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DEVELOPMENT OF AN OPEN-ACCESS LIBRARY OF PEDIATRIC CONGENITAL HEART DISEASES AND TREATMENTS: A TUTORIAL ON THE ATLAS OF HUMAN CARDIAC ANATOMY

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ABSTRACT

The major aim of this project is to construct a growing database of information regarding specific manifestations of congenital heart diseases (CHDs), subsequent treatments, clinical cases, and patient outcomes. This will include 3D models generated from clinical imaging of individual patient hearts and respective de-identified clinical case information – all of which will be incorporated onto the free-access Atlas of Human Cardiac Anatomy website (http://www.vhlab.umn.edu/atlas/), where anyone can learn more about these diseases and their complexities [1]. Generated models can also be used for 3D printing, such as for pre-surgical planning, as well as for incorporation into virtual reality in order to expand outreach and education efforts [2]. Future work will incorporate computational modeling to enhance insights relative to treatment strategies and surgical planning. By studying a broad range of these unique individual cases, it will be possible for patients, clinicians, and medical device designers alike to better understand the clinical presentations of congenital heart diseases and develop more effective treatment strategies.

Keywords: congenital heart defect, congenital heart disease, cardiovascular surgery, 3D printing, computational modeling, virtual reality

NOMENCLATURE

CHD	Congenital Heart Disease, Congenital Heart Defect
MRI	Magnetic Resonance Imaging
CT	Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
STL	stereolithography (file type)
VR	virtual reality

INTRODUCTION

Each year in the United States, around 40,000 children are born with one or more congenital heart defects or diseases [3]. These cardiac structural abnormalities present at birth and can range from a symptomless anomaly that resolves itself over time, to an incurably fatal deformity. Approximately 25% of babies born with a CHD are classified as having a critical CHD, meaning that they will require corrective surgery within one year after birth [3]. For many critical CHDs, the abnormality cannot be completely repaired within one surgery. Often, there are a series of staged surgeries the child will undergo as they age: i.e., as their heart continues to grow and remodel. As such, congenital heart defects as well as their respective corrective procedures are very individualized and complex. In other words, although a given abnormality may be classified as a certain CHD, there is considerable variation in its presentation from patient to patient [4]. For this reason, constructing an online database of de-identified case information coupled with 3D and computational modeling of these CHD patients' anatomies can significantly aid in understanding CHDs, their treatments, and potential patient outcomes.

METHODS

When a child presents with symptoms of a congenital heart disease, they will typically go through a series of clinical

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diagnostics, including clinical imaging with MRI, CT, and/or echocardiography. With the consent of the patient and/or their legal guardian(s), the resultant DICOM images are used to construct 3D models of the given patient's heart. At this step, to preserve participant anonymity, each patient's identifying information is removed from any models or publicly accessible content. Detailed models are created through manual segmentation of the clinical imaging using Materialise Mimics® software, which is then exported to Materialise 3Matic® as an STL for further refinement. During this process, models are sectioned or otherwise cut away in order to more readily visualize interior defects. Particularly for blood volume models, another version is always created in which the model is externally shelled to better elucidate bloodflow pathways and tissue anomalies within the given heart. After an appropriate 3D model is attained, it may be both printed and incorporated into a virtual reality (VR) scene.

Typically, 3D models are readied for printing using Ultimaker Cura software and then printed on an Ultimaker 3 Extended printer using PLA build material and PVA support material. For virtual reality, 3D models are readied using Meshlab and imported into Unity3D. From there, models are incorporated into various VR scenes and are interacted with by way of an HTC VIVE headset and controller.

RESULTS

To date, preliminary results for the project have included approximately ten different patient cases, representing nine different CHDs. Of these, four patients' anatomies were 3D-printed, and six patients' anatomies were incorporated into VR scenes. Three to seven different models were constructed for each printed case, which were then used for pre-surgical planning. All of these models were made from CT scans. 3D renderings of two models and photos of the completed prints can be seen in Fig. 1.

