

Surgical planning for a complex double-outlet right ventricle using 3D printing

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Rapid prototyping may be beneficial in properly selected cases of complex congenital heart disease, providing detailed anatomical understanding that helps to guide potential surgical and cardiac catheterization interventions. We present a case of double-outlet right ventricle, where the decision to obtain a three-dimensional printed model helped for better understanding of the anatomy, with the additional advantage of surgical simulation in planning the surgical approach and type of surgical repair.

KEYWORDS

congenital heart disease, double-outlet right ventricle, rapid prototyping

1 | INTRODUCTION

A thorough understanding of detailed intracardiac anatomy is critical to the formulation of an ideal surgical approach in patients with double-outlet right ventricle.¹ Comprehension of the complex three-dimensional (3D) spatial relationships of the intracardiac structures is often difficult using traditional planar imaging techniques, such as echocardiography, computed tomography, or magnetic resonance imaging. Furthermore, the two-dimensional images that are produced using the traditional imaging techniques cannot be maneuvered or manipulated. Rapid prototyping enables us to print 3D models of the patient-specific anatomy generated from the source images. In patients with double-outlet right ventricle, these 3D printed models can not only enhance the surgeons' understanding of the complex spatial relationship of the ventricular septal defect (VSD) to one or both great arteries and thereby aid in surgical planning, but these replicas can also be utilized to simulate various surgical approaches which may improve surgical decision making and thereby benefit the patient.^{2,3}

These images demonstrate the added utility of 3D printed heart models in depicting the detailed intracardiac anatomy of a newborn with double-outlet right ventricle, with the aorta slightly rightward and posterior of the pulmonary artery, and an unusual near intersection of a large oblong-shaped doubly committed VSD by a large conal septum (Figures 1–4, Movie S1). The presence of a large conal septum made the surgical VSD closure extremely challenging. The anatomy required the VSD patch to be placed in an axial plane extending from the right

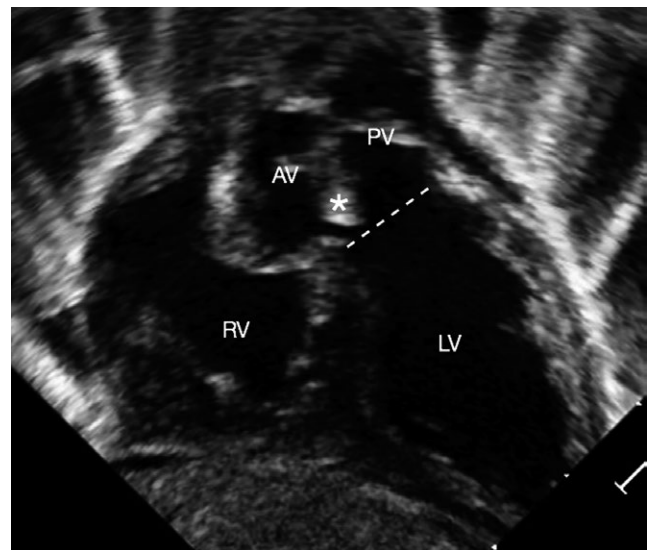


FIGURE 1 Two-dimensional (2D) transthoracic echocardiographic subcostal long-axis image. The aortic valve (AV) is positioned rightward of the pulmonary valve (PV), separated by a prominent conal septum (white asterisk). The diagnosis was initially misinterpreted as transposition of the great arteries, believing the ventricular septal defect (VSD) was the small communication between the conal septum (white asterisk) and interventricular septum; however, with further imaging planes, along with the aid of computed tomography, the anatomy was understood to be double-outlet right ventricle with the plane of the VSD depicted (white dashed line). LV=left ventricle; RV=right ventricle

FIGURE 2 Computed tomography axial stack images from inferior to superior (A–D). A. Four-chamber axial image demonstrating atrioventricular concordance. B. The plane of the ventricular septal defect (VSD; double-headed arrow) is demonstrated immediately below the level of the great arteries. C. The aortic valve (AV) is positioned rightward to the pulmonary valve (PV), both arising from the right ventricle (RV), with prominent conal septum coursing between the two valves from the plane of the VSD, anteriorly to the RV free wall. D. The aorta (Ao) is positioned rightward to the main pulmonary artery (MPA). LA=left atrium; LV=left ventricle; RA=right atrium

