JACC: CASE REPORTS VOL. 3, NO. 14, 2021

CASE REPORT

ADVANCED

CLINICAL CASE: DAVINCI CORNER

Use of Virtual Reality for Hybrid Closure of Multiple Ventricular Septal Defects

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ABSTRACT

A 28-month-old girl with multiple ventricular septal defects previously underwent surgical and transcatheter attempts at repair. Three-dimensional models were created from cardiac magnetic resonance–derived images. Viewing the models in virtual reality allowed the team to precisely locate the defects and decide on a hybrid transcatheter and surgical approach to ensure successful repair. (**Level of Difficulty: Advanced.**) (J Am Coll Cardiol Case Rep 2021;3:1579–1583) © 2021 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Surgical repair of multiple ventricular septal defects (VSDs) is often complicated by poor visualization of the defects owing to right ventricular (RV) hypertrophy and associated trabeculations (1-3). We present the case of a toddler with multiple VSDs who previously underwent several attempts at repair. Visualization of cardiac magnetic resonance (CMR)-derived models in virtual reality allowed for successful planning and execution of a combined surgical and transcatheter repair.

LEARNING OBJECTIVES

- To highlight procedural challenges inherent in the repair of multiple ventricular septal defects.
- To demonstrate the utility of 3D modeling and virtual reality in preprocedural planning for complex congenital heart disease lesions.

CASE

The patient was a 28-month-old girl with mild left ventricular hypoplasia, bicuspid aortic valve and "Swiss cheese" ventricular septum. At 5 months she underwent surgical closure of her VSDs, complicated by 7 days of extracorporeal membrane oxygenation. Owing to a continued left-to-right shunt, she underwent attempted transcatheter closure of a large residual apical VSD (**Figure 1**). There was difficulty in locating the defect in the heavily trabeculated RV, and ultimately the device only partially occluded the VSD. Subsequently she underwent pulmonary artery band placement. After 15 months of improvement in symptoms, she was referred for pulmonary artery band removal and closure of her residual defects. To elucidate the location of her VSDs, she was referred for CMR.

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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

Manuscript received April 15, 2021; revised manuscript received July 19, 2021, accepted July 21, 2021.

ISSN 2666-0849 https://doi.org/10.1016/j.jaccas.2021.07.033

JACC: CASE REPORTS, VOL. 3, NO. 14, 2021
OCTOBER 20, 2021:1579–1583

ABBREVIATIONS AND ACRONYMS

3D = 3-dimensional

CMR = cardiac magnetic resonance

LV = left ventricle/ventricular

RV = right ventricle/ventricular

RVOT = right ventricular outflow tract

VSD = ventricular septal defect

IMAGE ACQUISITION

CMR was performed on a 1.5-T scanner (Magnetom Avento, Siemens Healthcare) with the use of Ferumoxytol, an iron-based contrast agent (**Figure 2**). Imaging revealed a large (1.0 × 0.9 cm) anterior muscular defect obscured by a muscle-bound RV, a moderate (0.3 × 0.4 cm) conoventricular defect, and 2 smaller midmuscular defects.

3-DIMENSIONAL VISUALIZATION

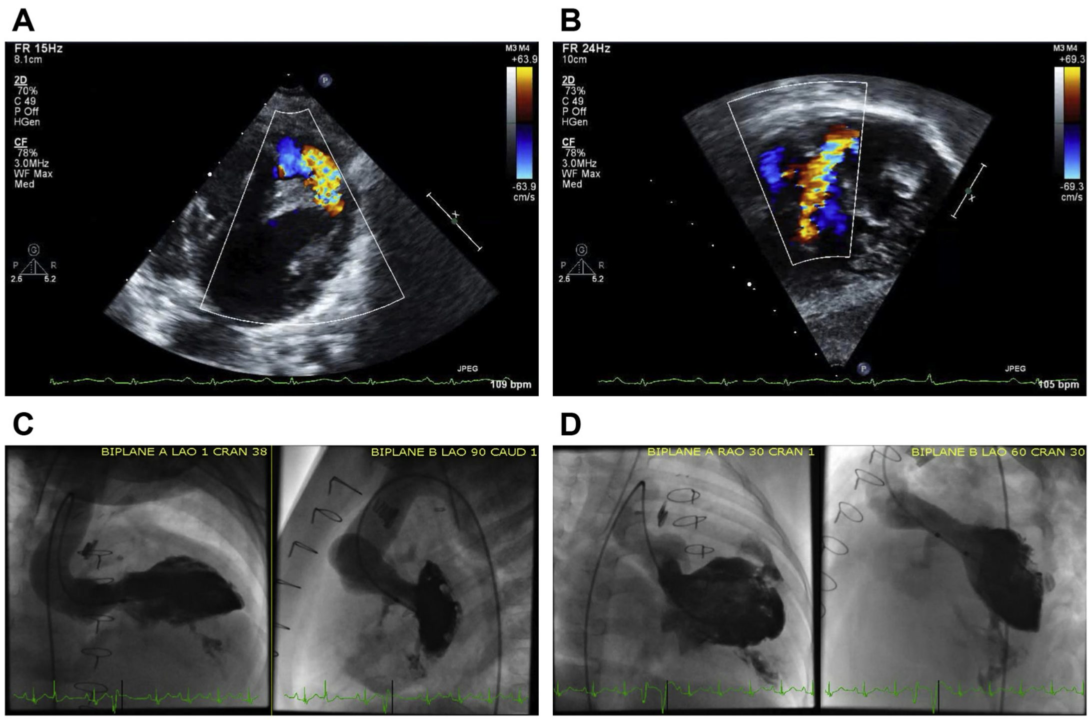
Diastolic images were converted into 3-dimensional (3D) volumes within FDA-approved software and postprocessed (Materialise) to create blood pool and myocardium models (**Figure 3**, Supplemental Files 1 to 6).