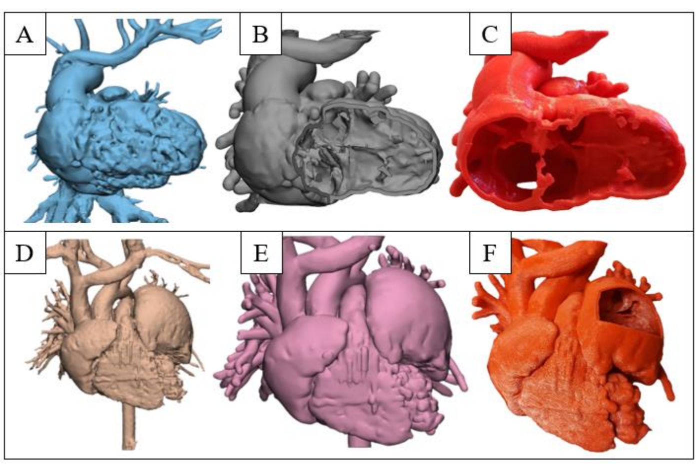

FIGURE 1: 3D MODELS AND PRINTS OF TWO HEARTS WITH CHDS, USED FOR PRE-SURGICAL PLANNING

Images A-C show blood volume, shelled, and printed models, respectively, of a heart exhibiting tetralogy of Fallot with pulmonary atresia and major aortopulmonary collateral arteries. Images D-F show the same, but for a patient whose heart presented with a large left atrial appendage aneurysm. As shown, different areas of the 3D models were cut away before printing, in order to reveal the internal details of the heart – particularly at the location of the defect.

For the cases with models incorporated into VR, a different virtual reality scene was created for each model, showcasing a different CHD. A screen capture from a VR scene featuring one such model can be seen in Fig. 2. This model was created from CT scans of a patient presenting with mixed aortic valve disease and a dilated ascending aorta.

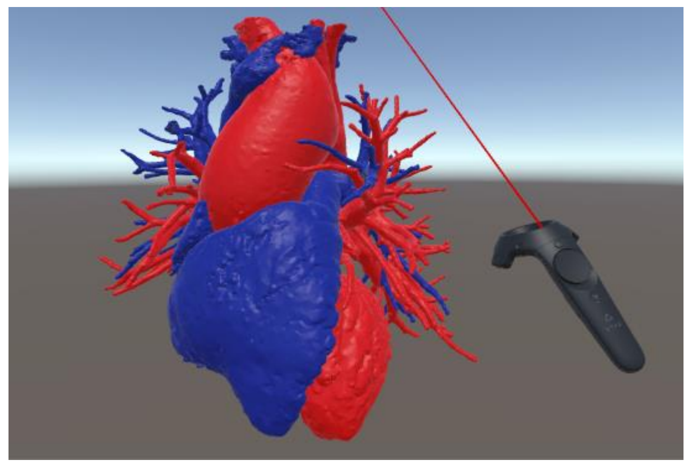

FIGURE 2: A SCREEN CAPTURE FROM A VIRTUAL REALITY SCENE CONSTRUCTED TO INCLUDE A BLOOD VOLUME MODEL OF A HEART WITH A CONGENITAL DEFECT

CONCLUSIONS AND FUTURE WORK

It has been demonstrably valuable to begin to build a database of congenital heart cases and surgeries [5]. In addition to the educational goal of making de-identified clinical case information widely available, 3D modeling is an invaluable aid in enriching understanding of each given clinical case, especially in those patient cases presenting with multiple defects or disease states. Learnings from this broad range of CHD models can be utilized for generalized surgical planning, as well as for developing a deeper appreciation for the high variability and complexities among the population of patients within a given congenital heart defect category. In addition to increasing awareness and understanding of CHDs for the general public, the construction of an open-access database to contain this extensive case information allows for engineers and medical professionals around the world to become more knowledgeable about CHDs and their inherent complexities. This can lead to future advancements in medical device design or surgical procedure development, ultimately improving cardiac healthcare for all children.

Future work within this project will include comparison models of a given patient's cardiac anatomy before and after corrective surgery so to better illustrate cardiac remodeling and supplement descriptions of patient outcomes. Additionally, computational modeling of bloodflow patterns will be generated for various patients, so to better study cardiac remodeling and predictability of patient outcomes.

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