3D Printing and Interactive 3D Visualization for Surgical Planning in Complex Congenital Heart Disease

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Background

- 3D printing, and interactive 3D visualization (I3DV) on True3DViewer (EchoPixel, Inc., Santa Clara, CA) for surgical planning in complex congenital heart disease (CHD) can influence decision-making, and alteration in surgical technique with positive impact on outcomes.
- 3D printed models and I3DV are also useful for education of patients, family members, medical professionals, and students.

Methods

- A retrospective review of clinical, imaging, and surgical reports was performed in patients with complex CHD where 3D printing and I3DV were utilized for clinical decision-making and surgical planning.
- We highlight the utility of 3D printing and I3DV for complex biventricular repair in patients previously considered to be unrepairable or declined surgery at other centers.

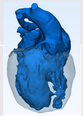
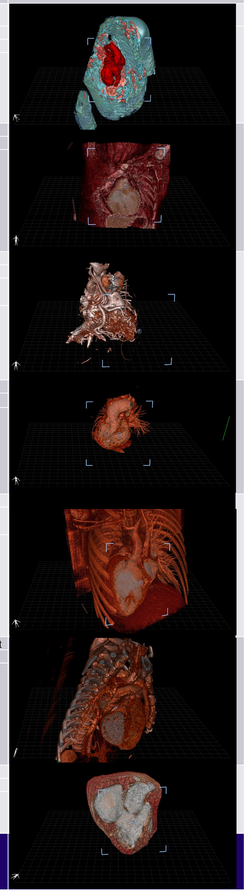
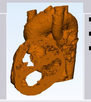
Results

- 3D printing was performed in all 7 patients with I3DV critical for decision-making in 4 cases and critical for surgical planning in 5 cases (Table 1).
- Two patients required ECMO support following surgery, but recovered without any neurodevelopmental deficiencies.
- There was no mortality and all patients have been discharged to home.

Conclusions

- 3D printing and I3DV are critical for decision-making and planning appropriate surgical techniques in highly complex CHD patients.
- Surgical techniques and repair strategies were altered based on 3D printing and I3DV.
- In patients with borderline intracardiac anatomy for biventricular repair, I3DV may offer additional insight compared to standard-of-care imaging.
- 3D printing and I3DV must be considered for clinical decision-making in patients with complex CHD prior to finalizing management plans.

Table 1. Impact of 3D printing I3DV for surgical planning and actual surgical procedure performed

