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Original Article

Integration of 3-dimensional imaging into a congenital heart disease curriculum for the cardiac intensive care unit

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ABSTRACT

Objective: Successful management of congenital heart disease involves understanding complex 3-dimensional anatomy and physiology. Implementation of 3-dimensional imaging with medical education has shown to improve learner retention and self-efficacy. At our institution, care is provided by physicians with varied training backgrounds including Neonatology, Cardiology, Surgery, Pediatrics and Intensive Care. We evaluated the implementation of a surgical case-based curriculum incorporating 3D imaging across multiple platforms to our multidisciplinary providers over a six-month pilot study period.

Methods: Surgical case-based lectures were developed utilizing 3D imaging derived from patient-specific radiologic studies and open source applications, incorporated with existing peer-reviewed curriculum. During the week of surgery, a thirty-minute didactic session reviewing pre-operative anatomy, physiology, surgical indications and options, and post-operative management was presented to the multidisciplinary team. Anonymous responses to "pre" and "post" surveys of knowledge, perceived care ability, session content and format, were compared utilizing ordinal logistic regression. The pilot study period lasted from July 2018 – January 2019.

Results: 45 cardiac intensive care unit providers, mostly non-physicians [53%, (24/45)], with less than 2 years' experience [48%, (22/45)] attended eight distinct case-based lectures throughout the study period. >80% of participants report strong agreement regarding effectiveness of the session format, including 3D imaging visualization. Our primary educational outcome measures included significant self-reported improvements in anatomic, physiologic, and surgical knowledge, and perceived care ability, independent of background and years' experience.

Conclusion: 3D imaging can be successfully integrated into clinical didactic curricula to refine knowledge and improve care ability for a broad range of congenital heart disease providers.

Key Words: 3D Imaging, Congenital Heart Disease, Medical Education

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INTRODUCTION

Congenital heart disease (CHD) prevalence has increased from 0.6 per 1,000 live births in 1930 to 9.1 per 1,000 live births in recent years, due to advances in medical diagnostics and treatment, with an estimated 1.35 million patients are born with CHD annually[1,2]. In the United States, survival for even the most complex forms of CHD is expected to be ~90%, with increasing focus on improved neurodevelopmental and psychosocial outcomes as many of these patients are now expected to live into adulthood[1,2].

Successful management of a patient with CHD involves intimate understanding of the complex cardiac anatomy and physiology pre-operatively, understanding of the surgical procedure undertaken for palliation or repair, and the subsequent changes in anatomy and physiology occurring post-operatively[3,4]. As care for children with CHD continues to expand in scope and complexity, so does the need to provide adequate education and preparation to care providers[2,5,6]. Currently, Cardiac Intensive Care Units (CICU) are staffed by Physicians with varied backgrounds and board certifications including Pediatric Cardiology, Pediatric Anesthesiology, Pediatric Critical Care, Congenital Heart Surgery and Neonatology; in addition to multidisciplinary providers including Nursing, Respiratory Therapy, and Pharmacy[5,7].

Three-dimensional (3D) imaging technology allows anatomically accurate reconstruction of complex congenital heart disease lesions and surgical repairs derived from cardiovascular imaging including CT, MR and echocardiography[3,4,8-10]. The increased use of this technology in medical and surgical care has been well documented in the last decade[9-14]. Evidence continues to emerge that 3D printed models of CHD anatomy improves resident-level medical education and retention compared to traditional two-dimensional (2D) imaging[3,15-18]. The complexity of the anatomy and physiology of CHD can never be fully elucidated with static 2D images or textbooks, yet traditional medical education continues in this format with inherent limitations, even for advanced training programs dedicated to cardiac intensive care and CHD[13]. 3D images can provide a deeper understanding of anatomic complexity, especially for a dynamic hollow organ such as the heart whose anatomy, physiology and surgical options are intimately related[3,4,10,13,14]. Individual variation in visual-spatial understanding is eliminated, promoting more rapid digestion and retention of complex 3D anatomy and physiology than can be achieved with a series of static 2D images or without mastering orientation of cardiac and radiologic imaging modalities[3,4,13,15].

The objective of this study is further evaluation of the integration of 3D imaging into multidisciplinary clinical medical education-in the form of "just-in-time" case-based didactic teaching sessions focused on individual CHD lesions and repairs spanning complexity from isolated atrial septal defects to the hypoplastic left heart syndrome-conducted in our CICU.

