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Short survey

3D-modeling of sternal chondrosarcomas from angio-CT-Scan: Clinical application and surgical perspectives☆

R. Burgade [a,b,*], J.F. Uhl [c], G.D. Prat [c], C. Ruiz [c], B. Lorea [d], V. Delmas [c], P. Rosset [a,b], L.R. Le-Nail [a,b]

[a] Service of Orthopaedic Surgery and Traumatology, CHU Tours, Université François-Rabelais de Tours, Centre-Val de Loire Université, Tours, France
[b] Inserm U957, Laboratoire de Physiopathologie de la Résorption Osseuse et Thérapie des Tumeurs Osseuses Primitives (LPRO), Faculté de Médecine, Université de Nantes, 44000 Nantes, France
[c] Anatomy laboratory, UFR biomédicale des Saints- Pères, université Paris-Descartes, 75006 Paris, France
[d] Laboratorio de Investigaciones Morfológicas Aplicadas "Dr. Mario H Niveiro", FCM, UNLP, La Plata, Argentina

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A B S T R A C T

Introduction. – Malignant bone tumors of the sternum are rare. Their surgical treatment remains largely based on precise knowledge of preoperative imaging in order to define appropriate margins during tumor resection. We provide a practical 3-dimensional (3D) modeling method to better understand the relationships between these tumors and neighboring organs.
Methods. – Axial view images from CT-scans were processed by the open source software Horos® after anonymization. A first surface reconstruction was carried out by the software to form a digital mesh. This raw model was processed by Meshmixer® software (Autodesk™) in order to remove artefacts. These models underwent a surface reduction of the mesh using Meshlab® software and were hosted on a secure private platform.
Results. – Six angio CT-Scan were performed in three patients with chondrosarcomas of the sternum. The segmentation of organs and vessels has made it possible to create a real 3-D anatomical board. Each of these protected models can be viewed on our server and can be manipulated virtually on 360° using the secure links provided in this article. 3D vision was available using inexpensive cardboard virtual reality glasses.
Conclusion. – The use of computer modeling could help in the teaching of anatomy, but also in the understanding of the disease by the patient himself. One of the perspectives would be the 3D printing of biocompatible materials in order to carry out tailor-made reconstructions.

Introduction

Chondrosarcoma is the most common primary bone tumor after osteosarcoma [1]. The sternum is a rare localization of chondrosarcoma with less than 1% among the bony sites [2]. The curative treatment of these tumors is based exclusively on cancer surgery [3]. Computer Aided Modeling (CAM) is a rapidly expanding tool in anatomy and surgery [4,5]. We present 3 cases of sternal chondrosarcomas which were treated after CAM using computed CT-scans.

CASE REPORTS

Case 1

An 80-year-old woman presented with swelling over the left third sternocostal joint with increasing in size for several months. The patient underwent a left mastectomy nine years earlier following an adenocarcinoma classified ACR 2, which occurred at the age of 71, treated by adjuvant radiotherapy. The CT scan found a single intraosseous tumor measuring 5 × 4.5 × 3 cm consisting of a cartilaginous matrix (Fig. 1) without secondary lesions. The anatomo-pathological examination of the surgical biopsy made it possible to diagnose a grade 1 chondrosarcoma compatible with a radiation-induced lesion. A sub-total sternectomy removing the

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* Corresponding author at: Service of Orthopaedic Surgery and Traumatology, CHU Tours, Université François-Rabelais de Tours, Centre-Val de Loire Université, Tours, France.
E-mail addresses: rodolphe.burgade@gmail.com (R. Burgade), jeanfrancois.uhl@gmail.com (J.F. Uhl), gdprat@gmail.com (G.D. Prat), ruizcam95@gmail.com (C. Ruiz), lima@med.unlp.edu.ar (B. Lorea), vdelmas39@gmail.com (V. Delmas), philippe.rosset@orange.fr (P. Rosset), lrlenail@hotmail.com (L.R. Le-Nail).

