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ORIGINAL ARTICLE

WILEY Congenital Heart Disease

Pediatric heart disease simulation curriculum: Educating the pediatrician

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Abstract

Background: Training guidelines state that pediatricians should be able to diagnose, manage, and triage patients with heart disease. Acutely ill cardiac patients present infrequently and with high acuity, yet residents receive less exposure to acute cardiac conditions than previous generations. Trainees must learn to manage these situations despite this gap. Simulation has been used successfully to train learners to provide acute care. We hypothesized that a simulation-based cardiac curriculum would improve residents' ability to manage cardiac patients.

Methods: Pediatric residents completed 4 simulation cases followed by debriefing and a computer presentation reviewing the learning objectives. Subjects returned at 1 month for postintervention cases and again at 4–6 months to measure knowledge retention. Cases were scored by 2 raters using a dichotomous checklist. We used repeated measure ANOVA and effect size to compare groups and intra-class correlation (ICC) to assess inter-rater reliability.

Results: Twenty-five participants were enrolled. Scores were low on pretesting but showed significant improvement ($P < .05$) in all 4 cases. No decay was noted on late testing. Pre-post effect sizes ranged from 1.1 to 2.1, demonstrating meaningful improvement. Inter-rater reliability (ICC) ranged from 0.61 to 0.93 across cases.

Conclusions: This novel simulation-based curriculum targets a gap in pediatric training and offers an effective way to train pediatricians. We plan to expand this curriculum to new populations of participants and have integrated it into our resident cardiology rotation.

KEYWORDS
congenital heart disease, medical education, pediatric cardiology, pediatric resident education, simulation

1 | INTRODUCTION

The American Board of Pediatrics (ABP) and the Academic Pediatric Association (APA) guidelines for residency training state that pediatricians should be able to diagnose, manage, and triage patients with heart disease. This includes acute presentations of congestive heart failure, cyanotic heart disease, and cardiogenic shock.[1,2] Multiple Accreditation Council for Graduate Medical Education (ACGME) milestones (particularly PC1–5, SBP1, and MK1) and ABP entrustable professional activities apply directly to these cardiac conditions.[3,4] Historically, trainees have learned by experience on clinical rotations and cardiology clinic as well as in the pediatric intensive care unit (PICU), neonatal intensive care unit (NICU), and emergency department (ED). This clinical training is supplemented by lectures, case presentations, and independent reading.

Recently graduating pediatricians are likely less experienced in managing acutely ill cardiology patients than previous generations. There are multiple factors influencing this change. First, in an effort to improve patient care and outcomes, many centers have developed dedicated cardiac intensive care units (CICU) to care for the cardiac patients previously managed in the NICU and PICU.[5,6] This frequently has the unintended consequence of minimizing the resident role in care, as residents may not rotate though the CICU. Burstein reported that pediatric residents were involved in post–cardiac surgical care at only 31% of centers with dedicated CICUs vs 71% of centers with PICU-based cardiac care.[7] Su and Munoz noted that resident education could be significantly affected by these changes and that residents would "be less able to provide knowledgeable support. . .and more likely to refer patients. . .for even the most routine care."[8] Furthermore, work hour guidelines have limited the clinical hours available to a trainee to learn. Meanwhile continuously expanding medical knowledge increases the material educators much teach. This dichotomy necessarily limits the amount of time educators can devote to each area of a curriculum. The most acceptable response is a requirement for more efficiency in educational efforts to cover more content in less time.

Over the Past few decades, we have seen significant changes in how children with critical congenital heart disease present to care due to advances in prenatal diagnosis[9] and the institution of universal neonatal pulse oximetry screening.[10–13] This decreases opportunities for trainees to work through the diagnostic challenge of an unknown congenital heart disease presentation. However, there are still patients presenting in extremis that must be quickly recognized and efficiently managed, both at the office and the hospital. To compound these systematic changes, these acutely ill cardiac patients present infrequently with high acuity requiring timely, precise care to avoid further morbidity and mortality.[14,15]

High-technology simulation-based curricula have been used successfully to train learners to provide acute care with improved efficiency, accuracy, and skill.[16,17] There is a large body of literature showing that simulation-based education is an effective methodology to teach pediatric and neonatal resuscitation (eg, Pediatric Advanced Life Support [PALS]/Neonatal Resuscitation Program [NRP]), seizure management, anesthesia, and procedural skills.[18–28] It has been applied to adult cardiology and catheter-based intervention education.[29,30] However, this educational methodology has only been applied to pediatric heart disease education in a limited fashion, without rigorously assessing resident performance after simulation.[31,32]

We hypothesized that a simulation-based cardiac curriculum would improve residents' ability to recognize, stabilize, and triage cardiac patients.

