The first Hong Kong–made three-dimensional–printed sternal implant for metastatic follicular thyroid carcinoma: a case report

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Case presentation

A 58-year-old female with good past health presented with an enlarging sternal mass. Computed tomography revealed a 7-cm osteolytic mass in the lower sternum with cortical destruction (Fig 1a and b). Core biopsy revealed metastatic follicular thyroid carcinoma (FTC) with oncocytic cell differentiation. Ultrasound of the thyroid showed a 1-cm calcified right thyroid nodule, and fine needle aspiration cytology suggested an oncocytic cell neoplasm.

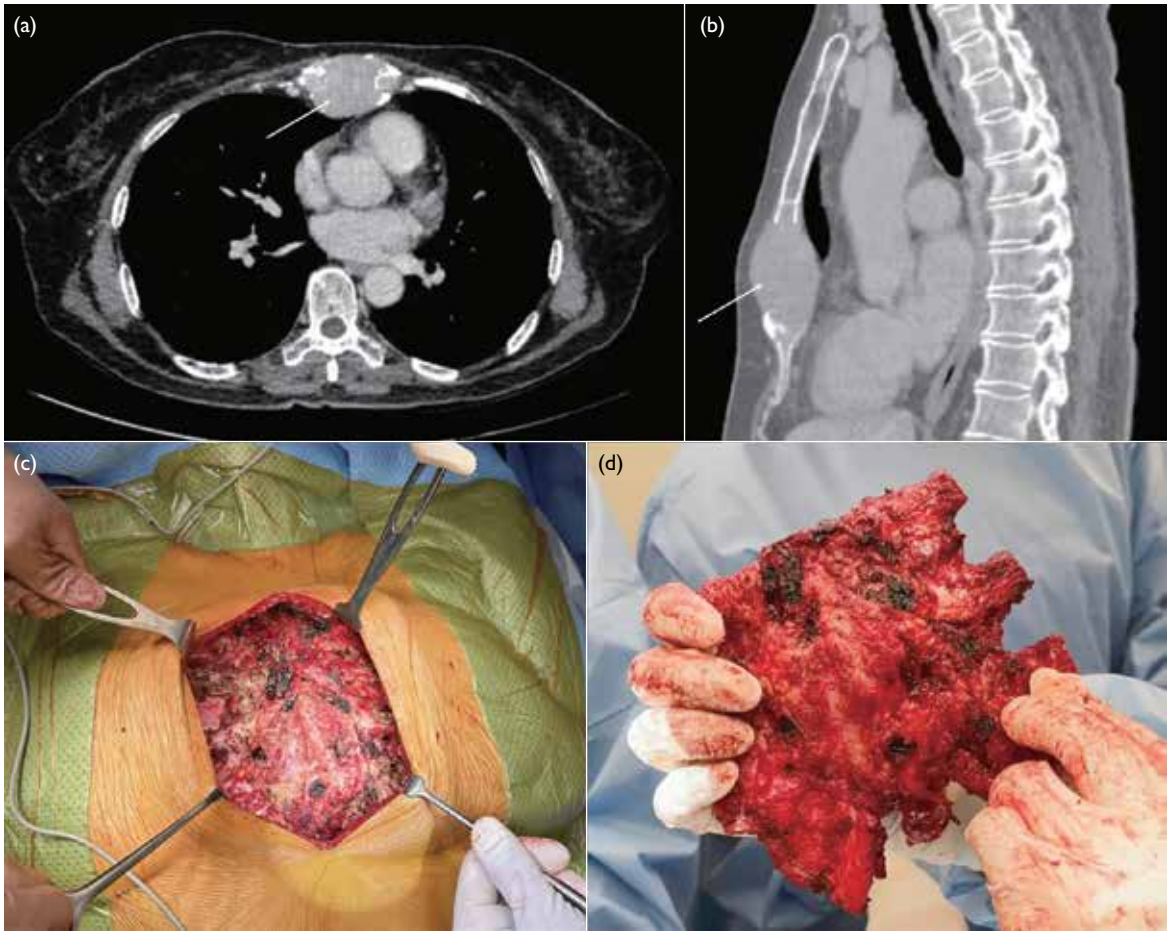

FIG 1. Sternal metastasis from follicular thyroid carcinoma. (a) Axial and (b) sagittal cuts of computed tomography images showing the lower sternal metastasis (arrows). (c) Intra-operative photo before resection. (d) En bloc resected sternal metastasis with part of adjacent ribs

^{18}F-fluorodeoxyglucose positron emission tomography–computed tomography demonstrated avid uptake in the right thyroid lesion, small pulmonary metastases and bone metastases, the largest at the sternum, with small lesions in the right mandible, left scapula and left tenth rib.

