The Use of 3D Printing in the Teaching of Congenital Heart Disease

Introduction

Congenital heart disease (CHD), one of the most common congenital anomalies, is a leading cause of infant morbidity and mortality, occurring in approximately 1% of live-births in the United States and 9 per 1000 worldwide[1,2]. Advances in congenital cardiac surgery and cardiac care have increased the prevalence adult patients with CHD. In fact, today there are more adults with CHD than children[3]. As a leading cause of morbidity in pediatric patients and an emerging field in adult medicine, the anatomy and pathophysiology of congenital heart disease is an integral part of medical education.

Unlike many other congenital diseases, CHD is unique in that the pathophysiology of disease is often directly related to pathologic anatomy. The teaching of CHD, therefore, relies heavily on 2-dimensional representations of cardiac defects including cartoons, diagrams, echocardiography, CT, MRI, and Cath images. The ability to transfer those 2D images into 3D mental representations of CHD lesions is critical to the understanding, diagnosis, and management of underlying disease[4–7].

To better demonstrate specific cardiac lesions in 3 dimensions, some institutions have collected cardiac specimens from deceased children over the course of decades and preserved them for CHD education. These specimens are incredibly useful in providing physical, manipulatable samples of cardiac lesions for the purposes of medical education. Unfortunately, these specimens are not widely available and are limited by the age and unique pathophysiology of each patient encountered. Furthermore, as we improve the management of patients with CHD, more recent cardiac specimens often consist of lesions that have undergone various forms of intervention. Using 3D printed models would allow for the production of models demonstrating classic CHD lesions in children of any age and specific lesions of living children either prior to, or post intervention [8–11]. These models would be widely accessible to students from varying backgrounds and can also help alleviate the financial and ethical considerations inherent in cadaveric specimen utilization[12]. When comparing the use of 3D printed cardiac models to cadaveric specimens, research suggests few disadvantages to using 3D printed models, demonstrating equivalent if not improved educational outcomes[13].

While prior studies have compared the utilization of 3D printed cardiac models to 2D representations of isolated lesions in parent education, surgical planning, and simulation, few studies have explored its utility in medical education across a variety of specific congenital heart lesions[11,14–18]. Even fewer have compared educational outcomes to those of cadavers, cath images, as well as 2D representations. The purpose of this study was to explore the use of 3D cardiac models of common CHD lesions – atrial septal defect (ASD), Tetralogy of Fallot (TOF), D-transposition of the great arteries (D-TGA), coarctation of the aorta, hypoplastic left heart syndrome (HLHS), and pulmonic stenosis (PS) – in medical education. We hypothesize that 3D models will improve students' understanding of these common cardiac lesions, as well as demonstrate an advantage to 3D modeling over other educational modalities.

Methods

Study design. Subjects consisted of first year medical students invited to participate in a CHD workshop as an adjunct to their normal cardiology lecture series. The workshop consisted of four separate stations, one station where students watched an embryology video, a second station where students learned about lesions from 2D diagrams and cath images, a third station where students examined pathology specimens, and a fourth station where students manipulated 3D printed cardiac models. Each station had a Cardiologist representative responsible for a spoken explanation and description of the educational tools provided, and every station aimed to teach students about all six congenital lesions – ASD, TOF, D-TGA, Coarct, HLHS, and PS.

When students arrived, they were given a numeric identifier randomly divided into four different groups and randomly assigned to a different station: embryology, pathology, 2D images, and 3D printing. Each group spent approximately 15 minutes at each station before moving on to the next. Prior to the 3D session students were asked to complete a pre-intervention survey to assess their perceived understanding of each cardiac lesion. The survey consisted of one question for each lesion asking, "How would you rate your knowledge of?" on a Likert-scale from 1 to 5 with 1 being "very low" and 5 being "very high" (fig. 1). At the end of the session students were asked to complete a post-intervention survey asking, "After visiting the 3D model table, how would you rate your knowledge of?" for each lesion. At the end of all the workshop, students were asked to rank all sessions in order from 1 (least helpful) to 5 (most helpful). They were also asked to complete a specific questionnaire regarding the utility of the 3D printed models (fig. 2).

Statistics. Data from the 'pre' and 'post' intervention survey was analyzed in Excel and a two-tailed paired T-test was performed to compare students' understanding of each specific lesion. Prior to data analysis, a power analysis was performed to assess for a standard deviation of 1, a P-value <0.05 and 80% power, demonstrating the need for at least 34 subjects to illustrate a score change above 0.5, or approximately 10%.

Preliminary Results

There were 45 first year medical students who attended the congenital heart disease workshop, and 44 students who successfully completed the pre- and post- intervention surveys. All students found the 3D models to improve their knowledge across all congenital lesions (table 1). The average increase in score for ASD was 0.6 ($p = <0.001$), TOF was 0.8 ($p = <0.001$), D-TGA was 0.88 ($p = <0.001$), Coarct was 0.84 ($p = <0.001$), HLHS was 1.1 ($p = <0.001$), and PS was 0.3 ($p = 0.001$) (fig. 3).

Tables and Figures

Table 1: Difference in Perceived Knowledge Before and After 3D Model Station

Lesion	N	Pre-Intervention		Post- Intervention		Mean Difference	Std. Dev.	*p* value
		Mean	Std. Dev.	Mean	Std. Dev.			
ASD	44	2.98	0.59	3.59	0.66	0.61	0.54	< 0.0001***
TOF	44	2.86	0.64	3.61	0.69	0.82	0.54	< 0.0001***
D-TGA	44	2.73	0.73	3.61	0.62	0.89	0.69	< 0.0001***
Coarct	44	2.89	0.78	3.73	0.63	0.84	0.61	< 0.0001***
HLHS	44	2.39	0.81	3.5	0.70	1.11	0.65	< 0.0001***
PS	44	3.0	0.57	3.32	0.56	0.31	0.60	0.001**

Medical Student Pathology Course Survey

Introduction: *Please complete the questionnaire below and circle your response.* This survey is meant to improve teaching methods. The PI of the study, Dr. Kanwal Farooqi would like to survey you before and after review of the 3D printed cardiac models. We will not collect any identifying information on you and all responses will be kept anonymous.