2 | METHODS

Institutional review board approval was given and informed consent was obtained. Basic demographic information was collected. Postgraduate year (PGY) 2 and 3 pediatric residents from our institution were recruited via e-mail. Total participant time commitment was 3 hours.

2.1 | Study design

We used a single group intervention study with a pretest/posttest/retention assessment design similar to many simulation-based education studies over the last 40 years[33] (Figure 1). Eight simulation cases were developed and then piloted with board-certified general pediatricians some of whom were cardiology fellows. Participants completed 4 cases in our simulation lab over a total of 40 minutes without interruption followed by a 20-minute structured debriefing. They independently completed the intervention at any time in the following month, a 45-minute narrated computer slide presentation that reinforced the learning objectives discussed in the debriefing (Supporting Information Appendix S1). Participants returned to the simulation lab approximately 1 month later for 4 posttest simulation cases. These cases covered the same physiologies with the same scoring checklist, but with different anatomy and presentation stems (Table 1, Supporting Information Appendix S2). Participants returned 4–6 months after enrollment to repeat the initial simulation cases to assess for retention of knowledge.

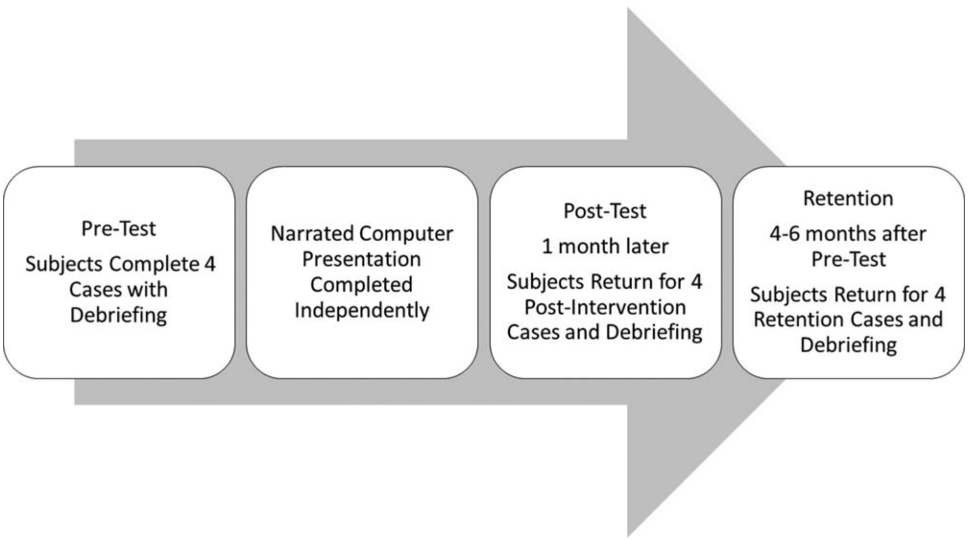

FIGURE 1 Study time line—participants completed pretesting, independent study, posttesting, and retention phases at prescribed intervals

TABLE 1 Cardiac physiologies and corresponding anatomies

Cardiac physiology	Pretest	Posttest
Left-to-right shunts	VSD	AVSD
dd-SBF	Critical coarctation	Interrupted aortic arch
Low cardiac output	Myocarditis	ALCAPA
TOF spell	Tetralogy of Fallot	DORV (TOF-type)

This table shows the cardiac physiologies covered in the cases with the corresponding typical anatomies at pre-testing and post-testing.
Abbreviations: ALCAPA, anomalous left coronary artery from the pulmonary artery; AVSD, atrioventricular septal defect; dd-SBF, ductal dependent systemic blood flow; DORV, double-outlet right ventricle; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

2.2 | Cases and checklist development

We chose to cover 4 distinct acute cardiac physiologies in our curriculum based on ABP[1] and APA[2] guidelines for pediatric training as well as our perceived educational gap in pediatric resident training.[1,2]

- Case A: left-to-right shunts
- Case B: ductal-dependent systemic blood flow
- Case C: low cardiac output due to systolic dysfunction
- Case D: tetralogy of Fallot hyper-cyanotic episodes

