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Case Report

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Corresponding author:
Nicholas Szugye; Email: szugyen@ccf.org

Advanced three-dimensional surgical planning of complex ventricular anatomy in transposition of the great arteries

Lama Dakik[1], Hani Najm[1], Ryan Klatte[2], Edgard Bendaly[1] and Nicholas Szugye[1]

[1]Department of Pediatrics, Pediatric Cardiology and Division of Pediatric Cardiac Surgery, Cleveland Clinic Children's, and the Heart, Vascular, and Thoracic Institute, Cleveland Clinic, Cleveland, OH, USA and [2]Diagnostics Institute, Cleveland Clinic Foundation, Cleveland, OH, USA

Abstract

This is a case of a 6-week-old male with D-TGA and multiple large ventricular septal defects who presented with oxygen desaturations into the 60s. He had initially undergone palliative pulmonary artery banding at a different institution, for concern that patch closure of his large ventricular septal defect would compromise ventricular function. We decided to undergo 3D printing and 4D modelling of his heart to delineate his ventricular septal defect anatomy in preparation for their closure and arterial switch operation. A 4D CTA showed a large perimembranous outlet ventricular septal defect and a very large "swiss cheese" muscular defect. We then segmented the heart and produced 3D models of the diastolic and systolic phases and printed 1- and 1.5x-sized 3D heart models. The 3D and 4D models were used to evaluate all ventricular septal defects from both sides of the ventricular septum to plan their closure. The systolic phase of the CTA demonstrated near obliteration of the apical muscular ventricular septal defects. The patient underwent complete surgical repair at 4 months. The posterior septal, apical, and large anterior muscular ventricular septal defects were closed by bovine pericardium. However, the large perimembranous and inlet ventricular septal defects were closed with a single patch, sparing the intervening muscle band that was thought to contain the conduction system. From the models, the most distal apical ventricular septal defects were shown to close with ventricular contraction during systole. Therefore, apical exclusion of the RV was not required. Thus, this additional information enabled an optimal surgical approach to efficiently close ventricular septal defects in need of closure without futile attempts at closing remote ventricular septal defects.

Case presentation

This case describes the surgical planning of a 6-week-old male with postnatal diagnosis of Dextro-Transposition of the Great Arteries (D-TGA) and multiple ventricular septal defects. He was born at an outside hospital and had undergone attempted arterial switch operation at one week of age. However, upon visualising complex ventricular septal anatomy, the surgeon performed palliative pulmonary artery banding. The infant presented to the outpatient cardiology clinic at 6 weeks of age and was asymptomatic with oxygen saturations in the mid-80%. One month later, he presented to the emergency department with difficulty breathing and desaturations to the 60s. He was rhinovirus positive and was admitted to the hospital. A cardiac catheterisation was performed at this time, which showed a Qp:Qs of 2.12.

The decision was made to undergo MRI and CT imaging for 3D printing and 4D modelling of his heart, with the goal of delineating his ventricular septal defect anatomy in preparation for surgical closure of ventricular septal defects and arterial switch.

Imaging and 3D surgical planning

A 4D CT Angiogram was completed (Siemens SOMATOM Force Scanner) that showed complex ventricular septal anatomy producing a very large interventricular communication. There was a large perimembranous outlet ventricular septal defect (9 x 4 mm) with anterior malaligned outlet septum. There was additionally a very large "swiss cheese" muscular defect which extended between the inlet, outlet, and apical trabecular (posterior, mid-, and apical) components of the right ventricle, with right ventricular muscle bundles extending from the inferior aspect of the septomarginal trabeculation, moderator band, and over into the left ventricular anterolateral papillary muscle.

