal function (providing rigidity but allowing physiological chest excursion) and soft-tissue reconstruction to get the best cosmetic appearance.^{2,3}

The importance of skeletal reconstruction is highlighted when it's a large defect to be covered (more than four or five ribs resected, more than 5cm in the transverse dimension, more than two adjacent ribs, more than 200 cm²).^{2,4–6} In

received
 July 17, 2016
 accepted after revision
 September 3, 2016
 published online
 October 20, 2016

DOI <http://dx.doi.org/10.1055/s-0036-1593738>.
 ISSN 2194-7619.

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 Stuttgart · New York

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these cases it is mandatory to maintain structural integrity, protect vital intrathoracic organs, keep the dynamic stability of the chest (prevent paradoxical movement and preserve physiological pulmonary function), and support the actions of the upper extremities.^{3,5} Many techniques have been described for providing soft tissue coverage in these patients, but pedicled muscle or myocutaneous flaps remain the most common flaps for chest wall repair.⁶

In this report, we describe the reconstruction of a large chest wall defect using three-dimensional (3D) titanium implants and pedicled latissimus dorsi flap.

Case Report

A 14-year-old male patient was referred to our department for treatment of costal Ewing sarcoma. Physical examination revealed scoliosis and a palpable subscapularis mass. The chest computed tomography (CT) scan showed affection of the entire sixth rib (→Fig. 1A, B) and the subcutaneous tissue on the back forming a subscapularis mass. The patient had already received chemotherapy (six cycles of vincristine, ifosfamide, doxorubicin, and etoposide finished

2 months before the surgery) and neoadjuvant radiotherapy (36 Gy).

A 3D preoperative planning was performed for prosthetic design (ACV. External SL., Madrid, Spain). The healthy adjacent ribs (fifth and seventh) served as a model to design the custom-made implants that were going to be used as rigid support on the chest wall reconstruction. The implants were made of titanium alloy with a posterior attachment to be bound with a rib fragment and several perforations along itself. Each implant was divided in half to make the implantation easier (→Fig. 1C). The overall duration of the process was 4 weeks.

A multidisciplinary team that included thoracic, orthopedist, and plastic pediatric surgeons performed the surgery.

The patient was placed in the lateral decubitus position and an extended left posterolateral incision was made (→Fig. 1D). The first step of the surgery was the dissection of the latissimus dorsi flap pedicled on the subscapularis artery, releasing it from its iliac and spinal insertions. The patient underwent a complete resection including the entire sixth rib and the fifth and seventh leaving only two posterior centimeters for anchoring the implant later on. The surgical



Fig. 1 (A) CT scan showing tumor affecting sixth rib and the surrounding tissue. (B) Three-dimensional reconstruction of preoperative CT where the affected rib is highlighted. (C) Custom-made titanium implants (each one divided in half). (D) Patient's surgical position (right lateral decubitus): The oblique lines outline the sixth rib. The transverse solid line represents the incision site. The dotted lines represent the latissimus dorsi edges to the iliac crest, with its vascular pedicle based on subscapularis artery in red. CT, computed tomography.



Fig. 2 (A) Chest wall defect after complete resection of the piece, with latissimus dorsi muscle flap dissected. (B) Three-dimensional printing titanium ribs implanted into the chest wall with the underlying 1-mm Gore-Tex patch anchored to the prosthesis. (C) Final appearance with the pedicled latissimus dorsi flap covering the rigid prosthesis. (D) Postoperative appearance 3 weeks after the surgery: lateral view.

specimen was measured: $35 \times 12 \times 6$ cm (**Fig. 2A**). Targeted intraoperative radiotherapy was applied to the posterior margins (15 Gy).

The titanium ribs were bound with the remaining ribs by intramedullary screws on the back, and by wires to the costal cartilage on the anterior part. The anchoring between the two halves was also performed by wires (**Fig. 2B**). One of the implants did not properly fit to the anterior part protruding too much. That is why we decided to use a standard osteosynthesis' titanium plate (Synthes Spain, Madrid, Spain) previously molded and also fixed with wires, maintaining better geometry.

A thick Gore-Tex patch (1 mm) was fixed on the inner surface of the titanium ribs, sutured to the implant's perforation to maintain the natural curvature of the pleural cavity (**Fig. 2B**). Finally, soft tissue coverage was provided with the latissimus dorsi flap previously dissected. Endothoracic and subcutaneous drainages were placed (**Fig. 2C**).

The patient could be extubated in the operating room. No intraoperative or postoperative complications were observed. One of the subcutaneous drainages was removed on

the fifth postoperative day, and the others (including endothoracic ones) were removed 24 hours later. After 9 months of the surgery the patient has complete mobility.

