Three-Dimensional Printing for Perioperative Planning of Complex Aortic Arch Surgery

Daniel Schmauss, MD, Gerd Juchem, MD, Stefan Weber, Dr Ing, Nicolas Gerber, Dr Ing, Christian Hagl, MD, and Ralf Sodian, MD

Department of Cardiac Surgery, Ludwig-Maximilians-University, Munich, Germany; and ISTB–Institute for Surgical Technology and Biomechanics, University of Bern, Bern, Switzerland

Purpose. **In this study, we show the use of three-dimensional printing models for preoperative planning of surgery for patients with complex aortic arch anomalies.**

Description. **A 70-year-old man with an extensively arteriosclerotic aneurysm reaching from the ascending aorta to the descending aorta was referred to our center for complete aortic arch replacement. We visualized and reconstructed computed tomography data of the patient and fabricated a flexible three-dimensional model of the aortic arch including the aneurysm.**

Evaluation. **This model was very helpful for the preoperative decision making and planning of the frozen elephant trunk procedure owing to the exact and lifelike illustration of the native aortic arch.**

Conclusions. **Three-dimensional models are helpful in preoperative planning and postoperative evaluation of frozen elephant trunk procedures in patients with complex aortic anatomy.**

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Surgery of aortic arches with complex anatomy, eg, extensive thoracic aortic aneurysms or aortic dissections, remains a challenge in cardiac surgery. The frozen elephant trunk (FET) procedure is a surgical technique developed for patients with aortic diseases involving the arch as well as the thoracic descending aorta [1, 2]. It allows single-stage treatment for such disease, combining conventional surgery with endovascular techniques. Preoperative planning and simulation of the procedure is often difficult because of the unpredictable anatomy of the aortic arch [3]. Therefore it might be of great value to develop high-quality preoperative data for optimal surgical planning and simulation of an FET procedure.

We developed a new rapid-prototyping technique to build three-dimensional models of the exact anatomy of the aortic arch in patients with complex aortic anatomy planned for an FET procedure. Rapid prototyping (stereolithography) is a technique used in engineering for building prototype models. Transferring this technology to cardiac surgery enables illustrating the exact anatomy of complex cardiovascular diseases for preoperative planning and decision making, hands-on simulation of the procedure, and intraoperative orientation.

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Address correspondence to Dr Sodian, Department of Cardiac Surgery, Ludwig-Maximilians-University, Marchioninistr 15, 81377 Munich, Germany; e-mail: ralf.sodian@med.uni-muenchen.de.

Technology and Technique

We present the case of a 70-year-old man with an extensive arteriosclerotic aneurysm reaching from the ascending aorta to the descending aorta. The patient's comorbidities included arterial hypertension and diabetes mellitus. The patient was referred to our institution for complete aortic arch replacement. We performed a 64-slice computed tomography (CT) of the patient's chest, visualizing the aneurysm that measured 5.5 cm in width. Owing to the complexity of the aortic anatomy and the severe calcifications of the aneurysm and the aortic arch, we decided to build a three-dimensional (3-D) model for better decision making and preoperative planning of an FET procedure (Fig 1).

The patient's CT dataset was loaded into an image processing and visualization software (Amira, Visualization Sciences Group, Burlington, MA), with which extraction of the aorta was completed in several steps. The user provided a seed position within the aorta to initiate a region growing with connected thresholds criteria. The lower intensity threshold was defined as 200 Hounsfield units (HU), and the upper intensity threshold was defined as 600 HU. Any pixel intensity within these thresholds was labeled as being part of the aorta. Manual segmentation corrections were performed to eliminate leaking voxels from the region growing. Erosion and dilation morphologic operators were subsequently applied to create the wall of the aorta with a wall thickness of 2 to 3 mm. Calcified depositions were similarly segmented

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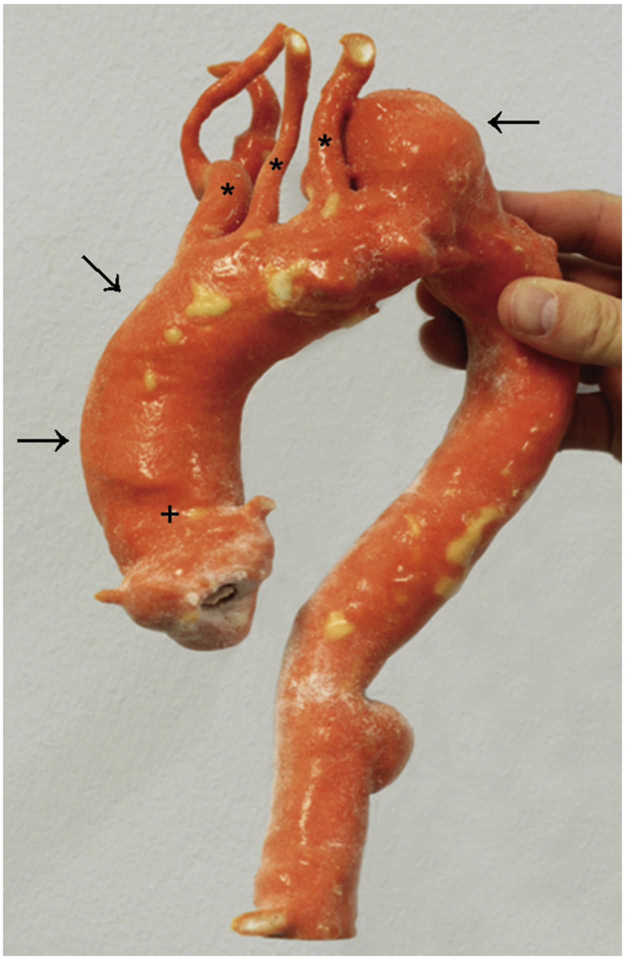