In addition, while not all-inclusive, these 4 physiologies cover a large percentage of acute cardiac presentations that are previously undiagnosed and almost all of the primary and secondary critical congenital heart disease targets of neonatal pulse oximetry screening.[34–37]

Cases with typical presentations for each physiology were created with 2 different anatomies and stems for each physiology (Supporting Information Appendix S2). Checklists were constructed to contain the key action items that would be required in order to take adequate care of a patient with each physiology. This assessment tool was constructed and modified based on consensus evaluation by experts in this field of practice (CICU and cardiology faculty members). We used anchored 5-point scales, which ranged from "performed very poorly" (1) to "performed very well with rare to no errors" (5). Individual scales were applied to assess performance in history taking, interpretations of vital signs, physical examination, chest x-ray interpretation, electrocardiogram interpretation, patient management, and ability to communicate a plan to the parent. In each content area, criteria for ideal performance are listed to anchor the checklist. Scores in each performance area were summed to create the total case score. In addition, participant communication with the cardiologist by phone was assessed using 5-point scales in 4 areas: communication of a differential diagnosis, supporting evidence, plan for their admission, and plan for care prior to transfer of the patient to the tertiary hospital. Finally, time to completion of the case and a 5-point score assessing efficiency of care were recorded. A total score of 50 or 55 points were possible for each case. In addition, a global evaluation score was given for each case on a 10-point overall performance scale. All cases were video-recorded and scored by the primary rater (TH). A portion of the checklist and global assessments were scored by the secondary rater (MM).

2.3 | Simulator and work flow

We completed all cases using a Laerdal SimBaby (Laerdal Medical, Wappingers Falls, NY) simulator. This mannequin simulates cyanosis using a blue light in the mouth that was corroborated with pulse oximetry data. Cases and debriefings were proctored by the first author acting as a confederate nurse (a person knowledgeable of the scenario and its goals who guides the simulation) and a simulation technologist. Hepatomegaly and capillary refill information were supplied by the confederate when asked by the participant. Debriefings focused on the learning objectives for each physiology as well as communication with specialists and time management. Commercially available pre-recorded representative heart sounds (BioSignetics Corporation, www.bsignetics.com) were played on an external speaker for higher fidelity sound during auscultation as heart sounds produced by the mannequin were too unclear to allow accurate discriminate interpretation. A newborn sinus tachycardia heart sound was unable to be found commercially so one was created digitally by speeding up an adult normal sinus rhythm at 80 bpm to a heart rate of 180 bpm. Representative deidentified printed electrocardiograms (ECGs) and chest x-rays (displayed on tablet device) were available if requested by the participants. Scenarios were designed to take place in a community hospital ED. Scenarios ended with a phone consultation with a pediatric cardiology fellow (TH) prior to patient transfer to the tertiary hospital. Case order was not randomized but the predetermined scenario order was changed for posttesting and again for retention testing.

2.4 | Statistics

Groups were compared using repeated measure ANOVA with post hoc comparisons (Scheffe's Method); a parametric analytic approach was used as suggested by Norman.[38] Effect size was calculated using's Cohen's *d*. To evaluate inter-rater reliability of scoring on a subset of participants, a sample size was calculated a priori using an intra-class correlation. All analyses were done using Stata 14.1 (Statacorp, College Station, TX). To detect a correlation of 0.70, a sample of 10 participants with 2 observations per participant achieves 80% power with an alpha of 0.05.

3 | RESULTS

The study was completed between January 2, 2015 and January 9, 2015. Twenty-five participants were enrolled, including 16 PGY-3 residents (64%) and 9 PGY-2 residents (36%) (Table 1). One participant withdrew after completing the pretest and 3 further participants were unable to return to complete the retention phase prior to graduation (Figure 2). All of these participants were PGY-3s. Seventeen (64%) participants had completed an intern rotation in cardiology and 10 (40%) had completed a senior rotation in cardiology. Career plans of participating residents and average weeks spent on relevant clinical rotations