Discussion

The morbidity and mortality of chest wall resections have been reported to be as high as 30 and near 50%, respectively.⁵ Progress in the anesthesia field, survival of oncological patients, and the development of new materials and reconstructive techniques have allowed a great improvement in postoperative outcomes.^{1,2,5}

The complications that should be avoided are: scapular entrapment, pulmonary herniation and paradoxical movement, parenchymal lesions due to material decubitus, permanent rigid deformity and, of course, minimization of the risk of prosthetic material fracture and migration.^{2,3}

The decision of restoring skeletal integrity is determined not only by defect size but also by defect location and condition of the surrounding tissues.² Skeletal reconstruction is required for anterior and lateral defects due to the fact that

they are highly mobile and this may result in a greater impact on respiratory function. Nevertheless, posterior deficiency usually just needs soft tissue coverage unless the defect is located at the tip of scapula due to the risk of scapular entrapment. Concerning the condition of the surrounding tissue it can determine the kind of reconstruction from anchoring rigid material, the contribution of muscle coverage or direct closure.^{2,5}

Conventional approaches include synthetic meshes (polypropylene, polyester, polytetrafluoroethylene, polyglactin-910), biological meshes (grafts from human dura, porcine collagen matrices, human acellular dermal matrices), and bone substitutes (allogeneic rib grafts, autologous rib and fascial grafts, methylmethacrylate and synthetic mesh “sandwich,” titanium implants, STRATOS system [Synthes Spain, Madrid, Spain], MatrixRIB fixation system [Synthes Spain]).¹⁻³ The meshes are easy to fix to the ribs and can be an excellent choice to cover small defects, but tend to lack rigidity and are unable to maintain the natural chest wall curvature if they are employed to cover a large deficiency. This not only has cosmetic importance but also functional importance because the anatomic alteration could lead to postoperative respiratory problems.^{2,3,7} There are multiple options available as the aforementioned, but most of them cannot be used to cover a defect that compromises the entire length of the rib because they are not long enough.⁸

The idea of using “neoribs” made from metal is not new, Gangolphe presented it in 1909.⁹ No consensus exists as to which product to use. Over the last decades titanium has been the most widely used metal; used as pure metal at the beginning and in alloys later on, since that it provides more strength than in isolation.³ The ideal characteristics of the prosthetic material are described: it should be sufficiently rigid to prevent paradoxical chest wall movement yet be malleable enough to allow shaping and fit in the defect. In addition, the material should be inert, radiolucent, and permit tissue incorporation.²

In our case, the defect measured $35 \times 12 \times 6$ cm and left a gap of three consecutive ribs from the transverse apophysis to the costal cartilage.

Due to the large size of this defect, we finally opted for custom-made titanium implants based on a 3D CT reconstruction. Recently a group from China published a similar case to ours, where they employed five custom-made prosthetic ribs.¹⁰ Aragón and Pérez Méndez, from Spain,¹¹ present a forward step creating a dynamic titanium-printed implant. We also found a pediatric case report published a few months ago by Anderson et al, from the United States.¹ They presented a case of Poland syndrome and another case of chest wall deficiency after osteosarcoma resection. They used a custom-made prosthesis in both cases with excellent results. It is the only reference we found in the English literature on biomimetic reconstruction in children.

Custom-made titanium implants offer personalized reconstruction with excellent function and cosmetic results, because it can provide almost infinite variety of designs according to the individual demands of each patient. However, it's important to keep in mind that the real surgical field

may differ from the surgery planned on 3D reconstruction or even intrasurgical findings may change the limits of the resection, which may lead to a lack of fit between the printed implants and the defect. It is exactly what happened to our patient. One of the implants bulged (probably because the residual rib was slightly over the length previously planned) and we preferred to use a combination of the back half of the custom-made implant and a standard osteosynthesis' titanium plate (Synthes). We recommend, as Wang et al,¹⁰ having prepared an alternative with conventional material.

Regarding the restoration of the pleural cavity, we choose a thick Gore-Tex patch (1 mm) which was sutured to the inner surface of the titanium ribs trying to maintain the natural shape of the pleural cavity. It provides a relative tightness and avoids complications such as decubitus parenchymal lesions and lung herniation among others.¹² We prefer this material over other absorbable meshes because of the primary diagnosis of this patient (Ewing sarcoma). The likelihood to develop pulmonary metastasis is really high and, therefore, we prefer to use a material that creates no adhesions to the surrounding tissue and not to hinder another eventual thoracic surgery.

Adequate soft tissue coverage is mandatory to be successful in chest wall reconstruction. In small defects a primary soft tissue closure may be the proper choice for prosthetic coverage,¹³ or even skin grafts or negative-pressure wound therapy. However, large defects or those where there is exposure of vital structures require a more complex reconstructive technique.⁴ In these cases, flaps are the best option for coverage. Myocutaneous, fasciocutaneous or muscles flaps are suitable, both pedicled and free. With the bountiful methods of pedicled muscle transfer and uncommon pedicled muscle flap loss, the necessity for the free flap in the reconstruction of the thoracic wall defect is minimal. According to Bakri et al, the flaps most commonly used are latissimus dorsi, pectoralis major, and rectus abdominis.¹⁴ In our case, we performed pedicled latissimus dorsi flap due to no infiltration of the muscle by the tumor, its large size and, obviously, the necessity of its dissection during the surgery. This allowed us to achieve almost complete coverage of the defect with minimal donor morbidity.

Finally, we want to emphasize the need of a multidisciplinary team to achieve good results in such a complex cases. In this surgery, resection is as important as reconstruction. Franco et al, from Brazil,¹⁵ suggested that the involvement of a plastic surgeon is a key element in planning the skin incision and dissecting the structures that allow preserving flap options to facilitate reconstruction but without harming surgical resection.² We believe that the presence of a surgeon used to working with the spine (pediatric orthopedist in our institution) is also beneficial if the resection extends beyond the costotransverse joint.

Conclusions

We think that a multidisciplinary team is mandatory for this surgery. The implant of custom-made ribs, combined with other techniques, is a good surgical choice for reconstruction

of large chest wall defects. The ideal implant should also be somehow malleable to allow implant adaptation during the surgery

Conflict of Interest

None.

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