As the large sternal metastasis caused severe pain, en bloc resection of the sternal tumour was performed along with the medial ends of the bilateral anterior ribs (Fig 1c and d). The bony resection margin was determined preoperatively using the data from positron emission tomography–computed tomography and virtual planning software (Mimics; Materialise, Leuven, Belgium). Reconstruction was performed with a custom-designed three-dimensional (3D)–printed titanium alloy implant (Ti6Al4V Grade 23; Koln 3D Medical, Hong Kong, China) [Fig 2]. Finite element analysis was performed to optimise the design for implant longevity by eliminating stress risers. The 3D-printed surgical guides ensured precise bone cuts and accurate implant fitting. The total planning and production time was 45 days, and the implant weighed 699 g.

The superior part of the implant was fixed to the native manubrium with eight 3.5-mm orthopaedic angle-stable titanium locking screws (DePuy Synthes, West Chester [PA], US). The undersurface of the implant was porous to allow bone ingrowth, enhancing long-term stability. Laterally, the implant comprised sockets accommodating the native third to fifth rib stumps, which were further secured with non-absorbable No. 2 FiberWire sutures (Arthrex, Naples [FL], US). Inferior to the sixth rib, the conjoint costal cartilage stump was loosely opposed to the implant using sutures passed through pre-formed holes of the implant. A Permacol (Medtronic, Minneapolis [MN], US) mesh was placed over the anterior surface of the implant, above which the muscle flap and skin were closed primarily.

Histopathological examination of the sternal specimen confirmed metastatic FTC with clear margins. The patient made an uneventful recovery and subsequently underwent total thyroidectomy, which demonstrated multifocal FTC with extensive capsular invasion.

Postoperatively, the patient received two courses of radioiodine therapy and continued bisphosphonate treatment with thyroid-stimulating hormone suppression. At 1.5 years after the operation, she had stable disease, was pain-free, and had resumed work and independent daily activities.

Discussion

To the best of our knowledge, this is the first 3D-printed sternal implant manufactured in Hong Kong using medical-grade titanium alloy powder (TiAl4V Grade 23) by direct metal laser sintering.