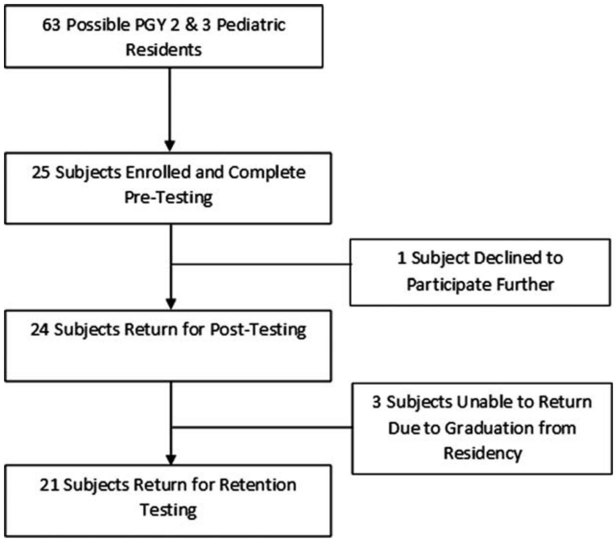

FIGURE 2 Participant flowchart

are shown in Tables 2 and 3. An average of 42 days (±11) elapsed between pretesting and posttesting while 141 days (±32) elapsed between pretesting and retention.

Total case scores (expressed as a percentage of possible points) are seen in Table 4 and Figure 3. Participants' scores were low on pretesting but showed statistically significant improvement ($P < .05$) in total case score (reported as a percentage of possible score) from pretest to posttest in all 4 cases. Participants also showed retention of knowledge at 4–6 months with statistically significant improvement from pretest to retention and statistically insignificant ($P > .05$) differences between posttest and retention phases. Of note, 9 participants (36%) failed to start prostaglandin (PGE) in the critical coarctation case and 10 participants (40%) did not accurately identify the "Tet Spell" during pretesting.

The effect sizes (Cohen's *d*) of the intervention ranged from 1.1 to 2.1 across the cases from pretest to posttest. Additionally, the amount

TABLE 2 Participant characteristics

Variable	Value	Percentage (%)
Year of pediatric training		
PGY-3	16	64
PGY-2	9	36
Completed intern cardiology rotation	17	68
Completed senior cardiology rotation	10	40
Career plans of subjects		
Cardiology fellowship	2	8
Acute care fellowship (PICU, NICU, EM)	8	32
Nonacute care fellowship (Others)	7	28
General outpatient pediatrics	2	8
Pediatric hospitalist	3	12
Undecided	3	12

Baseline characteristics of the 25 participants were collected at enrollment.
Abbreviations: EM, emergency medicine; PGY, post graduate year; PICU, pediatric intensive care unit; NICU, neonatal intensive care unit.

TABLE 3 Participant clinical experience

Rotation	Weeks completed, mean (SD)
Emergency medicine	17 (2.4)
NICU	11 (2.7)
PICU	7.4 (1.5)
Cardiology night coverage	3.3 (1.1)

Number of weeks of clinical rotations completed by the participant prior to start of study.
Abbreviations: NICU, neonatal intensive care unit; PICU, pediatric intensive care unit.

of variability in performance (as indicated by the standard deviation) decreased substantially at posttest and retention phases as participants were much more uniform in performance. Participants showed similar improvement in scores for efficiency and global evaluation of performance with significant increases in scores from pretest to posttest and nonsignificant score differences from posttest to retention.

Inter-rater reliability was assessed for the cases scored by both raters (Table 5). Intra-class correlation coefficients ranged from 0.6 to 0.9 for the total case score, 0.4 to 0.7 for the efficiency score, and 0.6 to 0.8 for the global score based on the case evaluated. The lowest agreement between raters was seen in case C with better agreement between raters seen on cases A and B. There was also better agreement when using the checklist to assign total case score vs assigning scores for efficiency and global performance.

A postintervention survey was completed by 21 participants (Table 6) and demonstrated overwhelming support for the curriculum and many participants urged inclusion of the curriculum into the residency program. The participant who withdrew after the pretest phase did not complete an evaluation form or respond to email for feedback as to why they withdrew.

4 | DISCUSSION

This study aims to address a perceived educational gap in resident cardiology training.[8] It presents a rigorously evaluated solution to current resident curriculum mandates from the ABP and APA[1,2] building on the only previously published options by Mohan and Costello.[1,2,31,32] Our study shows that residents at our program struggled to identify and manage acute cardiac presentations at baseline. Assessment scores were low at pretesting, particularly on cases dealing with ductal-dependent systemic blood flow and hyper-cyanotic spells. We noted that 34% of participants did not start PGE (and many more used an inappropriately low dose), which would potentially result in significant morbidity and mortality for a patient. Forty percent of residents were unable to identify a "Tet spell" in a typical presentation. It may be inferred that current methods for teaching these conditions via classrooms and by clinical exposure may not be sufficient to adequately prepare trainees.