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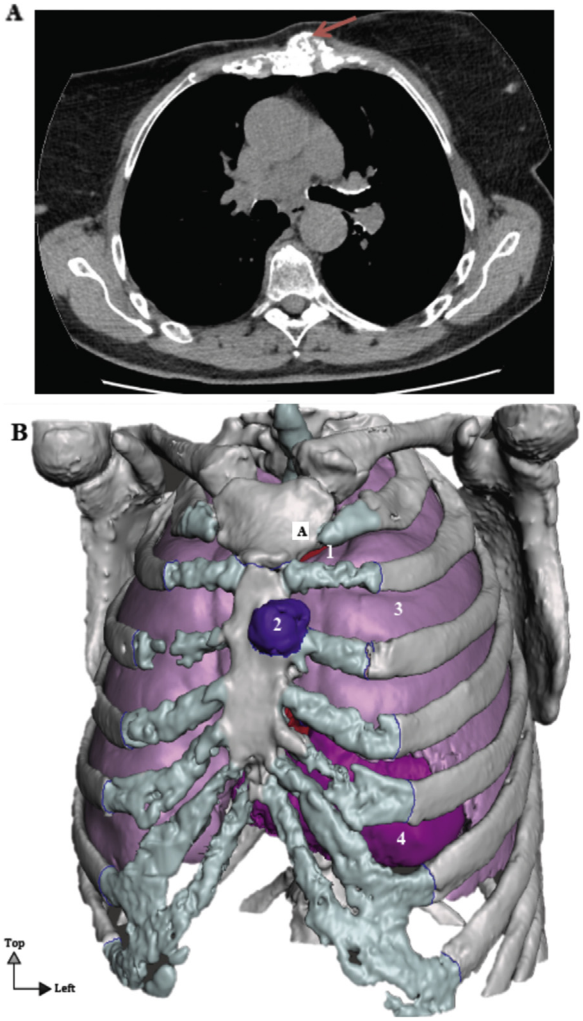

Fig. 1. A: CT scan in axial section passing through Th7 (arrow representing the tumor). B: 3D model according to the preoperative CT scan in anterior view. (1: internal thoracic artery, 2: tumor, 3: upper lobe of the left lung, 4 tip of the left ventricle).

2nd, 3rd and 4th sternocostal joints bilaterally was performed (Fig. 2) then followed by reconstruction with a massive titanium prosthesis associated with a bilateral pectoralis major flap (Fig. 3). The resection was complete (R0) without invasion of the margins and no adjuvant treatment was performed (Fig. 4). No tumor recurrence or infectious complication was observed after 2 years of follow-up.

Case 2

A 43-year-old woman with no medical history presented with diffuse sternocostal pain in which an x-ray found a tumor of the manubrium sternal. A chest CT scan and MRI showed a single cartilaginous-looking lesion located in the sternal manubrium measuring 10 × 7 × 5 cm, with the bone scan showing no secondary lesions. A surgical biopsy was performed by direct anterior approach and made the diagnosis of grade I chondrosarcoma. A carcinological resection was carried out removing the two sternocostal joints as well as the manubrium. Resection was complete and reconstruction using a flapless Vicryl® plate was performed. No tumor recurrence or infectious complication was observed 6 months postoperatively.

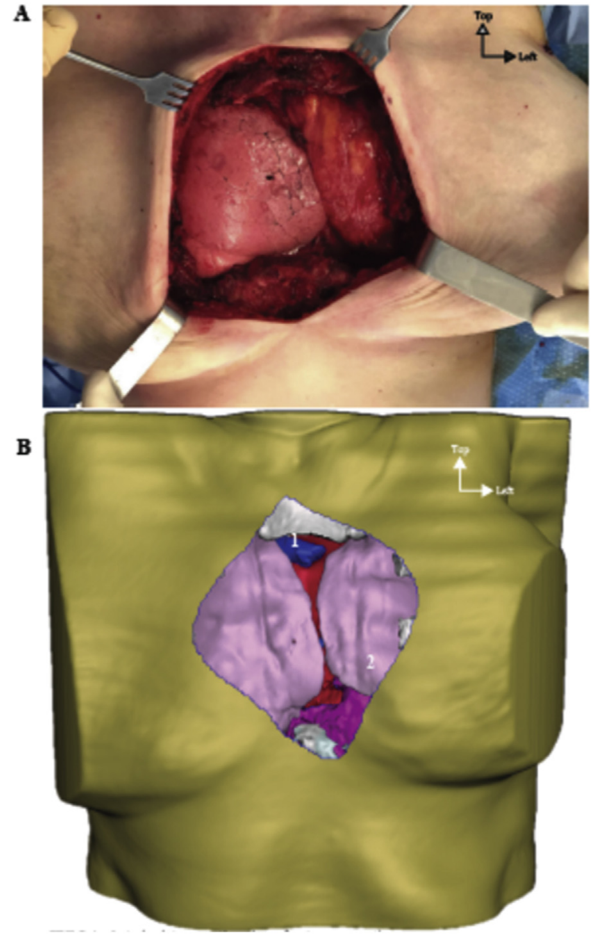

Fig. 2. A : Anterior intraoperative view after tumor resection. B : Modeling according to the preoperative CT-scan after removing the sternum (1: left brachiocephalic venous trunk, 2 : upper lobe of the left lung coverning the heart shape).

