Received: 2 April 2017 | Revised: 5 May 2017 | Accepted: 11 May 2017
DOI: 10.1111/chd.12486

ORIGINAL ARTICLE

WILEY Congenital Heart Disease

Use of 3D models of vascular rings and slings to improve resident education

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Funding information
Sarver Heart Center Congenital Heart Disease Education Grant and the University of Arizona College of Medicine Vernon & Virginia Furrow Award for Medical Education Research

Abstract

Objective: Three-dimensional (3D) printing is a manufacturing method by which an object is created in an additive process, and can be used with medical imaging data to generate accurate physical reproductions of organs and tissues for a variety of applications. We hypothesized that using 3D printed models of congenital cardiovascular lesions to supplement an educational lecture would improve learners' scores on a board-style examination.

Design and Intervention: Patients with normal and abnormal aortic arches were selected and anonymized to generate 3D printed models. A cohort of pediatric and combined pediatric/emergency medicine residents were then randomized to intervention and control groups. Each participant was given a subjective survey and an objective board-style pretest. Each group received the same 20-minutes lecture on vascular rings and slings. During the intervention group's lecture, 3D printed physical models of each lesion were distributed for inspection. After each lecture, both groups completed the same subjective survey and objective board-style test to assess their comfort with and postlecture knowledge of vascular rings.

Results: There were no differences in the basic demographics of the two groups. After the lectures, both groups' subjective comfort levels increased. Both groups' scores on the objective test improved, but the intervention group scored higher on the posttest.

Conclusions: This study demonstrated a measurable gain in knowledge about vascular rings and pulmonary artery slings with the addition of 3D printed models of the defects. Future applications of this teaching modality could extend to other congenital cardiac lesions and different learners.

KEYWORDS
3D printing, medical education, pediatric cardiology

1 | INTRODUCTION

Three-dimensional (3D) printing is a manufacturing method by which an object is created in a layer-by-layer additive process, typically using an inkjet-style applicator, to build complex objects for very little cost in a short amount of time.[1] This technology has been used with medical imaging data (computed tomography and magnetic resonance imaging) to generate accurate 3D models of organs, tumors, and prostheses for pre-surgical planning, patient education, clinical training, and implanted devices.[2,3] This technology has unique applications in pediatric cardiology due to its ability to reproduce complex anatomical relationships, such as those found in congenital heart defects.[4–9]

Many medical educators and trainees believe 3D printing technology has the potential to serve as a unique educational tool for physicians, residents, medical students, and other health professionals.[10] Indeed, work is already underway in some centers to utilize patient-derived models created through 3D printing for use as simulators for surgical valve placement and arterial access.[11,12] Other studies have demonstrated that using physical models of anatomic specimens may be more effective teaching methods than textbook or computer-based learning.[13] Multiple opportunities in simulation and didactic medical education exist for 3D printing technology for the field of pediatric cardiology.

However, there is a paucity of literature examining the effectiveness of 3D prototypes of anatomic and pathologic specimens in medical education, particularly for complex cardiovascular lesions. This purpose of the current study is to study the utility and effectiveness of 3D printed models of aortic arch anomalies, important and complex structures, in pediatric resident education.

2 | METHODS

After approval from the University of Arizona Institutional Review Board, patients with representative normal aortic arches and abnormal aortic arches (vascular rings and pulmonary artery slings) were identified from our local pediatric cardiology database. Those with appropriate axial imaging (CT or MR angiography) were selected and anonymized to use to generate 3D printed models. The anatomy selected included: normal aorta, double aortic arch (ring), right aortic arch with aberrant left subclavian artery (ring), left aortic arch with aberrant right subclavian artery (normal variant) and left pulmonary artery sling. Segmentation of the vascular anatomy of interest as well as the airway, when visible) was performed using Philips IntelliSpace Portal (Philips Healthcare, Best, The Netherlands) and Stereolithography files were generated from these segments. Models were then cleaned and prepared for printing using Autodesk MeshMixer (Autodesk, Inc., San Rafael, CA). Models were printed with poly-lactic acid on a Dremel 3D Idea Buidler (Dremel, Mount Prospect, IL).

Subjects were then identified and recruited on a voluntary basis from the Department of Pediatrics and combined Pediatrics/Emergency Medicine Residency programs at the University of Arizona College of Medicine. An email was sent to all trainees asking for their interest in the study. Participants were then randomly assigned to either the control or intervention groups based on the order of their response (first responder—control group, second responder—intervention group, etc.).

