Use of 3-Dimensional Printing to Demonstrate Complex Intracardiac Relationships in Double-Outlet Right Ventricle for Surgical Planning

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Double-outlet right ventricle falls under the category of congenital heart disease known as conotruncal defects, which possess abnormal ventriculoarterial relationships. For complex cases, the surgeon must determine whether the left ventricle and one of the great arteries can be aligned using the ventricular septal defect to construct an unobstructed pathway or baffle, resulting in a 2-ventricle repair. Creation of the baffle can be complicated by anatomic obstructions because of prominent conal septum, straddling atrioventricular valve attachments, or location of the ventricular septal defect in the inlet septum, remote from any great artery. Three-dimensional (3D) printing has been applied in the management of many different congenital heart diseases.

In this specific patient population, in whom communicating the complex intracardiac anatomy to the surgeon is so critical, the use of 3D modeling and printing is invaluable. We used this approach in a patient with dextrocardia, complex double-outlet right ventricle (S,L,A) and supraventricular atrioventricular septal defect. She underwent pulmonary artery banding in infancy and had been doing relatively well clinically; so that any further surgical intervention was deferred until she was 8 years old. Although she was growing well and required no medication, she had some dyspnea on exertion and had become progressively more desaturated with oxygen saturations in the low 80s. The patient underwent a cardiac MRI to better outline the anatomy (Figure 1). The 3D balanced steady state free precession images were used to create a 3D virtual model that allowed visualization of the intracardiac anatomy (Figure 2, left). The 3D stereolithography file was then printed (Projet 3500 HD Max; 3D systems, Rock Hill, SC) to create a physical model that allowed clear delineation of potential baffle pathways (Figure 2, right). The aorta, which was anterior to the pulmonary artery in this patient, was relatively far removed from the left ventricle, and the ventricular septal defect was subpulmonary. After assessment of the 3D intracardiac anatomy, it was decided that the patient would have a double-switch procedure. The right atrium was baffled to the right ventricle (left-sided), and the left ventricle (right-sided) was baffled, via the ventricular septal defect, to the pulmonary artery. An arterial switch was then performed to direct the deoxygenated blood to the pulmonary artery and the oxygenated blood to the aorta. There was an excellent correlation between the 3D model and the actual anatomy. She is doing well clinically 6 months post procedure.

There are a wide range of applications for 3D printing technology in preprocedural planning for patients with cardiac pathology. In addition to simply demonstrating complex intracardiac anatomy, as in our patient, it also allows us the possibility to test an intervention. For example, our interventional colleagues can use a 3D printed left ventricular outflow tract for sizing before transcatheter aortic valve implantation or a model of the dilated right ventricular outflow tract to size a valved conduit in a patient with previously repaired tetralogy of Fallot. A surgeon may use a whole heart 3D printed in a soft material to cut into and simulate the surgical procedure in a complex patient. Although this technology holds much promise, there are limitations which currently prevent its widespread application. The entire process of image post-processing and printing can take several hours depending on the image quality, the experience of the imaging specialist, and the 3D printer used. Ideally, the image data set has good blood to myocardium contrast allowing easy differentiation of the 2 across all planes. In addition, the cost of both the image processing software and 3D printer can make this technology inaccessible for programs interested in using this imaging technique. It seems most useful to use these models in more complex patients in whom the model would add some 3D spatial information or allow simulation of an intervention.

The intricate complexity of these patients’ anatomy demonstrates the optimal setting in which 3D intracardiac modeling and printing can offer a transition from virtual to real spatial modeling. The use of these models bridges this gap and humbly acknowledges that in these patients, in whom clear delineation...
of the intracardiac anatomy affects clinically significant decisions, we are better off leaving less to the imagination.

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None.

References

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Figure 1. Source cardiac MRI images. Coronal and sagittal views of the 3-dimensional (3D) balanced steady state free precession sequence from the cardiac MRI used to create the 3D virtual model. In the coronal view (left), the ventricular septal defect (VSD) relationship with the ventricles and pulmonary artery (PA) can be seen. In the sagittal view (right), the anterior–posterior relationship of the great arteries is well demonstrated. Ao indicates aorta.

Figure 2. Transition from virtual to physical models in double-outlet right ventricle. A. The 3-dimensional (3D) virtual and corresponding printed model is viewed from the anterior aspect. B. Both models are rotated to allow assessment of the intracardiac anatomy as viewed from the posterior aspect. The spatial relationships of the ventricles, ventricular septal defect (VSD), and great arteries are well demonstrated. The site of the pulmonary artery band (PAB) is also well represented in the 3D models. C. The models are angulated to allow better demonstration of the anterior–posterior relationship of the great arteries. The pathways from the left ventricle through the VSD to the PA (*) and aorta are delineated by red arrows. Note the relatively straightforward course from the LV to the PA compared with the more tortuous path to the aorta. Ao indicates aorta; LPA, left pulmonary artery; LV, left ventricle; RAA, right atrial appendage; RPA, right pulmonary artery; RV, right ventricle; and SVC, superior vena cava.
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SUPPLEMENTAL MATERIAL

Video 1. 3D balanced steady state free precession (bSSFP) cardiac MRI dataset – displayed in sagittal plane. The anterior – posterior relationship of the great arteries, both arising from the right ventricle, and the pulmonary artery band are well appreciated in this plane.

Video 2. 3D bSSFP cardiac MRI dataset – displayed in a coronal plane. The anatomic relationships of the ventricles, ventricular septal defect and posterior great artery (pulmonary artery) are best appreciated in this plane.