The models demonstrated all 4 VSDs. Notably they also demonstrated a "false lumen" within the RV trabeculations, that appeared to be a septal defect but was a channel leading to the true defect in the anterior muscular septum (Video 1). This raised the possibility of a hybrid transcatheter and surgical approach for this patient.

PROCEDURAL PLANNING

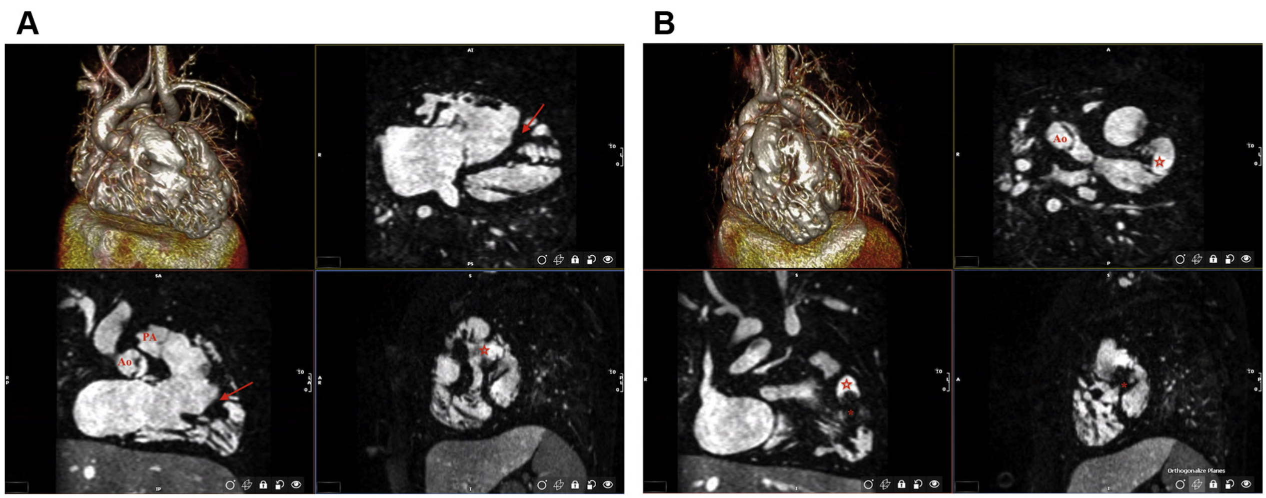
The previously created 3D files were imported into an open-source software platform, 3DSlicer (4) and the SlicerVR extension (5). Using an HTC Vive Headset, the surgical and interventional teams reviewed the model in virtual reality (Video 2), which illuminated 2 key aspects of the procedure: 1) challenging exposure of the largest VSD through RV trabeculations; and 2) inability to visualize the defect through the tricuspid valve, necessitating an incision in the RV outflow tract (RVOT). By "looking" through the RVOT (Video 3), the team identified the optimal location for the incision. A decision was made to perform a catheterization and advance a wire through the left ventricle (LV) and across the defect to mark it before patch closure.

