3D Models for Complex Congenital Heart Disease - A Game Changer?

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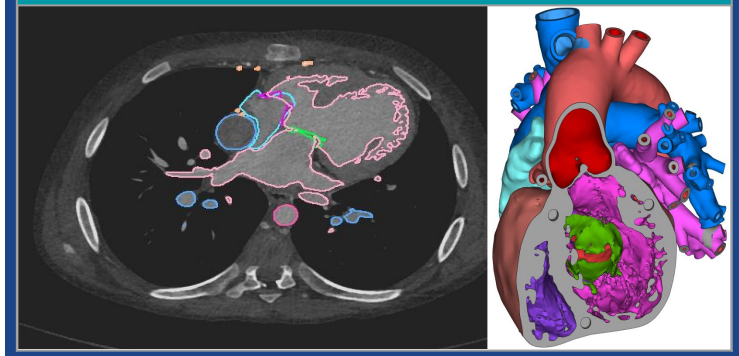
Introduction

- Congenital heart disease (CHD) encompasses a wide spectrum of malformations with diverse & complex pathology.
- A thorough understanding of the anatomy and physiology is key to the diagnosis and management of complex CHD.
- Preoperative surgical planning based on routine two-dimensional (2D) imaging studies can often be challenging.
- Three-dimensional (3D) printing technology has become an exceptional tool to help comprehend the complex cardiac anatomy of CHD patients.
- Using 3D heart models enhances visualization and understanding of the spatial relationships of intracardiac structures, increasing surgical confidence and potentially improving outcomes.
- Since 2015, we have used life-sized 3D heart models in selected cases to formulate multidisciplinary treatment plans for our patients.

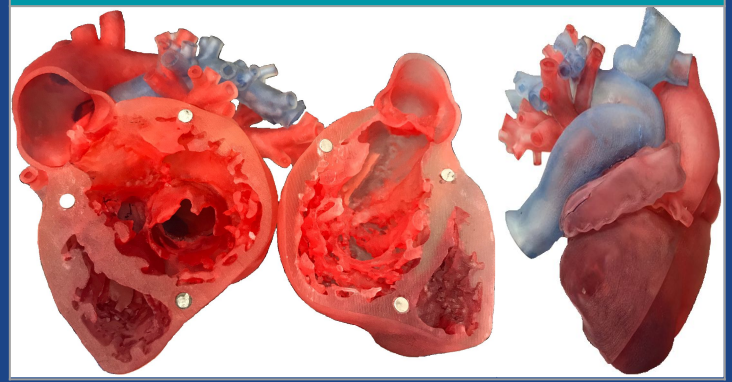
Case Description

- A 10 year old male presented with a history of congenitally corrected transposition of the great arteries, double outlet right ventricle, pulmonary stenosis, VSD and complete heart block.
- He was status post palliative repair with bidirectional Glenn, non fenestrated extracardiac Fontan, and pacemaker placement.
- His history was complicated by a failing Fontan with protein losing enteropathy, which prompted heart transplant evaluation.
- A 3D model of his heart was created from a contrast enhanced MRI and presented at a multidisciplinary conference.
- It was determined that a one and a half ventricle repair would be a feasible option.
- His surgical repair included takedown of the Fontan, creating a left ventricle to aortic tunnel through the VSD with Gore-Tex, Hemi-Mustard procedure diverting the IVC to the tricuspid valve, augmentation of the left atrium with bovine pericardium, and placement of a right ventricle to pulmonary artery conduit that had a Trifecta pulmonary valve. The Glenn anastomosis was left intact.
- The surgical procedure based on his 3D model was executed as planned with an excellent outcome.

Figure 1 (left): Segmented 2D Image Using Mimics;
Figure 2 (right): Virtual 3D Model



Figures 3-4: 3D Heart Model Post-Processing



3D Printing Method

- Materialize Mimics is an additive manufacturing software that calculates surface 3D models from stacked 2D image data.
- The contrast-enhanced cardiac MRI or CT scan is imported into Mimics software.
- Using Mimics, the structures of interest are manually segmented by the biomedical engineer in close collaboration with the pediatric cardiologist.
- The file is then converted into a 3D volume and compared slice by slice to the MRI or CT DICOM images to verify accuracy and make corrections as needed.
- The 3D volume is then converted into a Standard Tessellation Language (STL) format and imported into Materialise Magics in preparation for 3D Print.
- Magics is an STL editor software that allows you to repair, optimize and edit your 3D design.
- The final STL file is printed using a Stratasys Connex 350 using TangoPlus FLX930 resin.
- After printing is complete, the model undergoes post-processing, which includes cleanup and removal of supportive material.

Benefits

- Provides invaluable information regarding the spatial relationship of intracardiac structures and accurately replicates complex cardiac anatomy
- Aids in perioperative planning, simulations and device testing
- Can be excellent tools for patient-doctor communication for preoperative counseling and thereafter
- Can be used as an educational tool for trainees/students and enhance understanding about congenital heart disease
- Could improve patient outcomes and decrease operative times

Challenges

- Lack of standardization, where the steps of image acquisition, segmentation and printing are operator dependent
- Labor intensive with long average segmentation and printing times
- Coordination of efforts as it requires expertise in both navigating the segmentation software and medical knowledge of a patient's complex anatomy
- Unable to reproduce the physiologic variations during the cardiac cycle
- Radiation exposure to the patient
- Cost and resources needed to set up a workflow system in the hospital

Conclusion

- The application of 3D printing in healthcare is widespread and diverse and can potentially bring revolutionary changes in the near future.
- The 3D model allows us to overcome some of the limitations of 2D imaging modalities, which are often integrated into the clinical decision-making process.
- At this time, the production of a 3D model lacks standardization, is quite labor intensive and requires a significant amount of resources, which limits its use to large institutions.
- By addressing these obstacles, we can hopefully work towards a future where incorporating these models into clinical practice will become the standard of care.

References

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