As an institution, Loma Linda University provides CHD care in a "mixed-ICU" model. Many multidisciplinary providers do not work primarily in the CICU, potentially limiting clinical exposure to complex lesions and less frequently performed surgical interventions, while performing more than 150 congenital heart surgical cases annually, including VADs and transplants. Due to lack of consistent exposure to CHD, we chose the "just-in-time" model for this clinical educational project to capture a broad range of multidisciplinary providers[19-22].

Our hypothesis is utilization of 3D imaging improves self-reported provider knowledge and perceived care ability, across multiple medical specialties, years of experience, and levels of CHD complexity, especially for those providers in a "mixed-ICU" model. We hypothesize that the "just-in-time" model providing relevant, focused, case-based, clinical education is an effective teaching format across the same broad range of providers.

METHODS

Surgical case-based didactic sessions were developed incorporating 3D imaging derived from radiologic studies, open source applications and existing peer-reviewed curriculum [*Appendix, i*]. During the week of planned surgery, a 30-minute didactic session reviewing pre-operative anatomy and physiology, surgical indications and options, and post-operative management was presented to the multidisciplinary care team. With IRB approval, anonymous self-reported surveyed responses to pre- and post-session questionnaires of provider knowledge, perceived care ability, as well as session content and format, were compared utilizing ordinal logistic regression.

Utilizing a 10-point likert scale (1 = complete disagreement; 10 = complete agreement), prior to study enrollment, the investigators defined "strong agreement" as any answer ≥ to "7" for purposes of descriptive reporting. Study group demographics including provider role, years' experience, primary site of care provision, were recorded and analyzed to assess efficacy of the educational session, format and content across varied demographic backgrounds. Primary educational outcome measures included anonymous, self-reported changes in anatomic, physiologic and surgical knowledge and perceived care ability. Secondarily, we sought to report on the efficacy of the "just-in-time" clinical education format.

Finally, the pre- and post-analysis results were adjusted for surgical complexity per RACHS-1 category utilizing the ordinal logistic regression model.

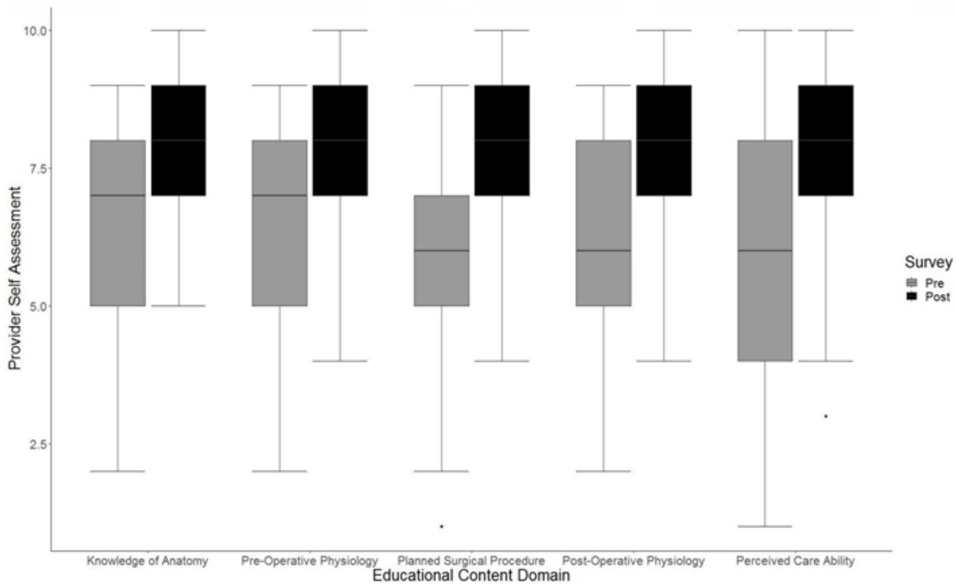
RESULTS

Forty-five cardiac intensive care unit (CICU) providers, 53% (24/45) non-physician, 48% (22/45) with less than 2 years' experience from multiple disciplines took part in didactic sessions for eight cases of varied surgical complexity (Table 1). Statistically significant increases in knowledge of anatomy, pre-operative physiology, planned surgical procedure, post-operative physiology, perceived care ability was reported after adjusting for surgical complexity ($p < 0.001$) (Figure 1).