Fig 1. Three-dimensional model of the native aorta including the aneurysm. The "+" indicates the ascending aorta, the "" indicate the supraaortic vessels. The arrows show the aneurysm reaching from the ascending to the descending aorta.*

using region growing with connected threshold criteria. Thus, any pixel intensity higher than 600 HU was labeled as being part of a calcified deposition. Final manual segmentation corrections were performed to eliminate irrelevant artifacts.

Finally, a virtual 3-D surface model of the aorta was created from the segmentation mask (Fig 1). Physical models of the resulting virtual 3-D surface models were created by a 3-D printer (Spectrum Z 510, ZCorporation, Rock Hill, SC). After completion of printing, the model was infiltrated using elastomeric urethane resin (Por-A-Mold 2030). The resulting structure was flexible, tough, and having a rubberlike quality. It is therefore possible to sew the model if you wanted to simulate the ascending aorta part of the procedure. The preoperative model demonstrates the exact anatomy of the aortic root including valve, leaflets, coronary arteries, ascending aorta, aortic arch, brachiocephalic artery, carotid arteries, subclavian arteries, and descending aorta (Fig 1).

Clinical Experience

The replica allowed us to better understand the disease of the aortic arch by holding the model in our hands and inspecting it from all angles.

Furthermore, we were able to talk ourselves through the procedure on a lifelike model, facilitating the intraoperative decision concerning the length and depth of the stent graft implantation and the landing zone. If needed, the procedure can also be simulated practically because the models are fabricated in a hollow fashion. However, this was not absolutely necessary in our case because the aortic anatomy was well illustrated through the model. The FET procedure was performed without problems (Figs 2, 3). We used a 23-mm Perimount aortic valve (Edwards Lifesciences, Irvine, CA), a 32-mm Tetrabranch arch prosthesis (Jotech GmbH, Hechingen, Germany), and a 36-mm Evita open descendens-hybrid (Jotech GmbH). The postoperative course was uneventful. At 12 months' follow-up, the patient is doing well.

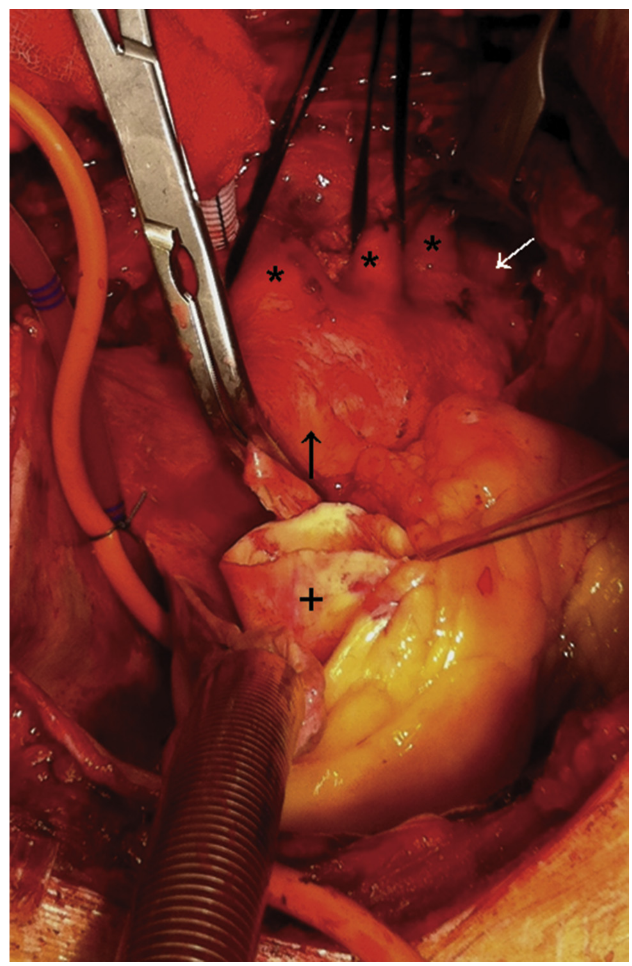

Fig 2. Intraoperative view on the operative field at the beginning of the operation. The "+" indicates the ascending aorta, the "" indicate the supraaortic vessels. The arrows (black and white) show the aneurysm reaching from the ascending to the descending aorta.*