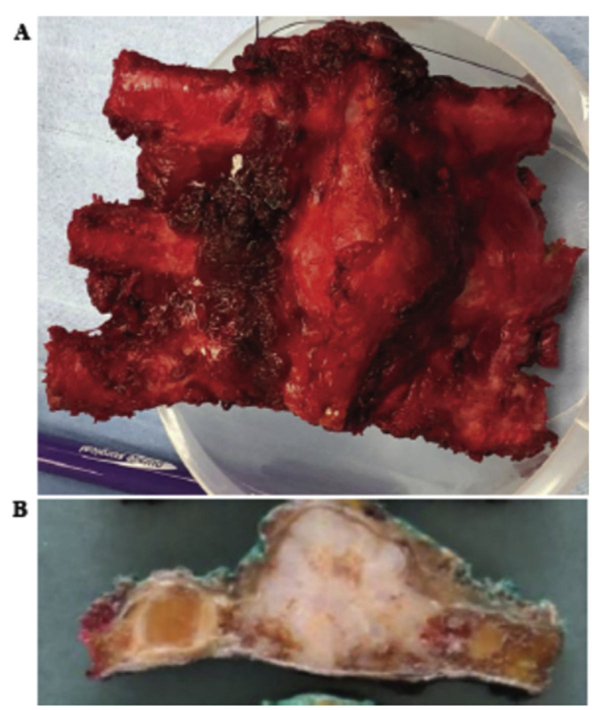

Fig. 3. A : Operative part in front view after resection. B : Axial section for anatomopathological analysis.

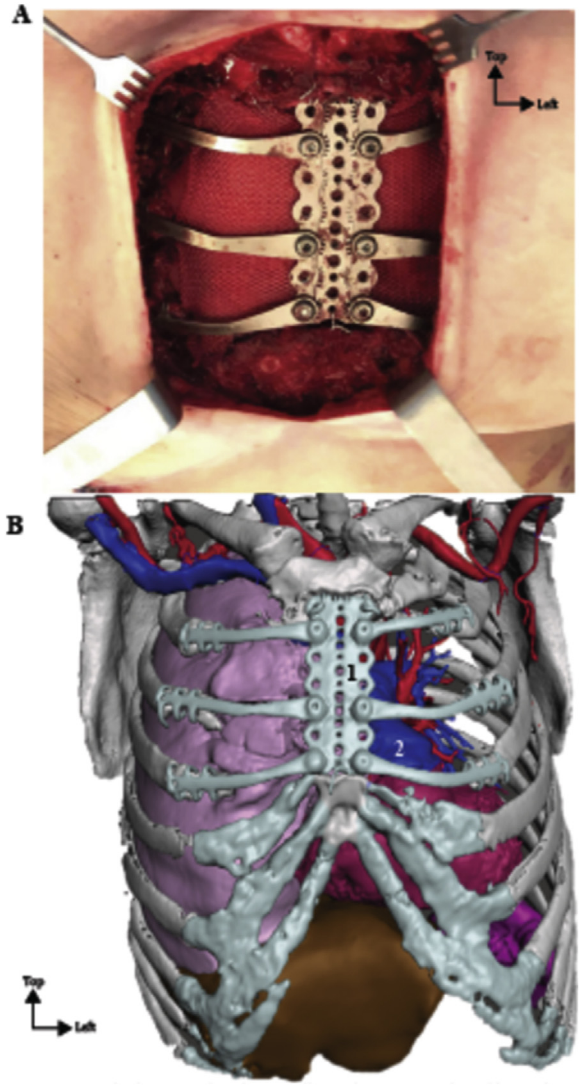

Fig. 4. A : anterior intraoperative view according to the reconstruction with massive sternal prosthesis and Vicryl® plate. B : Modeling after postoperative CT scan in anterior view (1 : massive prosthesis, 2 : Pulmonary arterial trunk).