Survey results showed strong agreement (>80% of study participants) regarding effectiveness of the length, format and content of each session including 3D imaging utilization (Table 2). These results were independent of provider role and years' experience. No significant difference was seen comparing survey responses between physicians and nurses, comparing those with ≤ 1 years' experience to those with > 1 years' experience in their current position, with the exception of the format of the session. After adjusting for RACHS-1 category, physicians were 333% more likely than non-physicians to completely agree with the format of the session being appropriate for clinical education.

DISCUSSION

Our results support integration of 3D imaging technology into existing and future medical education, given its unparalleled visualization of complex anatomy and physiology[3]. The cognitive benefits of learning with 3D imaging: improved visual-spatial understanding, hands-on interaction, learner satisfaction, continue to be elaborated on in the medical literature, by both learners and advanced providers of CHD[3,4,10,13,15,16,23,24]. We have demonstrated the ability to improve provider retention of complex anatomic and physiologic concepts related to the care of CHD patients, across a wide breadth of medical disciplines, training backgrounds, years of experience and levels of CHD complexity (Tables 1 and 2; Figure 1). We were able to achieve this in an accessible clinical didactic format within the CICU, providing the additional benefit of "just-in-time" education with immediate relevancy to clinical care[4,17,19-22,25].



Educational Content Domain	Pre-Assessment	Post-Assessment	P-Value
Knowledge of Anatomy	7 (5, 8)	8 (7, 9)	< 0.001
Pre-Operative Physiology	7 (5, 8)	8 (7, 9)	< 0.001
Planned Surgical Procedure	6 (5, 7)	8 (7, 9)	< 0.001
Post-Operative Physiology	6 (5, 8)	8 (7, 9)	< 0.001
Perceived Care Ability	6 (4, 8)	8 (7, 9)	< 0.001

Figure 1. Comparison of Pre- and Post-Session Provide Self-Assessment [median(IQR)]

As an academic teaching institution, Loma Linda University provides CHD care in a "mixed-ICU" model, where many of the multidisciplinary providers also work outside the CICU, and include rotating medical, nursing and respiratory therapy student learners. It is therefore important to optimize clinical exposures as educational opportunities, especially to complex and infrequently seen CHD lesions and surgical interventions. We therefore chose to develop a "just-in-time" model for this clinical educational project, taking place physically in the CICU to capture as many providers as possible, including rotating student learners, over a six-month study period[19-22]. Despite the differences in provider background and experience, greater than 80% of participants in the educational session strongly agreed that the format, content and utilization of 3D imaging was efficacious to their learning experience (Table 3). We believe the improved shared visualization provided by 3D imaging can help negate differences in previous exposures to these complex anatomic malformations, and allow ability to teach these topics to a broad audience[3,14]. It is not surprising that education is being increasingly considered the main potential application for 3D CHD models and imaging, above even pre-operative planning and research[4,14,26].

The only significant difference in assessment of the "just-in-time" session format was found between physicians and non-physicians regarding CHD cases of highest surgical, and by proxy, anatomic and physiologic complexity. This finding was independent of experience. This is potentially explained by both our center's surgical volume and lack of dedicated CICU providers, suggesting that more devoted time, or repetition of session concepts for the most complex forms of CHD is warranted.

Table 1: CHD Provider Background Demographics [n(%); n=45]

Caregiver Role	
Bedside Nurse	21 (46.7 %)
Pediatric ICU Fellow	13 (28.9 %)
Pediatric ICU Attending	2 (4.4 %)
Pediatric Resident	6 (13.3 %)
Cardiac ICU Nurse Practitioner	1 (2.3 %)
Respiratory Therapist	2 (4.4 %)
Level of Experience	
< 1 yr	18 (40 %)
1 yr	4 (8.9 %)
2 yrs	5 (11.1 %)
3 yrs	7 (15.6 %)
4 yrs	0 (0 %)
> 5 yrs or greater	11 (24.4 %)
Provide Care in CICU Only	
Yes	23 (51.1 %)
No	22 (48.9 %)