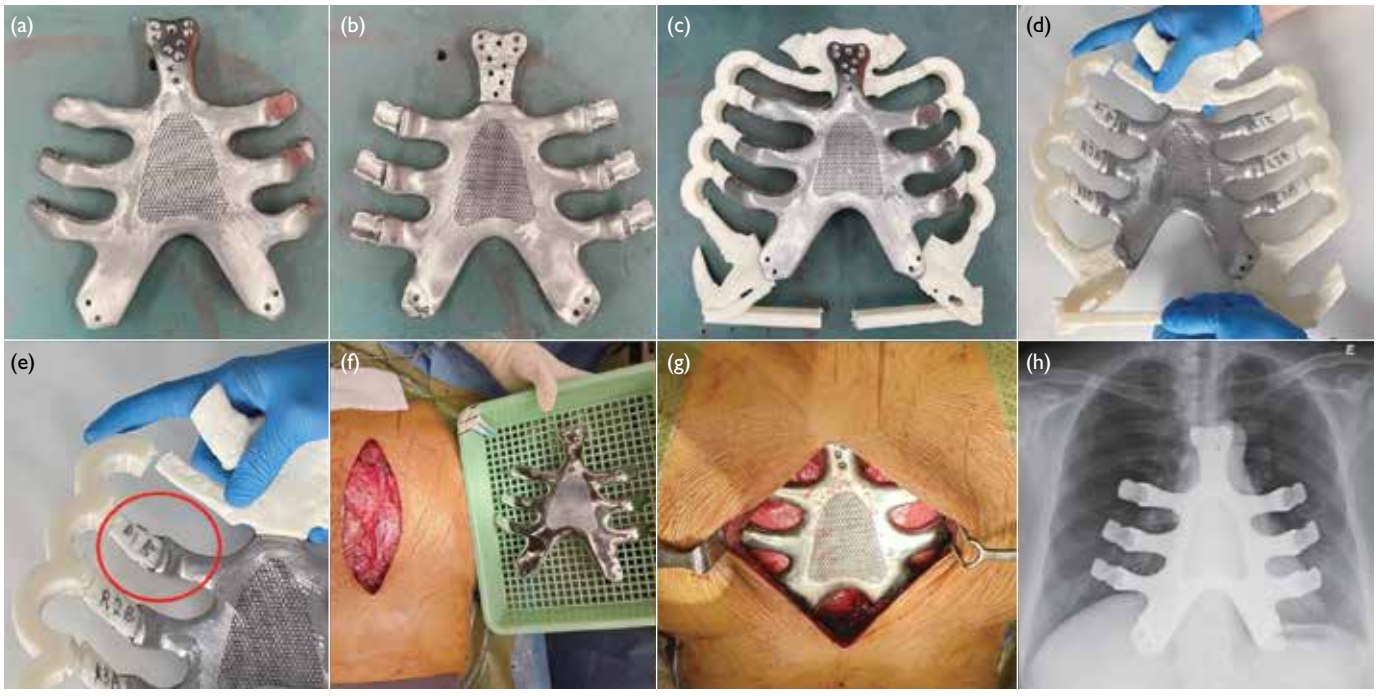

FIG 2. (a) Anterior view and (b) posterior view of custom-made three-dimensional–printed titanium alloy implant (Ti6Al4V Grade 23). (c) Anterior view and (d) posterior view when fitted on the patient's rib cage model. (e) Socket design at the junction between the lateral aspect of the implant and the patient's rib (circle). (f) Surgical field before implant placement. (g) Completed implant fixation. (h) Postoperative chest radiograph showing the implant

This custom-made implant represents a novel reconstructive option that provided excellent symptomatic relief. It restored the form and strength of the anterior chest wall while allowing chest wall motion through its rib-socket design. Previous case reports and series on resection of sternal metastases from FTC have utilised alternative reconstructive methods, including pectoralis major flaps, Marlex mesh, Gore-Tex mesh, titanium mesh, and acrylic plates.[1]

Follicular thyroid carcinoma is the second most common type of well-differentiated thyroid cancer after papillary thyroid carcinoma. Although the presence of distant metastases is a poor prognostic factor, the 5-year disease-specific survival rate for metastatic FTC can be as high as 82.2%.[2] Given this considerable life expectancy, balancing oncological with symptomatic relief is essential for optimal management.

Radioactive iodine is less effective in treating bone metastases from differentiated thyroid cancer. Surgical resection of bone metastases has been recommended for patients with solitary lesions with curative intent and for those causing significant morbidity for symptomatic palliation. Furthermore, metastasectomy for maximal tumour debulking may facilitate the effectiveness of radioiodine therapy, as a higher dose can be concentrated in residual malignant cells.[1]

The custom-made implant and tumour resection plan were based on the patient's fine-cut computed tomography images. The implant's central mesh structure was not anatomically identical to the sternum or costal cartilages but still served to protect the mediastinal structures. The mesh design reduced implant weight and allowed soft-tissue ingrowth, theoretically reducing infection risk. Post-processing involved proprietary heat treatment to reduce internal stress and material brittleness, while electropolishing smoothed the surface to reduce fatigue failure.

A 3D-printed polymer rib cage model was made to determine a good fit of the implant, and simulate the implantation process (Fig 2c to e). The lateral parts of the implant connected to the bilateral third to fifth ribs via 2-cm–deep socket design, allowing rib fixture without screws (Fig 2e). This unique design was adopted from the growing orthopaedic implants used in children,[3] and enabled free movement of the junctions between the implant and ribs as well as chest wall expansion and contraction during breathing.

In previously reported custom sternal implants, superior fixation was typically achieved using angle-stable screws in the remaining manubrial bone.[4,5] Costal fixation methods varied: most designs used rigid screws while others incorporated flexible elements at the rib junction, such as polymer material, spring mechanisms or metal cables and wires, to enhance implant flexibility.[6] One case report described two paediatric patients with a partially slidable design, theoretically accommodating chest cavity growth.[7] Nonetheless, fatigue failure remains a concern across designs, given the human respiratory cycle of approximately 25 000 breaths per day and over 250 million cycles over a 30-year lifespan. Long-term follow-up of patients with custom sternal prostheses would provide valuable insight into optimal design and fixation methods.

Our design theoretically reduces metallic stress and long-term fatigue risk by preserving motion at the rib-implant junction. Activities of daily living were gradually resumed, and exercise tolerance remained unaffected. The surgery successfully improved our patient's quality of life, which is vital given the relatively prolonged survival with FTC.

This implant achieved excellent functional outcomes and may serve as a model for reconstruction of large anterior chest wall defects. With technological advancements in 3D printing, similar custom-made implants will be more readily available in the near future, tailored to individual patient needs. This case demonstrates a novel treatment for sternal metastasis. Appropriate patient selection with good premorbid status and reasonable life expectancy is crucial to ensure maximum benefit from such surgery.

Author contributions

All authors contributed to the concept or design, acquisition of data, analysis or interpretation of data, drafting of the manuscript, and critical revision of the manuscript for important intellectual content. All authors had full access to the data, contributed to the study, approved the final version for publication, and take responsibility for its accuracy and integrity.

Conflicts of interest

All authors have disclosed no conflicts of interest.

Declaration

This case was presented at the Interesting Case session at the International Surgical Week 2024 held in Kuala Lumpur, Malaysia, 26-29 August 2024.

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This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Ethics approval

This study was approved by the Institutional Review Board of The University of Hong Kong/Hospital Authority Hong Kong West Cluster, Hong Kong (Ref No.: UW 25-049). Written informed consent was obtained from the patient for publication of this case report along with the clinical images.

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