Once the groups were assigned, they were both designated to meet at separate times for a lecture. Prior to the lecture, each group provided anonymous, coded responses for gender and year of residency, as well as a three subjective survey questions on a Likert scale regarding their level of comfort with understanding, diagnosing, and treating vascular rings and slings (Supporting Information 1). They also completed a seven question, objective, board-style test to assess their preexisting knowledge of vascular rings and slings (Supporting Information 2). Each group then received the same 20-minutes lecture on vascular rings and slings, covering the anatomy, clinical significance, diagnosis, and treatment of these lesions. The lecture included three views (frontal, posterior, and superior) of each of the virtual models used to generate the physical printed models (Figure 1). During the intervention group's lecture 3D printed physical models of each lesion (Figure 2) were distributed for inspection. After each lecture was complete, both groups completed the same subjective survey and objective board-style test to assess their comfort with and postlecture knowledge of vascular rings.

The results from each group were analyzed, comparing the change in subjective and objective scores within groups as well as the differences between the control and intervention groups. Continuous variables were compared with *t*-tests, subjective scores compared with Wilcoxon signed rank test, and categorical variables compared with chi-square test. Statistical analyses were performed with SPSS Statistics v23 (IBM Corp., Armonk, NY).

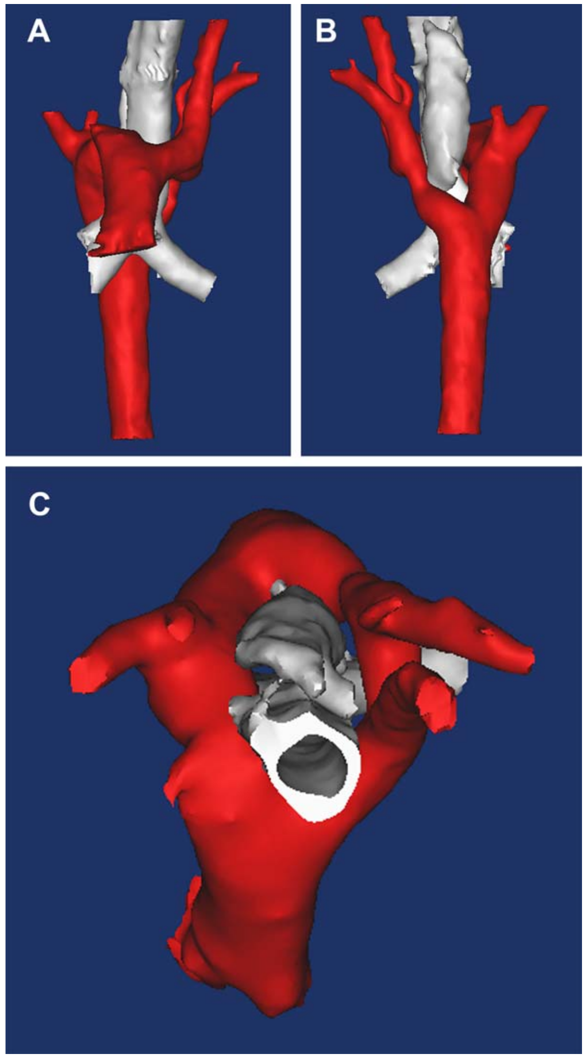

FIGURE 1 Virtual computer model from frontal (A), posterior (B), and superior views (C) generated from patient imaging data of a double aortic arch (a type of vascular ring) and used in the lecture for both groups. Aorta is red, trachea is white

3 | RESULTS

Sixty-three residents were approached for participation. Of these, 42 (67%) responded and 36 (17 in Group 1, 19 in Group 2) completed the study. Demographics are shown in Table 1. There were no differences in years of training or gender.

The results of the pre and postlecture subjective surveys are shown in Table 2. In both groups, participants were somewhat uncomfortable in their knowledge of the anatomy, diagnosis, and treatment of vascular rings and slings. After the lectures, both groups' subjective comfort levels significantly increased.

FIGURE 2 3D printed model of a double aortic arch generated from the same patient data set and use in the lecture for the intervention group. Aorta is red, trachea is white

The results of the pre- and postlecture objective tests are shown in Table 3. Both groups performed quite poorly at baseline, with no difference between the groups. After the lectures, both groups' average scores improved, with all but one in the intervention group scoring higher on the posttest; that participant was the only one who scored lower on the posttest. Despite this, the intervention group obtained a higher average score than the control group after the lecture. The intervention group's scores improved by 2.6 questions, compared to the control group's improvement by 1.8 questions, which did not reach statistical significance ($P = .084$).

4 | DISCUSSION

Our prospective educational intervention incorporating 3D models into teaching residents about vascular rings and slings showed a measurable improvement in their knowledge acquisition. There have been other studies reporting incorporation of 3D models anatomic models into education, but this is the first to our knowledge to systematically study and document an improvement in knowledge acquisition.

