Three-dimensional printed heart model for surgical reconstruction of the right atrium in a patient with malignant heart tumor

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Three-dimensional printed heart model used to enhance the right atrium reconstruction.

CENTRAL MESSAGE

Malignant tumors in the right atrium often infiltrate a substantial part of the atrial wall. Three-dimensional printed heart models enhance surgical planning of atrial reconstruction.

▶ Video clip is available online.

CASE REPORT

We report on a 43-year-old female patient with a large metastatic melanoma located in the right atrium (RA). The detailed report on the patient's medical history and diagnostic process has recently been published by Sajdok and colleagues.[1]

In brief, contrast-enhanced computed tomography performed on a Siemens Somatom 64-row scanner showed a hypodense mass (37 × 41 × 44 mm) in the RA infiltrating the RA free wall and the right coronary artery. It was adjacent to the anterior leaflet of the tricuspid valve, but did not impair the mobility of the tricuspid leaflets (Figure 1). Echocardiography revealed a hyperechogenic mass in the RA (33 × 31 mm) in the 4-chamber view. No valvular disorders were present.

The general clinical condition of the patient was good despite the dissemination of the melanoma. She was receiving immunotherapy with ipilimumab and nivolumab at the time of presentation. The deterioration of exercise tolerance, significantly limiting her everyday activity, was likely attributable to the metastasis in the RA. Therefore, surgical extraction of the tumor was attempted. Preoperative imaging showed the tumor arising from the atrium free wall, infiltrating most of its surface. It had to be assumed that surgical intervention might involve the resection of the majority of the atrial wall to achieve a clean oncological margin. In such circumstances, a standard intraoperative visual assessment might not be sufficient to correctly reconstruct the original size and shape of the atrium. Therefore, a 3-dimensional (3D) model of the patient's heart was printed to visualize the atrial anatomy and provide reference for the surgeon. We have utilized this technique previously during surgical ventricular restoration for the false aneurysm of the inferior wall.[2]

3D-Printing Procedure

Computed tomography DICOM files were uploaded into Slicer, a freeware software (version 5.2.2r31382/fb46bd1), which is a free, open-source package used for imaging research. Semi-automatic segmentation of volumetric data was performed using thresholding, followed by manual correction. Total segmentation time was 8 hours.

STL files were imported into the 3D printer software. Subsequently, the models were printed to actual size using the Polyjet printer (Stratasys). Rigid printing (IORA Model) and support (IORA Support) materials (Isquared) were