Case 3

A 66-year-old man with no history had pain in the right sternocostal joint for 1 year along with the appearance of a mass which gradually increased in size. MRI and computed tomography revealed a $5.5 \times 5 \times 5.1$ cm cartilage tumor developed in the lower part of the right sternoclavicular joint in contact with the anterior arch of the 2nd rib. A surgical biopsy was performed and diagnosed with dedifferentiated chondrosarcoma. The extension assessment by thoraco-abdomino-pelvic scanner did not show any distant secondary lesions. Carcinologic resection was performed removing half of the manubrium sternal, the right sternocostal joint and the first two right ribs. Reconstruction was performed using a Vicryl® plate without adding a flap. There was no tumor recurrence or infectious complication observed apart from persistent paradoxical breathing 2.5 years postoperatively.

Methods

The inclusion criteria concerned all patients who had a surgically treated sternum tumor and who had a pre and postoperative CT scan. The examinations were carried out on two types of scanner (SOMATOM® Force and SOMATOM® Definition AS +, SiemensTM Healthineers, Erlangen, Germany). The concentration of the contrast agent used was 370 mg iodine / ml, injected at 4 mL / s. The images were exported using PACS® (Picture Archiving Communication System) consoles from our Hospital center.

Once the chest scan was performed, the data was processed in DICOM (Digital Imaging and Communication in Medicine) format. Our reconstruction method consisted of 3 stages:

The first step consisted of a first surface reconstruction carried out by the Horos® software available for Mac OS-X Apple® 32 and 64 bits [6]. It was a free (open-source) software that allows us to analyze data and build 3D vector models. The theoretical principle of this process is based on the indexing of axial CT slices to form a digital mesh and create a solid form from polygons.

3D vector modeling can be an automatic or manual process. One of the automatic methods is based on establishing a Hounsfield unit (HU) threshold, allowing a value to be associated with each of the pixels on each of the CT slices. Thus only the pixels of the images included in the mentioned threshold were reconstructed in 3 dimensions. It is a particularly useful technique for tissues with extreme HU values such as vessels, bone segments, or air cavities. These structures can also be reconstructed manually by defining a perimeter around them, which is useful for soft tissues that cannot be reconstructed using automatic algorithms. However, this process is longer and less precise because it requires repeating the same operation on all the CT slices.

A second step consisted in simplifying and improving the contours of the models created by the Horos® software using dedicated software. Meshmixer® [7] is an example of free software developed by Autodesk™ that was used for editing vector models by allowing modification and delineation of the triangular mesh that made up the 3D vector model recovered from the scanner. A wide variety of tools were useful for correcting artefacts in the object's mesh and for segmenting different structures and thus separate vascular structures from bone structures, for example.

To achieve surgical planning, a preoperative reconstruction was performed in which the vessels were segmented and stained according to traditional anatomical colors. The tumor was arbitrarily shown in purple (Fig. 1). The process of segmentation was ultimately very similar to dissection. Another interesting feature was the creation of a simulation of the first approach after tumor resection from the preoperative modeling which was very similar to the intraoperative vision after the tumor was removed en bloc.

Finally, a reconstruction was carried out from the postoperative tomodensitometric data. The intraoperative surgical vision was also very similar to our model during reconstruction (Fig. 4). Once the models were created, these 3D files in *.obj* format underwent a surface reduction of the mesh using the Meshlab® software [8] in order to lighten the file. These anonymous files were hosted on a secure private platform that only link holders can obtain [9]. These models remained protected and made it possible to manipulate the modeling over 360° with virtual reality technology thanks to a smartphone, by attaching an economical 3D vision kit to it to obtain an immersive vision. Thumbnails were added to the models in order to present the different anatomical structures.

Results

Six CT-scans including 3 preoperative scans and 3 postoperative scanners were modeled using our technique for the three patients. These models can be viewed on our private platform by using the following links or by scanning these flashcodes (separately) using a smartphone:

Case 1

Pre-operative modeling:
https://sketchfab.com/3d-models/modele-1−7ff82f9340c041378ebb9b26a24c935e

Once the tumor had been resected by a xypho-pubic approach, post-operative modeling made it possible to highlight the anchoring of the reconstruction prosthesis on the 2nd, 3rd and 4th ribs.