Our intervention was able to demonstrate broad improved performance. Participants improved in all 4 cases with meaningful

TABLE 4 Total case scores and effect sizes

		Pretest mean (SD)	Posttest mean (SD)	Retention mean (SD)	Effect size (pre-post)
Case A	Left-to-right shunt				
	Total case score (% correct)	74.4% (12.3)	93.9% (3.6)[a]	93.9% (5.0)[ab]	2.13
	Efficiency (out of 5)	4.26 (0.72)	5 (0)[a]	4.93 (0.24)[ab]	1.43
	Global performance (out of 10)	7.08 (1.48)	9.38 (0.49)[a]	9.26 (0.74)[ab]	2.06
Case B	Ductal-dependent systemic blood flow				
	Total case score (% correct)	66.9% (15.8)	92% (4.4)[a]	92.4% (3.5)[ab]	2.14
	Efficiency (out of 5)	3.56 (1.15)	4.81 (0.36)[a]	4.9 (0.3)[ab]	1.46
	Global performance (out of 10)	5.56 (2.16)	9.15 (0.60)[a]	9.07 (0.58)[ab]	2.13
Case C	Low cardiac output				
	Total case score (% correct)	77.6% (10.2)	88.7% (9.5)[a]	94% (3.3)[ab]	1.13
	Efficiency (out of 5)	4.12 (0.74)	4.69 (0.48)[a]	4.95 (0.22)[ab]	0.9
	Global performance (out of 10)	6.80 (1.56)	8.73 (1.15)[a]	9.24 (0.54)[ab]	1.4
Case D	Tetralogy of Fallot spell				
	Total case score (% correct)	69.7% (14.9)	91.6% (4.1)[a]	92.6% (6.1)[ab]	1.99
	Efficiency (out of 5)	3.20 (1.14)	4.54 (0.61)[a]	4.38 (0.85)[ab]	1.46
	Global performance (out of 10)	5.64 (2.22)	9.02 (0.60)[a]	8.9 (1.06)[ab]	2.06

Mean scores for each case at each time point are presented along with effect sizes for the intervention from pretesting to posttesting.
[a]Significant difference from pretesting, $P < .05$.
[b]No significant difference from posttesting, $P > .05$.

effect sizes. Our lowest effect size was seen in case C (1.1), but the effect size was larger (up to 2.1) when evaluated from pretest to retention phase as participants continued to show added improvement at 4–6 months. In addition, participants showed retention of knowledge at 6 months of follow-up by having scores that were statistically the same as scoring at the posttest phase. Participants improved across all of the segments of the checklist from history taking to exam to management, except in ECG reading, which remained constant, as we did not include an ECG educational component to the curriculum.

Our secondary measures of performance, efficiency, and global score, also improved from pretesting to posttesting while time to complete the case did not improve consistently. While the time needed to complete the cases did not change, rater-scored efficiency did improve significantly as participants provided better care in the same amount of time. The improvement in global score is included to add to the objective total case score data, but does not vary significantly.

We found no predictive demographic variables that affected performance either on the pretest or posttest assessments. This suggests