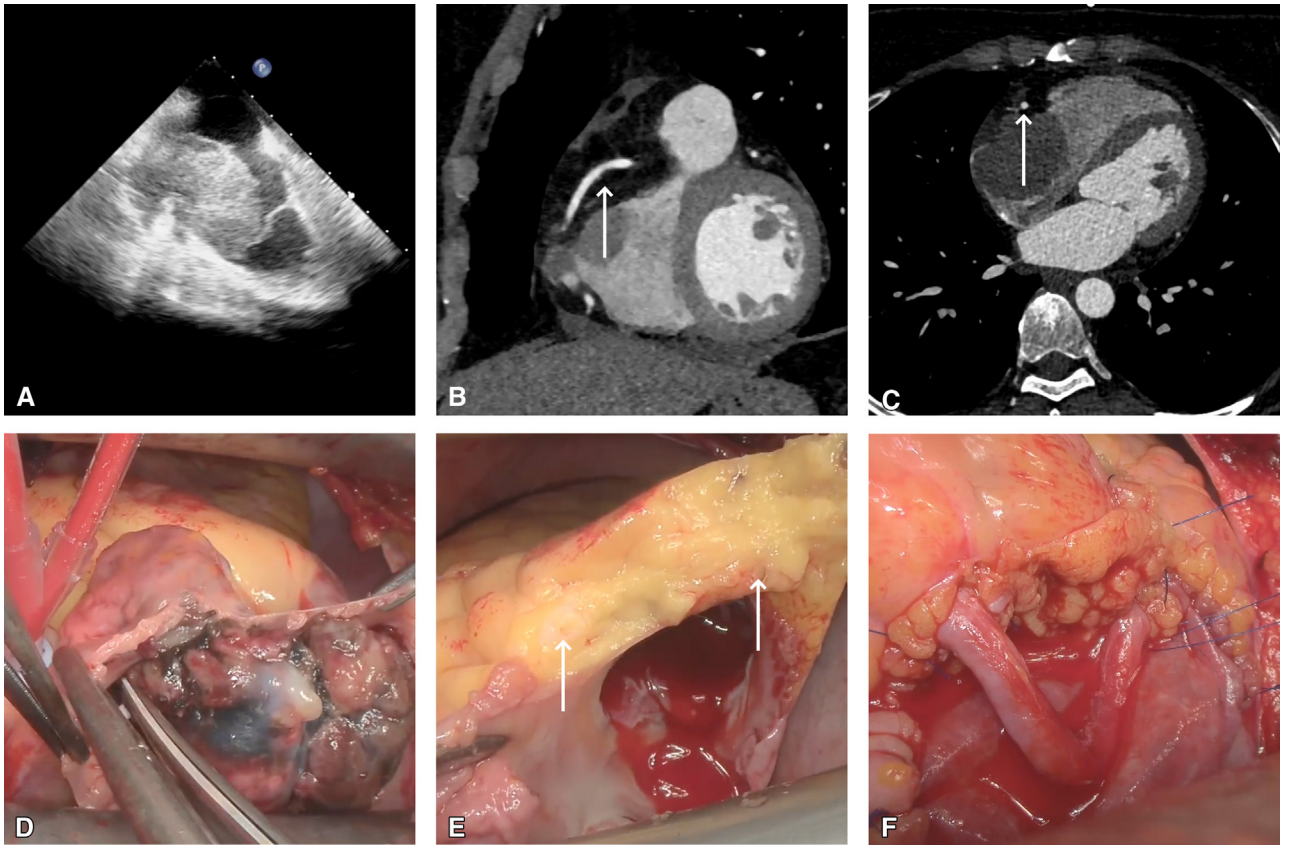


FIGURE 1. A, Tumor in the right atrium (*RA*) as seen via transesophageal echocardiography, B and C, Tumor infiltrating the RA wall. The *arrow* indicates the right coronary artery (*RCA*) as seen via computed tomography. D, Intraoperative view of the tumor. E, RA chamber after removing the tumor with large wall defect. The *arrows* indicate the extent of the RCA resection. F, Reconstructed RA and RCA.

utilized. The printing accuracy of the Stratasys Objet 30 printer, as provided by the manufacturer, for models printed with rigid materials is based on the actual size of the model. It is reported as the maximal size deviation from the original size of the model. For model dimensions <100 mm, the maximal deviation is ± 100 μm. The printing process took 24 hours. After printing, postprinting processing in a water blaster for support removal took approximately 1 hour. The total time for segmentation, printing, and postprocessing, excluding sterilization, was 33 hours. Our segmentation and printing processes were previously tested.[3,4]

Surgical Procedure

Median sternotomy was performed. The RA was incised in its inferior region, where the atrial wall seemed free from tumor infiltration. Subsequently, a large segment of the atrial free wall was excised, maintaining a clean margin around the tumor attachment area. As the tumor infiltrated the atrioventricular (AV) groove, the excision was continued into the AV groove fat, necessitating the resection of a segment of the right coronary artery. It was possible to keep a clean margin of several millimeters along the attachment of the anterior tricuspid leaflet.

For the reconstruction of the right atrium and the AV groove, a 3D model of the patient's heart was used. The defect visible on the model represents the tumor attachment and involves the AV groove. The distance from the superior vena cava RA junction, the right atrial appendage, and the inferior vena cava to the RA wall defect was measured in the patient. These distances were next transferred onto the 3D-printed heart model and the atrial wall defect was drawn on the cast using AV groove defect as 1 of the limits. A ProxiCor (Elutia) patch was next cut to shape according to the drawing on the 3D model (Figure 2). The patch was subsequently sewn into the right atrial wall and along the attachment of the anterior leaflet of the tricuspid valve. The previously excised segment of the right coronary artery was replaced by the fragment of the patient's saphenous vein (Video 1).

The patient was successfully weaned from cardiopulmonary bypass in sinus rhythm on mild inotropic support. Transesophageal echocardiography revealed normal function of the mitral and tricuspid valve.