TABLE 1 Demographic data of resident participants among the control and intervention groups. "Year in training" denotes the postgraduate year of education of the resident, ranging from intern (1) to fifth-year (5) pediatric/pediatric emergency medicine resident

	Control (n = 19)	Intervention (n = 17)	*P*
Year in training	2 (1–5)	2 (1–5)	.707
Female (n, %)	13 (68%)	13 (76%)	.436

TABLE 2 Results of the pre and postlecture subjective surveys of resident participants among the control and intervention groups

	Prelecture	Postlecture	*P*
Control			
1. Anatomy of rings and slings	4 (2–6)	5 (2–6)	.003
2. Diagnosis of rings and slings	4 (1–6)	5 (2–7)	.003
3. Treatment of rings and slings	3 (1–6)	5 (2–7)	.001
Intervention			
1. Anatomy of rings and slings	3 (1–5)	5 (3–6)	.001
2. Diagnosis of rings and slings	3 (1–5)	5 (5–6)	<.001
3. Treatment of rings and slings	3 (1–4)	5 (3–6)	<.001

As expected, both groups demonstrated subjective and objective improvement between pretest and posttest scores, suggesting that the lecture was delivered appropriately and well-received for each group. The intervention group achieved a higher average score than the control group after the lecture. While the total improvement from pre- to posttest scores did not reach statistical significance, if the one subject in the intervention group who did worse on the posttest was excluded from analysis, the difference in improvement becomes significant (2.8 vs 1.8 questions, $P = .017$).

3D printing is becoming a valuable resource in the world of medical and anatomical education, thanks to the ability to cheaply, efficiently, and rapidly reproduce complex relationships between structures.[14,15] To prove the versatility of this technology, educators have reproduced cadaveric limb segments, cranial sinuses, vascular structures,[16] orbital dissections,[17] pediatric laryngeal and cleft palate simulators,[18,19] training set ups for surgical valve replacement,[11] arterial access simulations,[12] and bronchial trees for simulated bronchoscopy.[20,21]

This ability to reproduce complex structures with high fidelity for manipulation and examination has also made 3D printing an attractive modality in cardiology. Reported cardiovascular applications of 3D printing range from valve simulations in the physiology laboratory,[22] reproducing structures as scaffolds for tissue engineering technologies,[23–25] manufacture of personalized devices for cardiac interventions[26,27] and preprocedural planning for interventional catheterization and surgery.[5,7–9,28–39]

Given the utility of 3D printing in anatomic and medical education, as well as its suitability for helping physicians understand complex cardiac disease, its potential application for resident and fellow education of congenital cardiology seems obvious. When presented with a range of 3D printed patient-specific models of pathologic lesions, the

TABLE 3 Results of the pre- and postlecture objective tests of resident participants among the control and intervention groups

	Control (n = 19)	Intervention (n = 17)	*P*
Pretest score (%)	19.5 ± 15.9	25.2 ± 13.9	.266
Posttest score (%)	45.1 ± 12.8	62.2 ± 16.7	.001
Improved (n, %)	15 (79)	16 (94)	.206
Score increase	1.8 ± 1.2	2.6 ± 1.5	.084

consensus of trainees and educators has been overwhelmingly positive regarding the potential applications of this technology.[10] Others have found that by printing a model of a pancreatic lesion for presurgical planning, there were unanticipated benefits for resident and patient education.[40] More specific to congenital heart disease, the application of rapid 3D prototyping of patient-specific lesions for the education and preparation of multidisciplinary teams and nursing staff has been found to increase learner comfort and understanding of the pathophysiology of the defect.[41,42]

However, in spite of the exponentially increasing educational applications available for 3D printing, there are few objective assessments in the literature. The results of the present study demonstrate that by incorporating models of complex congenital vascular lesions, residents may gain a measurable improvement in their education and understanding compared to standard two-dimensional projected images during a lecture.

There are several limitations to the present study. First, the study was limited to a small group of congenital cardiovascular lesions reproduced via 3D printing and may not be applicable to all congenital heart defects. An interesting future study would be to repeat a similar intervention for complex congenital cardiac defects. A second limitation was the study population, which was entirely comprised of pediatric and pediatric/emergency medicine residents, a group whose surgical experience is limited. This may limit the generalizability of our findings to other specialty and subspecialty trainees, as well as medical students or allied health professionals. A final limitation is that participants were only tested for acute knowledge gain. Repeat testing at a future date would be interesting to see if the intervention group was able to retain the information better long term.

In conclusion, we were able to demonstrate a measurable gain in knowledge about vascular rings and pulmonary artery slings by supplementing standard lectures with 3D printed models. Future applications of this teaching modality could extend to other congenital cardiac lesions and different learners.

CONFLICT OF INTEREST

The authors have no conflicts of interest relevant to this article to disclose.

AUTHOR CONTRIBUTIONS

All authors read and approved the final manuscript.

Study design: Jones, Seckeler

Conceptualization and manuscript drafting: Jones

3D model production, initial analyses, reviewed and revised: Seckeler

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

Supporting Information 1. Subjective survey questions regarding participants comfort level with the subject.

Supporting Information 2. Objective questions for pre- and post-lecture testing.

How to cite this article: Jones TW, Seckeler MD. Use of 3D models of vascular rings and slings to improve resident education. *Congenital Heart Disease*. 2017;12:578–582. https://doi.org/10.1111/chd.12486