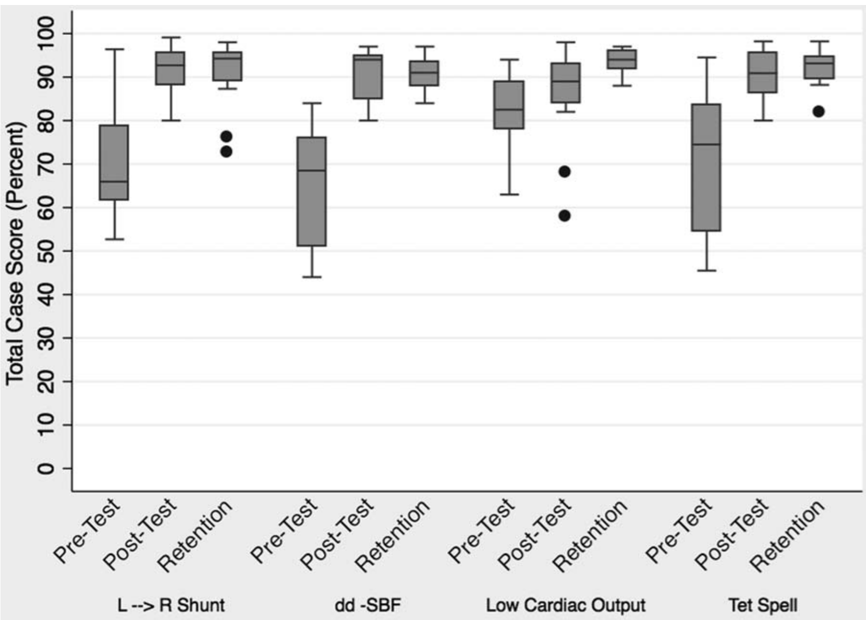

FIGURE 3 Total case scores—participant total case scores are presented for each physiology at each time point with medians and standard error bars. Dots represent outliers. Scores are presented as a percentage of possible points

TABLE 5 Inter-rater reliability

ICC (*k*,2)	Case A	Case B	Case C	Case D
Total Case Score	0.9	0.9	0.6	0.9
Efficiency	0.6	0.7	0.4	0.6
Global Performance	0.6	0.8	0.6	0.8

Intra-class correlation coefficients were calculated for each of the 10 cases scored by both raters.

that year in training, additional time on the cardiology rotation, or additional time on acute care rotations did not add significant knowledge or experience applicable to these cases. This supports our hypothesis that the current training environment and methods do not appear to be effective for teaching management of these acute disease processes. Additionally, we had a group of participants with diverse career goals, which represent a typical pediatric training program.

Major points arguing for the validity[39] of our data arising from our instruments include: (a) our cases, checklists, and key scoring elements were reviewed and vetted by content experts in the field to ensure it represented standard pediatric cardiac care. The checklist covered a broad range of skills and difficulty expected of a general pediatrician based on both ABP and APA guidelines, (b) scoring (both live and using video-review) by 2 independent raters showed acceptable agreement on participant performance using the checklist, (c) the simulator (with added speaker for heart sounds) was able to closely mimic key vital signs and physical exam findings required for replicating cardiac conditions, and (d) resident scores improved after the intervention and were retained/demonstrated minimal decay. We did not test learners at different levels to assess for discrimination. This assessment is intended for low-stakes formative feedback and as such is a low-consequence intervention. Additional work would be required prior to using this assessment for a high-stakes exam.[39]

This study does have limitations. It was a single-center study with a small cohort of pediatric residents who volunteered to participate and thus may not be representative of all pediatric residents. Additionally, participants could have been biased to suspect cardiac etiologies as recruitment and proctoring was done by a cardiology fellow they knew. This likely made the initial case scores artificially higher than they would have been if participants had been completely blinded to the nature of the cases. Participants also could have improved from pretest to posttest solely due to awareness of what physiologies would likely be covered. However, case order and clinical presentation was changed in an attempt to minimize this bias. Finally, retention scores could have been artificially high if participants reviewed provided material directly relevant to the test immediately prior to retention testing.

In summary, this novel simulation-based curriculum targeted a gap in current pediatric residency training and offered an opportunity to improve resident performance. In an era of ever increasing medical knowledge with both less ACGME-mandated time and the potential for less experiential-based resident learning opportunity in cardiology, this curriculum offers an effective way to train pediatricians in this domain. This could lead to faster identification of acute heart disease and improved care by pediatricians who are the first line in preventing morbidity and mortality for this population. We plan to expand this curriculum to new populations of participants such as emergency medicine providers and pediatric hospitalists. It could also be used to educate multidisciplinary cardiology and cardiac surgery teams involving nursing, advanced practice providers, and respiratory therapists. Given our study outcome and the perceived value of this curriculum by the participants, we have integrated cardiac simulation into our resident senior cardiology rotation with a 1-hour session replacing a didactic session in their scheduled lecture series.

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TABLE 6 Postintervention survey

Question	1. Strongly disagree	2. Disagree	3. Neutral	4. Agree	5. Strongly agree
Participation helped me learn about Cardiac Diseases	0	0	0	1	20
The SIMULATIONS were helpful	0	0	0	0	21
The DEBREIFINGS were helpful	0	0	0	1	20
The NARRATED COMPUTER PRESENTATION was helpful	0	0	0	8	13
Participation was useful for future career	0	0	1	0	20
I am more comfortable/confident in initial care of heart disease	0	0	0	3	18
Participation was a positive experience	0	0	0	0	21
I would do this study again	0	0	0	2	19
I would recommend this study to other residents	0	0	0	1	20

Twenty-one participants completed an anonymous postintervention survey about the curriculum and their experience.

