Thoracic Cancer

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Thoracic Cancer ISSN 1759-7706

CASE REPORT

Three-dimensional custom-made carbon-fiber prosthesis for sternal reconstruction after sarcoma resection

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Keywords
Carbon-fiber prosthesis; chest wall reconstruction; custom-made prosthesis; sternal sarcoma.

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Received: 22 March 2019;
Accepted: 11 April 2019.

doi: 10.1111/1759-7714.13084

Thoracic Cancer **10** (2019) 1500–1502

Abstract

Radical resection is the preferred therapy for primary malignant sternal tumors. Sternal reconstruction is required to guarantee the best preservation of respiratory mechanics, and adequate mediastinal protection and acceptable cosmetic results after extensive tumor resection. A wide variety of methods and materials have been described for sternal reconstruction. Titanium implants are preferred by many surgeons because of their optimal features. However, the smooth surface of the metal prostheses does not facilitate the inward growth of the tissue, and the high density of metal can block the X-ray and cause adverse effects on postoperative imaging and radiotherapy. Therefore, in this article we present a case of sternal reconstruction by means of a three dimensional (3D) custom-made carbon-fiber prosthesis following extensive resection of a sternal synovial sarcoma. The microporous structure on the surface of the carbon fiber composite material facilitates the inward growth of the tissue. Low density (1.5 g/cm^3) of carbon-fiber implant will not block the X-ray and eliminates the adverse effects caused by metal material of postoperative imaging and radiotherapy. The 3D custom-made carbon-fiber prosthesis matched the thoracic defect perfectly and the chest wall reconstruction was stable for more than 24 months.

Introduction

Primary malignant sternal tumors (PMST) are uncommon and most are sarcomas, arising from the bone or soft tissues of the sternum.[1,2] Radical resection is the preferred therapy for primary malignant sternal tumors. Chest wall reconstructions, which are mainly needed after surgical treatment of malignant sternal tumors, are still a challenge for thoracic surgeons. While there is no consensus regarding the application of materials, a variety are available for sternal reconstruction, and the choice mostly depends on the location and defect size after radical resection. Most prostheses used for the chest wall reconstruction are titanium implants. However, the smooth surface of the metal prostheses does not facilitate the inward growth of the tissue, and the high density of metal will block the X-ray and cause adverse effects on postoperative imaging and radiotherapy. In this case, we present a case of sternal reconstruction by means of a three-dimensional (3D) custom-made carbon-fiber prosthesis after extensive resection of a sternal synovial sarcoma. This novel individualized treatment for sternal reconstruction produced satisfactory results and eliminates the adverse effects caused by metal implants.

Case report

A 61-year-old female presented with a 5 × 4 cm painful sternal mass. Computed tomography (CT) scan showed involvement of both pectoral muscles, the sternal body and the second to fourth left ribs (Fig 1a,b). Needle biopsy of the tumor revealed low malignant synovial sarcoma. Positron emission tomography-computed tomography (PET-CT) showed a 4 cm visible glucose metabolism increased sternal mass (maximum standardized uptake value = 42) with no other local or distant metastasis (Fig 1c–d). Preoperative pulmonary function tests showed mild ventilatory