Case	Diagnosis	Surgery	Age (w=weeks; m=months; y=years)	Dataset(s) for 3D virtual model	3D virtual model	Impact of 3D printing for surgical planning	Actual surgical procedure performed	I3DV
1	▪ Situs inversus totalis ▪ Right atrial isomerism ▪ TAPVC ▪ Unbalanced AVSD ▪ Hypoplastic RV ▪ Bilateral SVC *Acquired right pulmonary vein occlusion following TAPVC repair*	1	Unknown	1. CMR for cardiac contours and myocardial architecture		▪ Define feasibility of 1.5 ventricle repair ▪ Plan placement of intraventricular baffle around the aortic valve ▪ Delineate the optimal location for placement of RV-PA conduit	1. Left-sided BT shunt 2. Right bidirectional Glenn shunt and ligation of left SVC 3. Repair of TAPVC 4. 1.5 ventricle repair	
		2	8 m					
		3	18 m					
		4	3 y					
2	▪ Large perimembranous VSD with muscular extension ▪ Large ASD ▪ Functional single ventricle with hypoplastic RV ▪ Mitral and Tricuspid valve insufficiency ▪ Interrupted aortic arch *Large, unrestrictive mid-muscular VSD measuring 21 mm in basal-apical length, extending from posterior at the AV valves to the outlet septum with biventricular septum noted on first echocardiogram at our center*	1	1 m				1. PA banding 2. Interrupted aortic arch repair	
		2	2 m					
		3	4 y	1. Cardiac CT for cardiac contours and myocardial architecture		▪ Confirm feasibility of biventricular repair	3. Septation of complex univentricular heart with Gore-Tex patch, excision of PA band, re-anastomosis of main PA with Gore-Tex ventricular outflow tract patch augmentation, and ASD and VSD repair	
3	▪ DORV, TGA type with subpulmonary VSD ▪ Ventricular hypertrophy ▪ Subvalvular aortic stenosis ▪ Straddling mitral valve ▪ Tricuspid valve regurgitation ▪ Pulmonary valve stenosis *Medical record(s) unavailable for 1st and 2nd surgical procedure performed at another institution*	1	Unknown				1. Bidirectional Glenn shunt 2. Lateral tunnel Fontan procedure 3. Subaortic stenosis resection, pulmonary valve closure, and tricuspid valve annuloplasty 4. Fontan takedown, biventricular repair with VSD closure, reconstruction of RA and PAs, re-anastomosis of the aortic arch, and RV-PA conduit placement	
		2	Unknown					
		3	7 y					
		4	7 y	1. Cardiac CT for cardiac contours and myocardial architecture		▪ Define possibility of biventricular repair ▪ Plan intraventricular tunnel placement		
4	▪ Situs inversus totalis ▪ Superior-inferior orientation of the ventricles ▪ DORV with pulmonary atresia ▪ Subaortic VSD with single coronary artery ▪ Bilateral SVC *Medical record(s) unavailable for 1st and 2nd surgical procedure performed at another institution*	1	Unknown				1. Unknown 2. Bilateral bidirectional Glenn shunt	
		2	2 y					
		3	8 y	1. Cardiac CT for cardiac contours and myocardial architecture		▪ Asses RV for biventricular repair ▪ Plan for ventriculotomy ▪ Plan placement of RV-PA conduit without affecting the tricuspid valve	3. Biventricular repair	
5	▪ Dextrocardia ▪ Unbalanced AVSD with right-sided LV hypoplasia ▪ DORV ▪ Sub-pulmonary stenosis ▪ Bilateral SVC ▪ Mixed (supra and infra cardiac) TAPVC *Heart and lung transplant offered due to pulmonary hypertension and acquired right pulmonary vein occlusion at another institution, which was refused by parents*	1	3 w					
		2	11 y	1. Cardiac CT for cardiac contours and myocardial architecture		▪ Feasibility for pulmonary vein repair ▪ Assess LV and intracardiac anatomy for biventricular repair	1. TAPVC repair with atrial septectomy 2. Left pulmonary vein marsupialization with pulmonary artery banding (staged palliation)	
		3	11 y				1. Urgent complete repair with ECMO support 2. Complex ASD and VSD patch closure 3. AVSD repair 4. Right PA ligation	
6	▪ DORV ▪ L-TGA ▪ Pulmonary stenosis ▪ Interrupted IVC ▪ Large VSD ▪ Mitral valve regurgitation *RV-PA conduit placed at age 9 years at another institution was compressed by the sternum*	1	15 m				1. Rastelli-Senning repair with mechanical mitral valve replacement	
		2	9 y				2. RV-PA conduit replacement with upsized mitral valve	
		3	16 y	1. Cardiac CT for cardiac contours		▪ Plan sternotomy ▪ Plan placement of RV-PA conduit while maintaining integrity of RCA and other cardiac structures	3. RV-PA conduit replacement in a new position with upsized mitral valve	
7	▪ Pulmonary atresia with intact ventricular septum ▪ Large secundum ASD *Obstructed double chambered RV*	1	1 w				1. 5 mm left-sided BT shunt with transpulmonary valvotomy	
		2	2 y				2. Bidirectional Glenn shunt	
		3	26 y	1. CMR for cardiac contours and myocardial architecture 2. 3DTEE for tricuspid valve anatomy		▪ Assess RV for 1.5 ventricle repair ▪ Plan right ventriculotomy and muscle bundle resection ▪ Delineate tricuspid valve spatial anatomy	3. 1.5 ventricle repair with resection of muscle bundle in the RV	

Note. Age unknown – medical record(s) unavailable as procedure was performed at another institution; 3D – three-dimensional; ASD – atrial septal defect; AVSD – atrioventricular septal defect; BT – Blalock-Taussig; CMR – cardiac magnetic resonance; CT – computed tomography; DORV – double outlet right ventricle; IVC – inferior vena cava; LAD – left anterior descending; LV – left ventricle; RCA – right coronary artery; RV – right ventricle; RV-PA – right ventricle to pulmonary artery; SVC – superior vena cava; TAPVC – total anomalous pulmonary venous connection; TEE – transesophageal echocardiogram; TGA – transposition of the great arteries; VSD – ventricular septal defect