How would you rate your knowledge about:	Before visiting the 3D model table					After visiting the 3D model table				
	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High
Atrial Septal Defects	1	2	③	4	5	1	2	3	④	5
Tetralogy of Fallot	1	2	3	④	5	1	2	3	④	5
D-Transposition of the great arteries	1	2	3	④	5	1	2	3	④	5
Coarctation of the aorta	1	2	3	④	5	1	2	3	④	5
Hypoplastic Left Heart Syndrome.	1	2	3	④	5	1	2	3	④	5
Pulmonic stenosis	1	2	3	④	5	1	2	3	④	5

1. Very Low= Don't know anything about this topic.
2. Low= Know very little about this topic
3. Moderate= Know about this topic but there are more things to learn
4. High = Have good knowledge but there are things to learn
5. Very High = Know almost everything about this topic

Figure 1. Pre- and Post- Intervention Survey

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On a scale of 1 (strongly disagree) to 5 (strongly agree) please rate the following statements:

1 The 3D printed heart models helped me to learn about atrial septal defects.
(strongly disagree)   1   2   3   4   **5** (strongly agree)

2 The 3D printed heart models helped me to learn about Tetralogy of Fallot.
(strongly disagree)   1   2   3   **4**   5 (strongly agree)

3 The 3D printed heart models helped me to learn about D-Transposition of the great arteries.
(strongly disagree)   1   2   3   **4**   5 (strongly agree)

4 The 3D models helped me to learn about coarctation of the aorta.
(strongly disagree)   1   2   3   **4**   5 (strongly agree)

5 The 3D models helped me to learn about pulmonic stenosis.
(strongly disagree)   1   2   3   **4**   5 (strongly agree)

6 The 3D models helped me to learn about Hypoplastic Left Heart Syndrome.
(strongly disagree)   1   2   3   **4**   5 (strongly agree)

7 I would recommend the use of 3D printed models for future sessions.
(strongly disagree)   1   2   3   **4**   5 (strongly agree)

8 I feel more confident about explaining the congenital heart disease anatomy to others after learning from 3D printed heart models.
(strongly disagree)   1   2   3   **4**   5 (strongly agree)

Please rate the following from 1-5 in order of **least (1) to most (5)** helpful for learning about the anatomy of a specific congenital heart disease:

_Embryology Video **1**
_Spoken explanation about the congenital heart disease physiology **2**
_Pathology specimen **3**
_3D printed model **5**
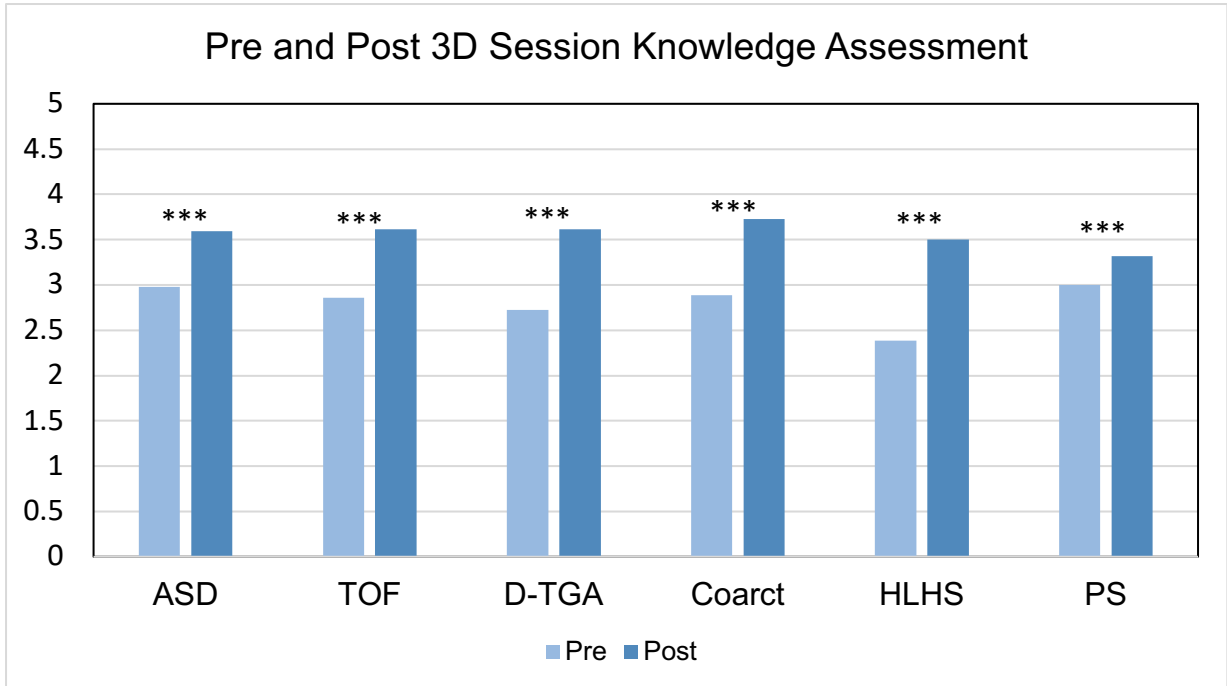_2D drawing **4**

Figure 2. Post-Workshop Questionnaire

Figure 3. Mean Assessment of Student Knowledge

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