A large (9x9 mm) secundum atrial septal defect (ASD) was also seen. The aortic root was positioned anteriorly and slightly rightward to the pulmonary root. The aortic valve commissures were well aligned. The size of the aortic valve was found to be 1.2 cm at the sinuses of Valsalva

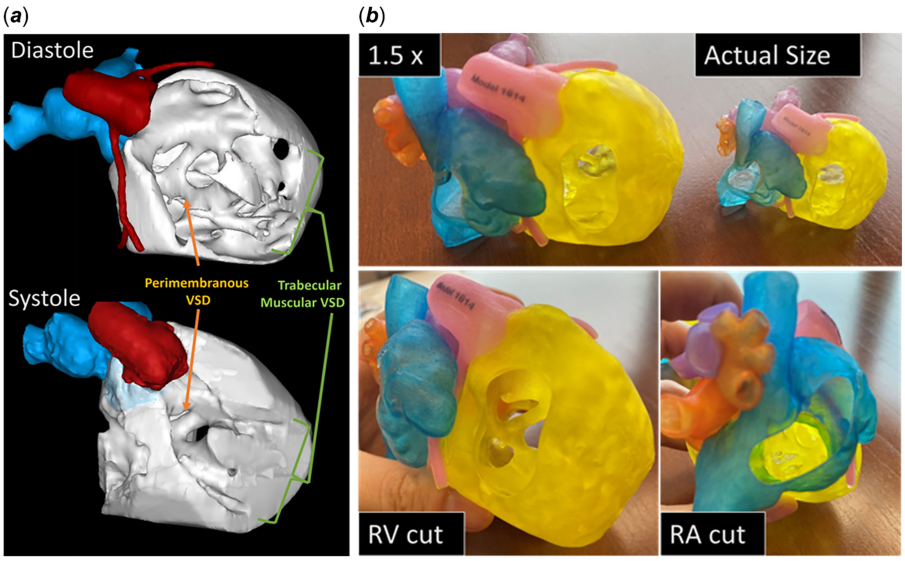

Figure 1. (***a***): 3D model of the heart showing the large perimembraneous VSD and "swiss-cheese" muscular VSD. The apical VSDs were nearly obliterated during systole. (***b***): 1x and 1.5x sized 3D printed models of the heart.

(centre to centre measurement). CT showed a thickened bicuspid pulmonary valve, with commissural fusion between the two anterior-facing cusps. The pulmonary band was well-positioned at the pulmonary sinotubular junction, narrowing the junction to 8 mm in diameter, with immediate bifurcation of the branch pulmonary arteries following the band due to short main pulmonary artery. There was usual coronary arterial arrangement for D-TGA.

Cardiac MRI demonstrated a normal sized left ventricle with normal global systolic function (EDV of 76 cc/m^2, ESV of 34 cc/m^2, and EF of 55%). The right ventricle was mildly hypoplastic and moderately hypertrophied, with a normal global systolic function (EDV of 54 cc/m^2, ESV of 27 cc/m^2, and EF of 50%). The patient's Qp:Qs was 1.7, and his cardiac index was 5.0 l/min/m^2.

Materialise Mimics (Belgium, version 25) software was used to segment and produce 3d models of the diastolic and systolic phases of the heart (Figure 1a, videos 1a & 1b). A 3D model was printed on a PolyJet 3d printer (Stratasys, Eden Prairie, USA) using the diastolic phase of the heart. 1x and 1.5 x sized 3d heart models were printed (Figure 1b, video 2). A 4D video model was also made by using the Aquarius Intuition Viewer (Terarecon, Durham, NC, USA) (video 3). The 3D and 4D models were used to evaluate all the ventricular septal defects from both sides to properly plan their surgical closure. The systolic phase of the CT scan demonstrated near obliteration of the apical muscular ventricular septal defects.

Surgical repair

The patient underwent complete surgical repair at 4 months of life. The main pulmonary artery band was first removed. He then underwent cardiopulmonary bypass for ventricular septal defect closure and arterial switch. The posterior septal ventricular septal defects along with the apical ventricular septal defects were closed with a bovine pericardium patch shaped to occupy the area from the apex to the tricuspid valve. The large anterior muscular ventricular septal defect was closed separately by a circular patch of bovine pericardium. Finally, the large perimembranous and inlet ventricular septal defects were closed with a single patch, sparing the intervening muscle band that was thought to contain the conduction system. An arterial switch procedure was performed in a typical fashion and the ASD was closed.