FIGURE 1 **VSDs Seen by Echocardiography and Angiography**



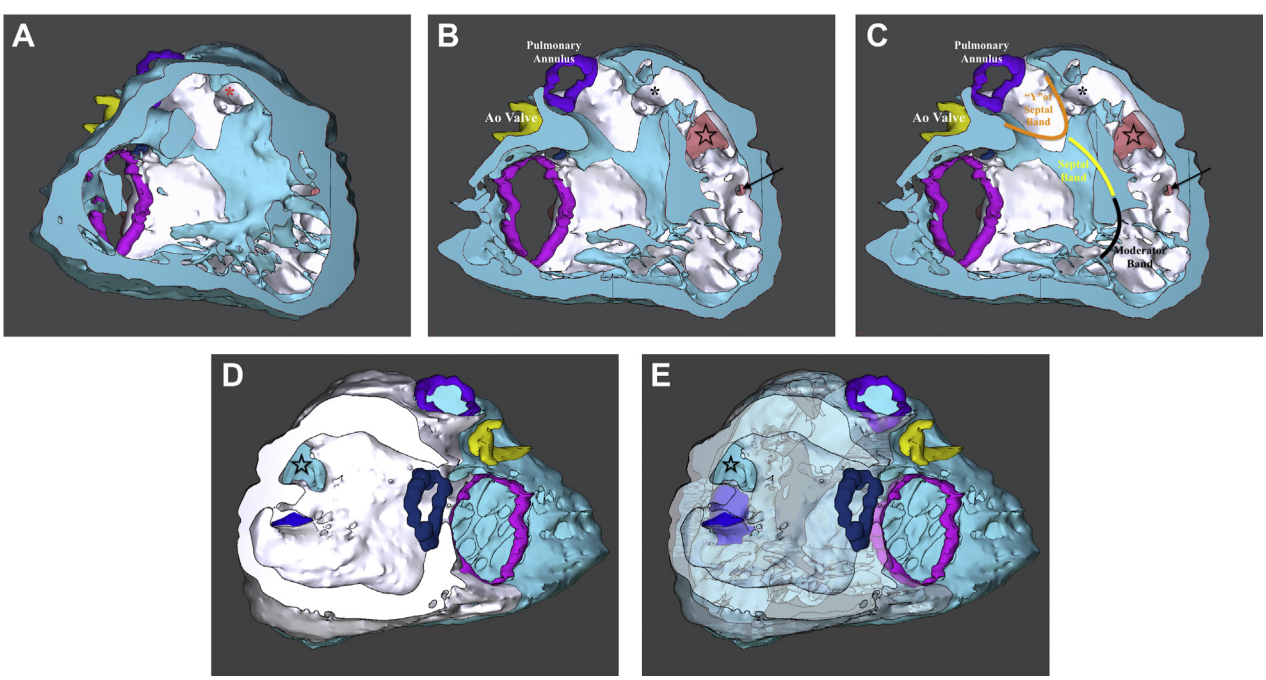
Large anterior muscular ventricular septal defect (VSD) as seen by means of transthoracic echocardiography in **(A)** parasternal short-axis view and **(B)** subcostal left anterior oblique view, and by means of angiography: **(C)** anteroposterior-cranial and lateral projections of a retrograde injection into the left ventricle (LV) demonstrating a conoventricular and small muscular VSD, and **(D)** anteroposterior-right anterior oblique and left anterior oblique projections of a retrograde injection in the LV demonstrating the large anterior and small midmuscular VSDs.

FIGURE 2 **Ferumoxytol-Enhanced Cardiac Magnetic Resonance Imaging and Digital 3D Reconstructions**



(A) Detailed right ventricular (RV) anatomy. Coronal view demonstrates the moderator band (**arrow**) and RV outflow tract. Sagittal view demonstrates the septal band anterior to the large ventricular septal defect. **(B)** Coronal and sagittal views delineate the profile of the occluder device **(star)** located predominantly on the left ventricular side of the septum. Ao = aorta.

FIGURE 3 **Digital 3D Reconstructions**



(A) Right ventricular (RV) **(aqua)** side of the septum **(silver)** with visualization of the "false lumen" **(asterisk)** of the anterior muscular ventricular septal defect (VSD). **(B)** View more posteriorly in the RV, demonstrating the false lumen and muscle-bound channel connecting to the anterior muscular VSD **(star)**. Left ventricular (LV) **(pink)** is seen through the defect. A smaller anterior muscular defect is seen inferiorly **(arrow)**. **(C)** RV anatomy labeled. **(D)** Anterior muscular VSD **(star)** viewed from the LV. **(E)** Through the transparent septum, the outline of the VSD occluder device **(royal blue)** is visible. Ao = aorta.

