

Three-dimensional printing in surgical planning: A case of aortopulmonary window with interrupted aortic arch

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ABSTRACT

Better anatomical understanding and conceptualization of complex congenital heart defects using three-dimensional (3D) printing may improve surgical planning, especially in rare defects. In this report, we utilized 3D printing to delineate the exact cardiac anatomy of a neonate with an aortopulmonary window associated with interrupted aortic arch to devise a novel approach to the repair.

Keywords: Aortopulmonary window, interrupted aortic arch, three-dimensional printing

INTRODUCTION

Surgical planning in congenital heart disease may be challenging due to the complex relationships among various components of the malformed heart despite advanced three-dimensional (3D) virtual modeling.^[1] One of the most recent techniques is the creation of a 3D physical model using rapid prototyping (syn: 3D-printing; additive manufacturing) technology.^[2]

This technology has been used widely for surgical planning in maxillofacial, cranial, and dental surgeries, as well as, for teaching purposes.^[3,4] This report demonstrates utilization of a 3D-printed heart model to plan the surgery for a neonate with an aortopulmonary window (APW) and interrupted aortic arch (IAA).

CASE REPORT

A 7-day-old, 2.5 kg full-term, neonate was diagnosed with IAA distal to the left subclavian artery (type A), APW and large patent ductus arteriosus (PDA). Echocardiography confirmed the diagnosis [Figure 1]. Computed tomography (CT) was obtained to further demonstrate the relative position of the APW to the

interruption [Figure 2]. It became clear during the surgical conference that both 2D imaging planes and a 3D-CT reconstruction limited the ability to interpret the size/position of the APW and its proximity to the interruption. We decided to utilize a 3D-printed model to help plan the surgical approach. The CT data was imported into Mimics Innovation Suite 3D visualization software (Materialise Inc., Belgium) and segmentation was performed. The 3D-model rendering was then converted to a 3D-printable stereolithography (STL) file. The STL file was then 3D-printed utilizing a color powder plastic printer (3D-Systems; ProJet 4500 ColorJet). The model was available <6 h after the conference and was reviewed with the surgeon before the procedure the next morning.

The 3D-model allowed a clear appreciation of the extent of the APW and its proximity to the interruption [Figure 3]. The APW took the entire left lateral and posterior side of aorta and even wrapped around to the part of the right lateral side (2/3 circumference of the aorta), which was not well appreciated on our standard imaging. It became clear to the surgeon that he would be able to

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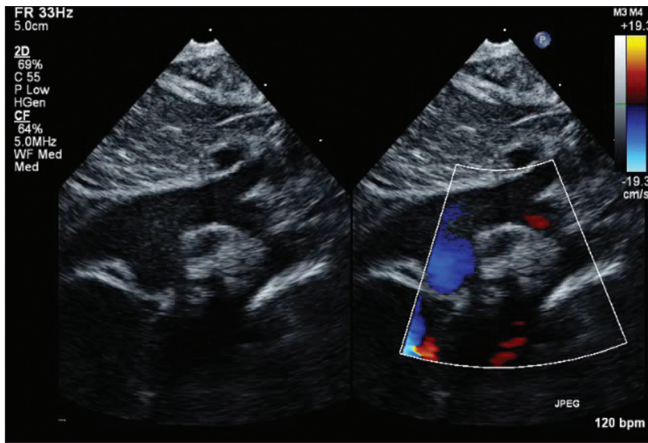


Figure 1: Echocardiogram image in the suprasternal notch position. Color compare acquisition showing a sweep from the interrupted aortic arch to the ductal arch and descending aorta. The proximal aortopulmonary window is seen at the lower left corner of the color box

transect the aorta just proximal and distal to the APW and use the anterior wall of the aorta hinged above the most leftward aspect of the APW to close the pulmonary atresia side of the defect. The 3D model also made it clear that the surgeon could primarily anastomose the ascending aorta with space to sew the descending aorta to the proximal arch and extend onto the left subclavian (arch advancement). The surgeon was able to repair the defect in this manner under antegrade cerebral perfusion and use no patch material. The patient tolerated the procedure well and was discharged from the Intensive Care Unit on postoperative day 5, to home on postoperative day 13, and is clinically well 4 years later.