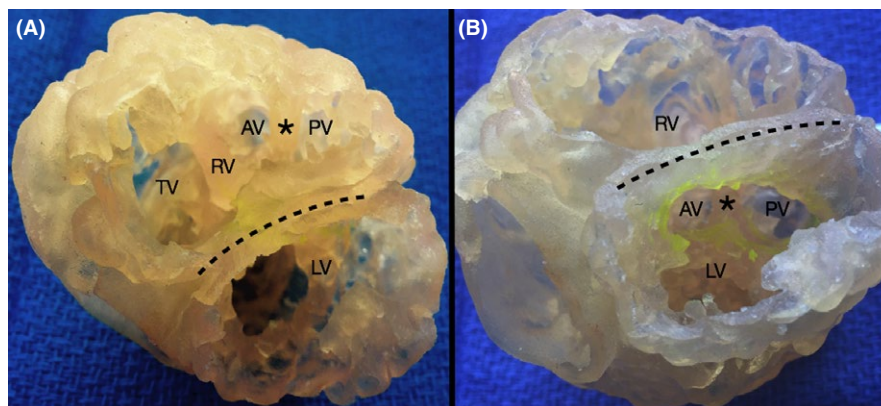
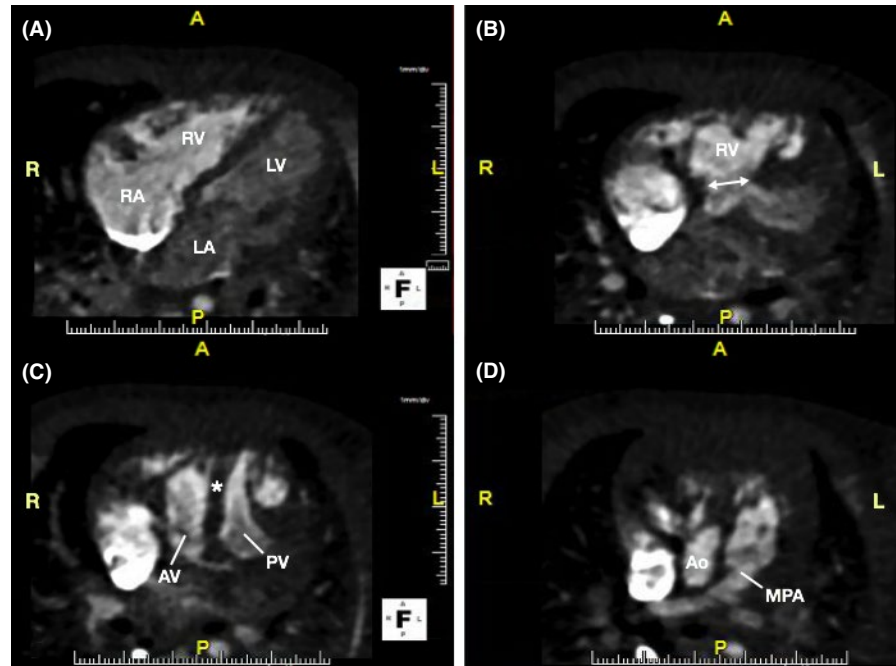


FIGURE 3 A. The apices of both ventricles have been removed in this three-dimensional (3D) printed model, viewing both ventricles from an inferior point of reference. The interventricular septum is denoted (black hashed lined). The prominent conal septum is demonstrated (black asterisk) extending from the right ventricular free wall, between the aortic valve (AV) and pulmonary valve (PV) to the plane of the ventricular septal defect (VSD), which itself is out of view. B. The same 3D printed model is rotated to view the VSD, the borders of which were stained yellow, from the left ventricle (LV). The prominent conal septum is visualized encroaching on the plane of the VSD between the AV and PV. The pathway to the PV is significantly larger than that to the AV. RV=right ventricle; TV=tricuspid valve

ventricle free wall anteriorly (adjacent to the left anterior descending coronary artery) to the leftward and anterior margin of the VSD posteriorly (Figure 3), separating the potential left ventricle-to-pulmonary artery pathway from the right ventricle cavity. The VSD patch then had to be extended in a coronal plane from the conal septum to the rightward anterior border of the VSD and to the mitral valve posteriorly (Figure 4), separating the right ventricle-to-aortic pathway from the left ventricle.

The patient-specific anatomy was printed as multiple, flexible whole-heart models using a polyjet printer. A supplemental layer of myocardium was added outside the blood pool on these models that enabled the surgeon to perform surgical simulation with a realistic soft tissue feel, allowing visualization of the anatomy from various potential approaches

(Movie S2). The surgical simulations permitted better understanding of the complex anatomy, confirmed the feasibility of closing the VSD via the tricuspid valve approach, and highlighted the potential challenges of patching the VSD via the right ventriculotomy and/or the pulmonary valve approach. This enabled us to be better prepared while performing the actual surgical repair, anticipating the necessity of using a nontraditional right atriotomy with tricuspid valve approach, baffling the left ventricle to the pulmonary artery, with subsequent arterial switch (Movie S3).

ACKNOWLEDGMENT

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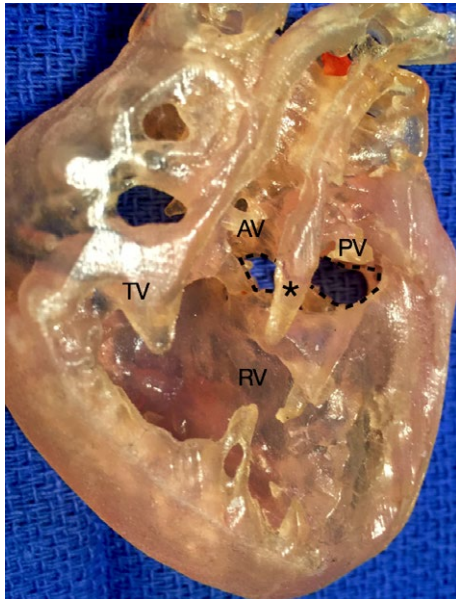


FIGURE 4 A coronal plane three-dimensional printed model with the right ventricle (RV) free wall removed demonstrating the prominent conal septum (black asterisk) interposed between the aortic valve (AV) and pulmonary valve (PV), extending to the plane of the ventricular septal defect (outlined by black hashed line). The left ventricle-to-PV pathway is significantly larger than that to the AV

CONFLICT OF INTEREST

None.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

Movie S1. Two-dimensional transthoracic echocardiographic parasternal short-axis video.

Movie S2. Surgical simulation with anatomical explanation of the three-dimensional model.

Movie S3. Transesophageal echocardiogram sweeping between the right ventricular inflow and outflow tract, and the ventricular septal defect patch baffling the left ventricle to the neo-aortic valve.

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