The postoperative course was uneventful. The patient was receiving low-molecular weight heparin (therapeutic dose) during the postoperative hospitalization and was

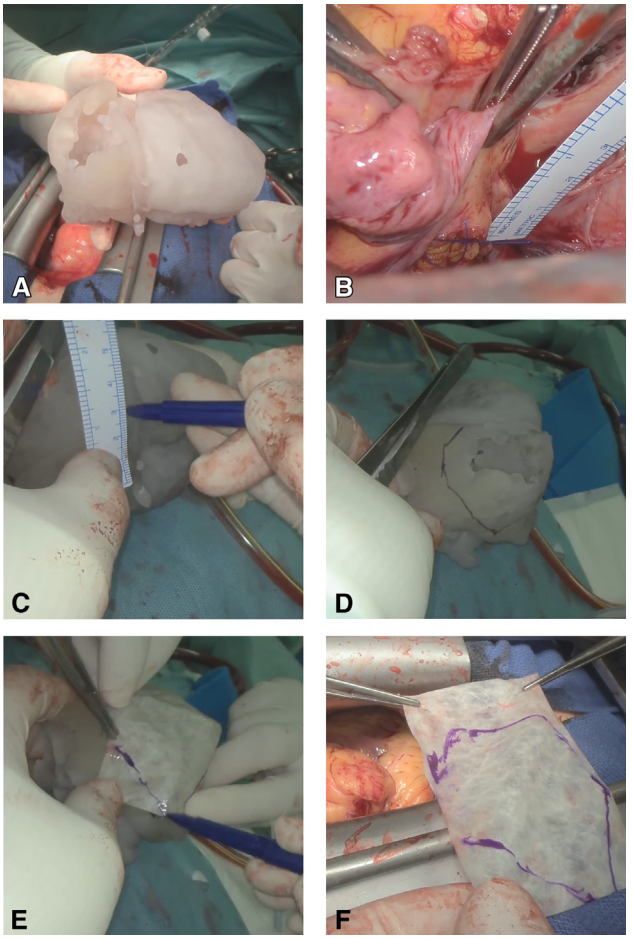
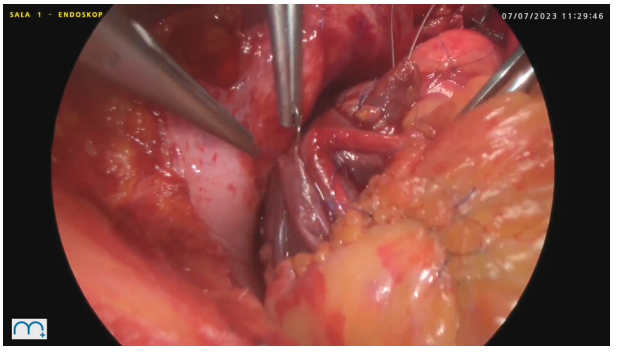


FIGURE 2. A, Three-dimensional model of the patient's heart. Note the atrial wall defect corresponding to the area infiltrated by the tumor. B through F, Consecutive stages of transferring the measurements from the heart onto the model and the pericardial patch.

discharged home on the seventh postoperative day receiving dual antiplatelet therapy (aspirin 75 mg and clopidogrel 75 mg). The histopathologic examination confirmed the diagnosis of malignant melanoma.



VIDEO 1. Reconstruction of the right atrium. Video available at: https://www.jtcvs.org/article/S2666-2507(24)00155-X/fulltext.

Ethical Statement

Our local institutional review board was consulted, and we were advised that our report was not a medical experiment and as such did not require review board approval. We contacted the patient who agreed to anonymized publication of this report.

Comment

In previous reports, the implementation of 3D-printed models in the context of a malignant heart tumors has been rather limited to preoperative procedure planning when traditional imaging proved insufficient.[5] To the best of our knowledge, this is the first report on using a 3D-printed heart model intraoperatively as reference for reconstruction of the right atrium. With extensive resection of the wall it becomes very difficult to appropriately assess the size and shape of the defect, especially because the thin and flaccid atrial wall can easily be closed with the patch much smaller than the resected segment or could inadvertently be expanded to the size much bigger than original. Meanwhile, a restrictive atrium might result in symptoms of heart failure, whereas an atrium that is too large might promote blood clot formation.

CONCLUSIONS

There are patients with cardiac melanoma metastases who can benefit from surgical treatment. When reconstruction of anatomical structures is necessary, 3D printing can be implemented as a useful addition to surgical armamentarium.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling manuscripts for which they may have a conflict of interest. The editors and reviewers of this article reported no conflicts of interest.

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