Post-operative modeling:
https://sketchfab.com/3d-models/cas-1-postop-1796fd428ad84e42b7fb7ace6fd2a38b

Case 2

Pre-operative modeling:
https://sketchfab.com/3d-models/cas-2-pre-operatoire-9c522d54c3ff4c698ffbd5101cf97087

The preoperative modeling allowed to underline the relationship between the tumor and the left brachiocephalic venous trunk, as well as with the internal thoracic arteries. We note that these arteries were ligated as expected after their birth at the underside of the subclavian arteries according to postoperative modeling.

Post-operative modeling:
https://sketchfab.com/3d-models/cas-2-post-operatoire-f2228d7e0f2649f4a3f80da9149206ca

Case 3

Pre-operative modeling:
https://sketchfab.com/3d-models/cas-3-pre-operatoire-fe4f745c3bf3496795dbc77ce7cc3c47

A right hemi-manubriectomy was performed to remove the tumor after ligation of the internal thoracic vein and artery which were demonstrated on preoperative modeling. The main danger of the intervention was the subclavian vein wich was clearly visible on the 3D virtual model.

Postoperative modeling made it possible to visualize the osteotomy zone at the level of the manubrium in 3D. A custom embedded biological reconstruction could be printed in biomaterial using identical modeling software. This could help fight paradoxical breathing caused by the excessive expansion of the upper lobe of the right lung in the loss of bone substance visible on this postoperative model.

Post-operative modeling:
https://sketchfab.com/3d-models/cas-3-post-operatoire-00578f1ebb8e42069ebff105516b12fb

Discussion

The development of 3D technology makes it possible to supplement the spatial information provided by tomodensitometric sections. Details and some anatomical relationships can be more easily analyzed in three-dimensional vision. Virtual reality and 3D printing could still provide additional help in understanding a 3D structure compared to that displayed on a flat screen. The benefits of using these new tools would be to obtain visual and tactile feedback before surgery, which could help recreate the 3D architecture of the patient's lesion in the mind of the surgeon before entering in the operating room [10].

3D modeling of these bone tumors would provide a better understanding of the proximity to neighboring organs that present a risk during surgical resection such as the internal thoracic arteries, the left brachiocephalic venous trunk and the anterior costo-mediastinal sinuses which can largely cover the heart silhouette [11]. This 3-dimensional view would also make it possible to better understand certain vascular anatomical variations encountered on the first pathway, providing security thanks to this anticipation.

The reconstruction of a loss of substance caused by the resection of a tumor of the sternum remains difficult and not without mechanical and infectious complications. Some teams use a synthetic Vicryl® plate that serves as a support for flaps such as the perforator flap from the deep inferior epigastric artery type DIEP (Deep Inferior Epigastric Perforator) [12]. These pedicled or perforating flaps made it possible to cover a massive prosthesis and a chondrosternal allograft in some teams [13]. Other surgeons are using 3D modeling from the patient's scanner to make custom 3D printed slice guides to accurately guide tumor resection. An allograft was cut to size by another guide and made it possible to fill the loss of substance precisely [14]. Our 3D modeling technique of these tumors could make it possible to consider the production of cutting guides or even the printing of custom biomaterials to reconstruct these losses of complex substances.

Although these new technologies come at a high cost and require technical knowledge when introduced nowadays, the low cost and simplification of software have made these new tools accessible.

This would allow the surgeon to perform patient-specific 3D modeling improving surgical planning for cases where surgery would be particularly delicate. 3D modeling from the scanner would allow the creation of custom prostheses, which could reduce certain mechanical complications [15]. Another approach would be to create virtual or 3D printed simulators to train residents in surgery [16]. 3D models identical to those we have presented could thus be created from an angio-scanner.

However, our modeling method has a limitation such as the use of several software which requires training and sometimes manual control of the segmentation. However, this could be solved by automatic segmentation software such as Nextmed® [17] which runs on a digital tablet, which would allow the surgeon to simplify and speed up the production of 3D models.

Conclusion

Our 3D modeling technique of sternum tumors seems to help the surgeon to achieve a more precise anatomical assessment and better define the operating strategy. Easy to use, 3D modeling using open-source software would provide an educational, scientific but also surgical approach, the main objective of which is to better understand the patient's anatomy in order to optimize interventions and reduce complications.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

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