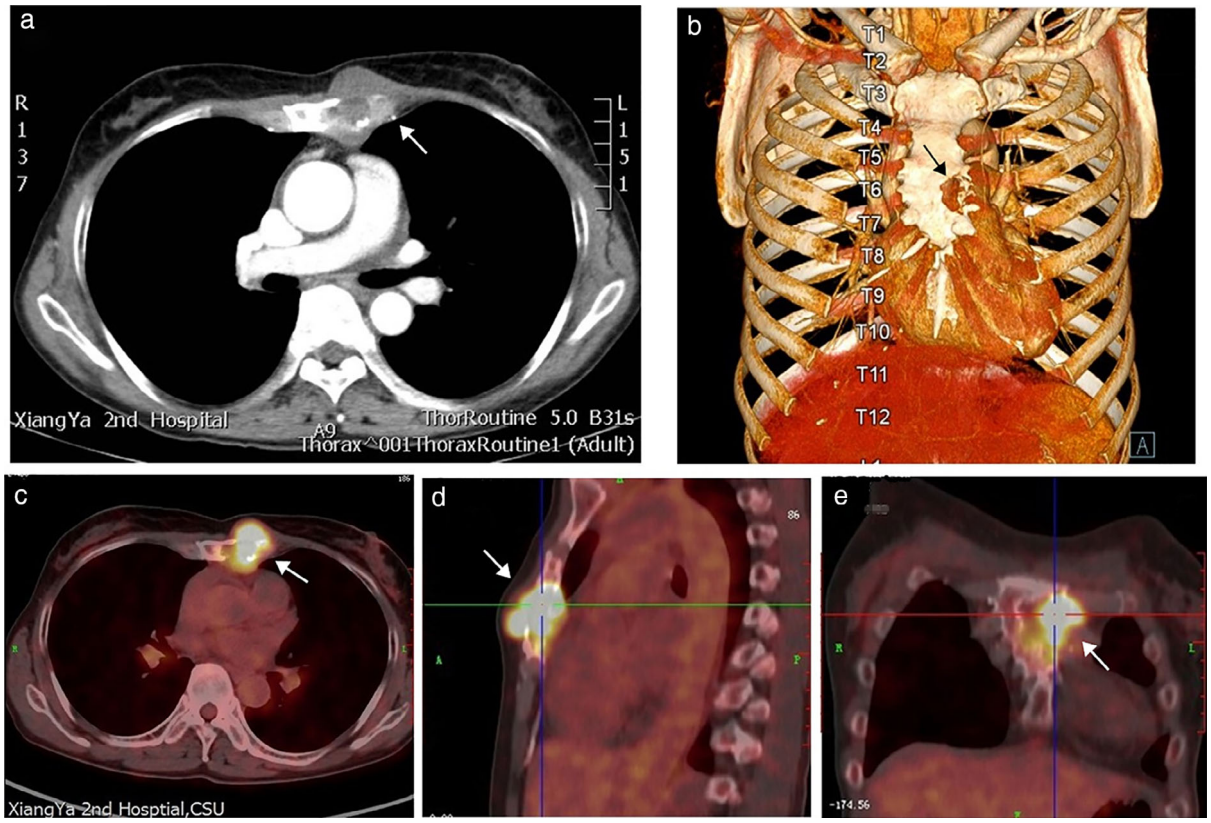

Figure 1 (**a**,**b**) Initial computed tomography (CT) scan of the thorax. White arrow indicates the sternal tumor. (**b**) 3D reconstruction of the chest skeleton. (**c**–**e**). Initial positron emission tomography-computed tomography (PET-CT) scan of different sections showed a 4 cm visible glucose metabolism increased sternal mass (maximum standardized uptake value = 42). White arrow indicates the glucose metabolism increased mass.

dysfunction (best forced expiratory volume in one second, 1.68 L; ratio of forced expiratory volume in one second to forced vital capacity, 83.17%) and normal diffuse dysfunction. Extensive tumor resection and sternal reconstruction was planned after preoperative assessment. A three-dimensional (3D) carbon fiber-printed prosthesis to achieve an optimal sternal reconstruction was proposed and approved by a multidisciplinary committee.

Firstly, a 3D model of chest skeleton was caused by MIMICS software (Materialise Magics; Materialise Software, Leuven, Belgium) with CT data analysis. The structural improvement and defect connection processing were then performed in the 3D electron model. A custom implant was then manufactured with the carbon fiber 3D sintering printing technique (Tankang biotech, Changsha, China) (Fig 2a). We performed the tumor extensive resection and caused an 8 × 7 cm thoracic defect (Fig 2a,b). The custom-made carbon-fiber implant had been fixed to rib stumps using the cruciate ligament sutures and separately to manubrium using steel wires (Fig 2b). The sutures woven on the implant were used for flap adhesion when the incision was closed (Fig 2b). Surgery was successful with normal postoperative thorax shape and thoracic respiratory movement. The patient was discharged seven days later. The prosthesis did not cause any subjective discomfort during 24-month follow-up and obtained acceptable cosmetic results. Radiographic results showed that the carbon fiber prostheses were fixed well, with no shift or deformation (Fig 2c) and the lung was in good condition. Postoperative pulmonary function tests showed mild ventilatory dysfunction (best forced expiratory volume in one second, 1.49 L; ratio of forced expiratory volume in one second to forced vital capacity, 73, 76%) and normal diffuse dysfunction.