DISCUSSION

APW is a rare congenital heart malformation with an incidence of <0.3% of all congenital heart diseases. Fifty percent of cases are associated with other cardiac anomalies, of which, IAA, especially type A, is the most frequently encountered association in 22% of APWs.^[5] The association of both anomalies increases the risk of neonatal mortality to 22% and the risk of postoperative re-intervention for recurrent aortic or pulmonary stenosis to 29% compared to simple APW.^[6]

Use of 3D-printing technology has been reported in congenital heart surgery. Kiraly *et al.* reported usage of the 3D-printing for surgical planning of a multilevel aortic arch obstruction after a modified Norwood procedure.^[7] They stated that CT angiography could not reveal the exact site, severity or possible twisting of the involved segments; however, the 3D-model enabled them to repair the obstruction using autologous flaps without the need for further patching. Furthermore, Valverde *et al.* used a 3D-model to plan for surgery in a

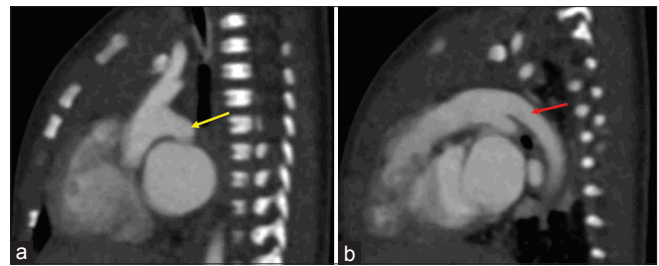


Figure 2: Computed tomography sagittal image demonstrating the interrupted aortic arch (frame a, yellow arrow) and the ductal arch (frame b, red arrow). The two-dimensional images limit the ability to view the entire defect in one plane; however, three-dimensional renderings easily demonstrate the entire anomaly

patient with transposition of great arteries, ventricular septal defect (VSD), and pulmonary stenosis.^[1] They reported that the 3D-model helped identify the spatial relationships between the VSD, outlet septum and the great arteries. Enhanced understanding of the anatomic relationships revealed that the Nikaidoh procedure was a more favorable approach than the Rastelli operation.

In the present case, 3D-printing helped us identify the size of this unique APW and its proximity to the interruption, which in turn allowed us to devise a repair of both defects using only native tissue. It is standard at our institution to perform an arch advancement without patch material, but in this unique case, the surgeon was uncertain patch material could be avoided until he was able to assess the 3D-printed model. At our hospital, we have used 3D-printing technology to predict the intraoperative scenario and plan innovative surgical repairs. We feel that it has reduced the operative time, improved the surgical decision planning, and reduced overall health-care burden of complex cases, which is starting to be objectively measured. With that in mind, each model costs between \$100 and \$500 but has been invaluable in certain scenarios. We find 3D printing particularly helpful when performing complex surgery involving electrophysiology. When performing a Fontan conversion on a patient who required a unique lesion set for his Maze, we were able to 3D-print his heart in a clear rubber-like material (TangoJet-clear). We examined his anatomy with our electrophysiologists to determine the lesion set preoperatively which improved efficiency in the operating room while the heart was arrested. We presently use 3D-printing of congenital heart defects on a weekly basis for complex surgical repairs or combined hybrid procedures.

Moreover, 3D-printing is helpful for educational and training purposes. It provides physical models that help navigate the complex pathological anatomy for both physicians and families. Costello *et al.* conducted a study on 23 pediatric residents who underwent a 60 minute simulation of VSDs using 3D-models. The

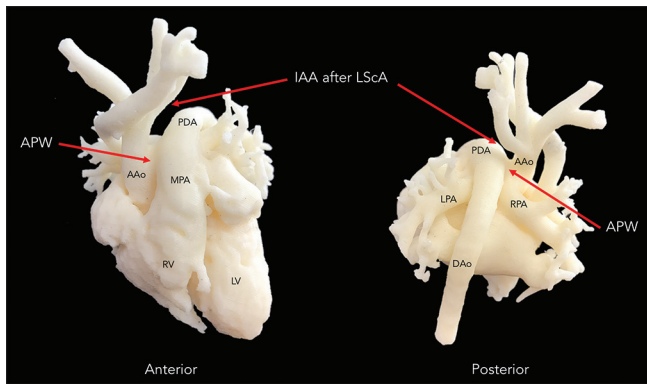


Figure 3: Three-dimensional model. AAo: Ascending aorta, APW: Aortopulmonary window, DAo: Descending aorta, IAA: Interrupted aortic arch, LPA: Left pulmonary artery, LScA: Left subclavian artery, LV: Left ventricle, MPA: Main pulmonary artery, PDA: Patent ductus arteriosus, RPA: Right pulmonary artery, RV: Right ventricle

residents showed improvement in knowledge acquisition and better structural conceptualization of VSDs in comparison to the non-3D model group.^[8] Practicing surgery on these models by junior surgeons enhanced their understanding of the interspatial relations of complex pathology, familiarized them with sophisticated procedures, and improved their surgical skill.^[2] Overall, we believe that 3D-printing technology represents a paradigm shift in imaging that will enhance surgical planning, education for health-care providers and families, and is already impacting how we care for patients with congenital heart disease.

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Conflicts of interest

There are no conflicts of interest.

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