Table 2: CHD Lesions and Associated Surgery Performed by RACHS-1 Category

CHD Lesion	Surgery Performed	RACHS-1 Category*
Secundum Atrial Septal Defect	Pericardial Patch Closure	I
Partial Anomalous Pulmonary Venous Return	Waarden Procedure	
Tetralogy of Fallot with Pulmonary Stenosis	Transannular Patch Repair with Ventricular Septal Defect Closure	II
Dextro-Transposition of Great Arteries with Ventricular Septal Defect	Arterial Switch Operation with Ventricular Septal Defect Closure	IV
Truncus Arteriosus Type 1	Truncus Arteriosis Repair with Ventricular Septal Defect Baffle Closure and Right Ventricular to Pulmonary Artery Conduit	
Hypoplastic Left Heart Syndrome	Norwood-type Arch Reconstruction with Sano Conduit	VI

*Risk adjustment for congenital heart surgery[24].

Table 3: CHD Provider Assessment of Didactic Lecture [%(n); n=45]

Domain of Interest	Strong Agreement*
Length of Session	82.2 % (37/45)
Content of Session	88.8 % (40/45)
Format of Session	93.3 % (42/45)
Utilization of 3D Imaging	91.1 % (41/45)

*defined as response ≥ 7 on 10-point likert scale (1 = complete disagreement; 10 = complete agreement)

As part of the effort promoting advanced education for CHD and cardiac intensive care, we offer this strategy of 3D curriculum development. We intend for this to serve as pilot data for ongoing exploration into integration of burgeoning 3D, virtual and augmented reality imaging technology into existing and future medical curriculae and educational platforms.

With regards to study limitations, this was performed at a single center with data collected via anonymous survey with a limited sample size. Due to the clinical need for provider education and existing evidence promoting 3D imaging as an efficacious learning modality, we did not create "control" education sessions without 3D images at the understood expense of more robust statistical comparative data, limiting us to self-reported short-term outcome measures.

Provider self-assessments were made with subjective Likert-scale ratings, not objective evaluation measures such as "board-style" or content assessment questions. To eliminate potential recall or selection bias, participants were only approached for study involvement prior to the first educational session for any given CHD lesion, while enrollment in the study was not a prerequisite for participation in the session. To minimize observation bias, the survey and demographic data were kept anonymous, and participants were given unlimited time for completion. The study was not designed to assess long-term knowledge retention, but rather to focus on the potential efficacy of "just-in-time" clinical training with integrated 3D imaging on short-term improvements in provider ability and management[19,21,26].

Future studies should further examine the integration of 3D imaging and medical education, and attempt to address the limitations of our study, including the single center nature and short-term outcome focus. As the breadth of medical knowledge required to provide clinical care ever expounds, the ability to transmit that knowledge effectively is going to become increasingly dependent on technologies like 3D visualization to improve time to comprehension. Short and long-term retention of 3D compared to 2D learning should become increasingly scrutinized for such efficacy. Efforts to broadly incorporate 3D visualization into medical education should continue in earnest.

CONCLUSION

3D imaging across multiple visualization platforms can be successfully integrated into clinical didactic curriculae to refine knowledge and improve care ability for multidisciplinary CICU providers across many discipline backgrounds and levels of experience. As more 3D technology becomes available and accessible, we hope to continue to assess its integration into medical education.

AUTHOR CONTRIBUTIONS

Richard Lion contributed to the concept and design of the study as well as creation of didactic lectures and data collection.

Grace Oei contributed to the concept and design of the study, as well as creation of didactic lectures and data collection.

Nancy Collado and Sharn Singh of the Research Consulting Group reviewed the survey prior to study initiation, provided statistical analysis and interpretation as well as contributing to the manuscript.

Timothy Martens contributed to the content and development of the didactic lectures, contributed to and provided critical revision of the article.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to report and no relevant disclosures.

APPENDIX

Abbreviated List of Open Source Applications and Peer-Reviewed Curriculum

https://sketchfab.com/eLearningUMCG - E-learning University Medical Center Groningen

https://www.cincinnatichildrens.org/patients/child/encyclopedia/heartpedia - Cincinnati Children's Heartpedia Application

https://3dpring.nih.gov/collections/heart-library - NIH 3D Library

https://www.pcics.org/forms/publications - Pediatric Cardiac Intensive Care Society Curriculum for Pediatric Cardiac Critical Care Medicine. First Edition. Ronald A. Bronicki, ed.

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