The institutional review board of our hospital approved the study. The patient gave informed written consent to report her case.

Discussion

The majority of traditional materials for sternal reconstruction are Goretex soft tissue patches, prolene mesh patches and autologous myocutaneous flaps.[3] In recent years, the titanium alloy material has gradually been used in sternal

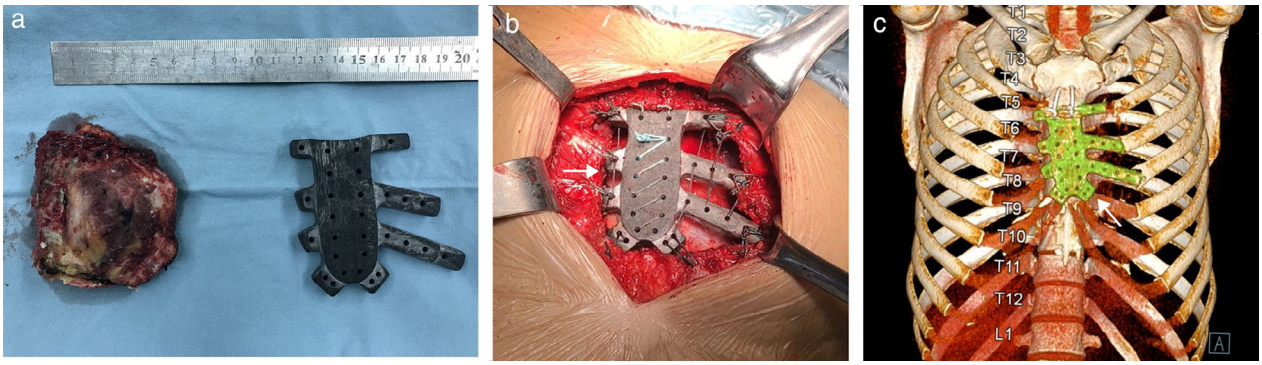

Figure 2 (**a**) The tumor excised during the surgery and the 3D custom-made carbon-fiber implant. (**b**) The custom prosthesis implanted into the sternal defect with the cruciate ligament sutures and steel wires. (**c**) 3D reconstruction of chest skeleton with the CT data six months after surgery. White arrow indicates the custom-made implant.

reconstruction. However, these materials have unavoidable shortcomings. The ideal prosthetic material for chest wall reconstruction should have the following characteristics.[4]

- Rigidity to abolish paradoxic chest wall motion
- Malleability to allow for appropriate contouring
- Physically and chemically inert
- Allowance for tissue in-growth
- Radiolucent
- Sterile and resistant to infection

Gore-Tex soft tissue patches and prolene mesh patches are inherently deficient in strength and rigidity and therefore cannot provide sufficient structural support for the chest wall. Titanium mesh plates are made of inelastic material, and it is difficult to restore the original structure and obtain an acceptable cosmetic effect of the chest wall when the thorax defect is large.

The choice of 3D custom-made titanium-printed prosthesis (3D-CTPP) by José L. *et al.*[5] and Isabel Simal[6] seems to be an optimal solution for sternal reconstruction, and also achieves a better cosmetic result and strength. However, as a metal material, titanium will not only affect the postoperative imaging around the implants, but also block the radiation therapy and decrease the accuracy of the radio therapeutic dose. The smooth surface of the metal prostheses does not facilitate the inward growth of the tissue. The 3D custom-made carbon-fiber implant with relatively low density (1.5 g/cm^3) could eliminate the adverse effects caused by metal material and ensure the high accuracy of postoperative imaging and radiotherapy. The microporous structure on the surface of the carbon fiber composite material facilitates the inward growth of the tissue. Moreover, one month was required to create the 3D-CTPP in the study by Aranda *et al.*[5] which may have resulted in intraoperative difficulties, or worsened the disease prognosis. However, only seven days were required to create the carbon-fiber implants for surgery in the present study, minimizing the impact on surgery caused by tumor progression.

In conclusion, we reported a case of sternal reconstruction with a customized 3D carbon-fiber implant. This is a novel individual treatment for sternal reconstruction which produced a satisfactory result.

Acknowledgments

This research received technology support from Hunan Tankang Biotech Company and was supported by a grant from the Key Research and Development Program of Hunan Province (2018SK2103).

Disclosure

No authors report any conflict of interest.

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