Post-operative course

The patient was extubated on post-op day 2 and discharged on post-op day 16 without any pertinent hospital events and was saturating well on >95% on room air. There was no evidence of intraventricular conduction delay (QRS < 90 msec).

A post-operative transthoracic echocardiogram on post-op day 2 showed moderate left ventricular dilation with an ejection fraction of 41%. The right ventricle showed normal function, with normal systolic motion of the right ventricular free wall.

At 18 months post-op (age 21 months), the patient was doing well with no cardiac symptoms, while maintained on enalapril for afterload reduction. His growth significantly increased, from below the 3rd percentile at the time of surgery to the 74th percentile at most recent follow-up. On his echocardiogram, few tiny restrictive ventricular septal defects were seen toward the apex (Vmax:4 m/s). His left ventricle was moderately dilated with mildly decreased systolic function (EF: 48%). His right ventricle had normal size and function.

Discussion

This case demonstrates a novel use of 3D printing and 4D imaging for pre-operative planning of complex D-TGA and ventricular septal defect repair. To our knowledge, this is the first such report on this approach of surgical planning in this anatomy. Surgery for D-TGA is performed in the first week of life often without necessity nor time needed for a 3D-printed model. The additional information provided by a 3D and 4D model enabled an optimal surgical approach to identify an efficient means to close specific ventricular septal defects in need of closure without futile attempts at closing remote ventricular septal defects. For example, the most distal apical ventricular septal defects closed with ventricular contraction during systole. As such, an apical exclusion of the right ventricle, which would have further reduced the RV volume, was not required.

Three-dimensional printing has been shown to be helpful to individualise surgical repair on a case-by-case basis. In larger case series, three-dimensional printing has been shown to anticipate the appropriate surgical repair pre-operatively. In a study by Ponchant and colleagues,[1] ten paediatric patients with double outlet right

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ventricle underwent multimodality imaging followed by 3D virtual valvular annuli reconstruction (3DVVAR), and finally 3D printing. At each stage, the surgical repair decision was updated for each patient. By retrospective analysis, it was shown that 50% of the surgical strategies were correctly predicted by multimodality imaging, followed by 90% by 3DVVAR, and 100% by 3D printing. A prospective study by Valverde et al showed that 3d modelling helped refine the surgical approach in about 50% of complex CHD surgeries.[2]

Related to surgical planning of D-TGA, Peel B. et al., used silicone molded models of TGA using an injection molding technique. These models were used for a course for cardiovascular surgeons to simulate arterial switch operations alongside typical 3D printed models. Surgeons noted via a questionnaire that the models were superior in terms of anatomic information and resemblance to human tissue than their 3D printed counterparts. However, silicone models are of higher cost and require more labour-intensive production, so are not as conducive for patient-specific models.[3] Furthermore, a prior case reported by Yokoyama and colleagues[4] used 3D printing for surgical planning of TGA with severe CoA. They reported that by using the 3D model, they were able to put incisions on the model for surgical simulation and properly plan for her arterial switch.

In addition to surgical planning, 3D printed models have also been shown to aid in patient communication. In a study done by Biglino and colleagues,[5] 3D models were used in patient and parent communication for 100 patients, both practitioners and patient families reported that the models facilitated the discussion and understanding. The models also have implications in surgical resident education as they can practice and improve their techniques on them.

Conclusion

The use of 3D printing and 4D imaging in TGA with multiple ventricular septal defects has not been previously reported in the literature. The use of these complex techniques in our patient guided the surgery, particularly by delineating his ventricular septal defect anatomy, which enable a nuanced approach by the surgical team. In select cases, 3D printing is demonstrated to be a beneficial tool to optimise surgical repair strategies.

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Disclosures. None.

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