JACC: CASE REPORTS, VOL. 3, NO. 14, 2021
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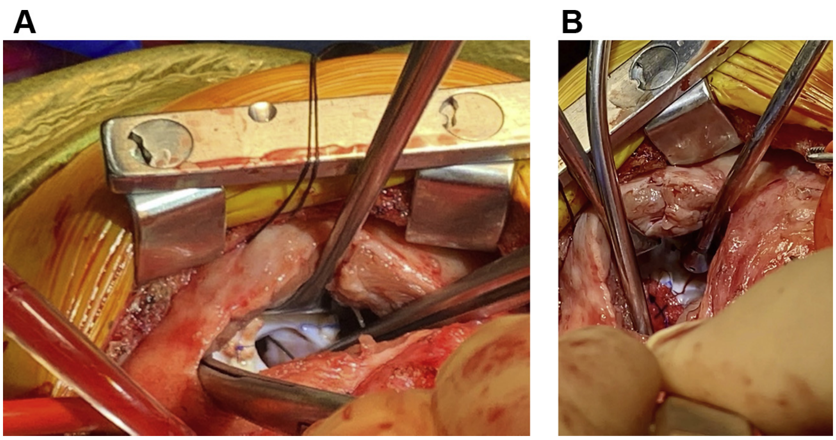
FIGURE 4 **Intraoperative Photos**



(A) Wire inserted retrograde across the anterior muscular defect to easily identify it intraoperatively. **(B)** Demonstration of patch closure of the defect.

PROCEDURE

The procedure was performed in a hybrid operating room-cardiac catheterization laboratory. The catheterization team gained femoral access and placed a wire through the large anterior muscular defect, from the LV into the RV. Subsequently the patient underwent redo sternotomy, cannulation, cardiopulmonary bypass, and cardioplegia arrest. A right ventriculotomy was performed in the infundibulum just below the pulmonary valve, as identified previously with the virtual reality model. There was a large muscle bundle which was divided, and the anterior muscular VSD with the wire extending across was readily visible (**Figure 4A**). A Dacron patch was cut to an appropriate size, and 5-0 Prolene was used in a running fashion to close the VSD with this patch. (**Figure 4B**) The conoventricular VSD was visualized through the right ventriculotomy and closed with the use of a pledgeted 5-0 Prolene suture. The remainder of the procedure included pulmonary artery debanding and augmentation of the main pulmonary artery and RVOT with the use of bovine pericardial patch. The 2 small midmuscular defects identified by means of CMR could not be located.

Intraoperative echocardiography demonstrated moderately decreased RV function, mildly decreased LV function, and no residual anterior muscular VSD. The catheterization team performed exit angiography and hemodynamic evaluation that revealed a pulmonary to systemic flow ratio (Qp:Qs) of 1.5 due to 3 tiny residual midmuscular VSDs.

POSTOPERATIVE COURSE

The patient was discharged on postoperative day 11. Follow-up echocardiography (day 21) demonstrated low-normal RV function and normal LV function, half-systemic RV pressure, no residual anterior muscular VSD, and a tiny midmuscular VSD.

COMMENT

It is intuitive and well documented that 3D visualization of cardiac anatomy provides better understanding of visuospatial relationships than 2D imaging (6-9). Our challenge in harnessing this advantage is to identify procedures for which 3D technologies are not just “helpful” but provide clear added value to patient care.

We have reported the case of a toddler with multiple VSDs who underwent several attempts at repair. Viewing the VSDs in virtual reality allowed the team to not only locate the defects, but also to: 1) precisely plan the RV incision site; 2) visualize the muscle bundle that would need to be divided to see the anterior muscular defect directly; and 3) decide on a hybrid transcatheter and surgical approach to ensure success in the repair.

Integration of 3D visualization into procedural planning will allow imagers, surgeons, and interventionalists to identify the highest-impact indications for use of these technologies. Targeted application will facilitate iterative improvement of the technology and provide a framework for research on its impact on surgical outcomes.

FUNDING SUPPORT AND AUTHOR DISCLOSURES

This work was supported by a Children's Hospital of Philadelphia Cardiac Center Research Grant (Philadelphia, Pennsylvania), a National Institute of General Medical Sciences of the National Institutes of Health Training Grant under T32GM008562 (to Dr Ghosh) and a National Heart Lung and Blood Institute of the National Institutes of Health under R01HL153166 (to Dr Jolley). The funding agencies had no role in planning the study. The manuscript represents the opinions of the authors alone. The authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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KEY WORDS 3-dimensional printing, cardiac magnetic resonance, congenital heart defect, imaging, ventricular septal defect

APPENDIX For supplemental files showing the hollow blood pool, myocardium, tricuspid valve annulus, mitral valve annulus and pulmonary valve annulus, and the virtual VSD patch, as well as supplemental videos, please see the online version of this paper.