CONFLICT OF INTERESTS

Drs Harris, Adler, Unti, and McBride declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

Dr Harris conceptualized and designed the study and curriculum, performed the simulations, and debriefings, collected data, and drafted the initial manuscript and approved the final manuscript as submitted.

Dr Adler assisted with study design, performed the data analysis, reviewed, and revised the manuscript and approved the final manuscript as submitted.

Dr Unti assisted with curriculum and study design, reviewed, and revised the manuscript and approved the final manuscript as submitted.

Dr McBride conceptualized and designed the study and assisted with curriculum design, served as second rater, reviewed, and revised the manuscript and approved the final manuscript as submitted.

REFERENCES

[1] American Board of Pediatrics Content Outline for General Pediatrics. 2016; https://www.abp.org/content/content-outlines-0. Accessed May 16, 2017.

[2] Kittredge D, Baldwin CD, Bar-On ME, Beach PS, Trimm RF. APA educational guidelines for pediatric residency. 2004. http://www.academicpeds.org/egwebnew. Accessed May 16, 2017.

[3] Carraccio C, Englander R, Gilhooly J, et al. Building a framework of entrustable professional activities, supported by competencies and milestones, to bridge the educational continuum. *Acad Med.* 2017; 92(3):324–330.

[4] Hicks PJ, Schumacher DJ, Benson BJ, et al. The pediatrics milestones: conceptual framework, guiding principles, and approach to development. *J Grad Med Educ.* 2010;2(3):410–418.

[5] Burstein DS, Jacobs JP, Li JS, et al. Care models and associated outcomes in congenital heart surgery. *Pediatrics.* 2011;127(6):e1482–e1489.

[6] Eldadah M, Leo S, Kovach K, et al. Influence of a dedicated paediatric cardiac intensive care unit on patient outcomes. *Nurs Crit Care.* 2011;16(6):281–286.

[7] Burstein DS, Rossi AF, Jacobs JP, et al. Variation in models of care delivery for children undergoing congenital heart surgery in the United States. *World J Pediatr Congenit Heart Surg.* 2010;1(1):8–14.

[8] Su L, Munoz R. Isn't it the right time to address the impact of pediatric cardiac intensive care units on medical education?. *Pediatrics.* 2007;120(4):e1117–e1119.

[9] Donofrio MT, Moon-Grady AJ, Hornberger LK, et al. Diagnosis and treatment of fetal cardiac disease: a scientific statement from the American Heart Association. *Circulation.* 2014;129(21): 2183–2242.

[10] Ailes EC, Gilboa SM, Honein MA, Oster ME. Estimated number of infants detected and missed by critical congenital heart defect screening. *Pediatrics.* 2015;135(6):1000–1008.

[11] Garg LF, Van Naarden Braun K, Knapp MM, et al. Results from the New Jersey statewide critical congenital heart defects screening program. *Pediatrics.* 2013;132(2):e314–e323.

[12] Mahle WT, Martin GR, Beekman RH 3rd, Morrow WR. Endorsement of Health and Human Services recommendation for pulse oximetry screening for critical congenital heart disease. *Pediatrics.* 2012;129(1):190–192.

[13] Peterson C, Ailes E, Riehle-Colarusso T, et al. Late detection of critical congenital heart disease among US infants: estimation of the potential impact of proposed universal screening using pulse oximetry. *JAMA Pediatr.* 2014;168(4):361–370.

[14] Brown KL, Ridout DA, Hoskote A, Verhulst L, Ricci M, Bull C. Delayed diagnosis of congenital heart disease worsens preoperative condition and outcome of surgery in neonates. *Heart.* 2006;92(9): 1298–1302.

[15] Schultz AH, Localio AR, Clark BJ, Ravishankar C, Videon N, Kimmel SE. Epidemiologic features of the presentation of critical congenital heart disease: implications for screening. *Pediatrics.* 2008;121(4): 751–757.

[16] Issenberg SB, McGaghie WC, Hart IR, et al. Simulation technology for health care professional skills training and assessment. *J Am Med Assoc.* 1999;282(9):861–866.

[17] Wayne DB, Didwania A, Feinglass J, Fudala MJ, Barsuk JH, McGaghie WC. Simulation-based education improves quality of care during cardiac arrest team responses at an academic teaching hospital: a case-control study. *Chest.* 2008;133(1):56–61.

[18] Lopreiato JO, Sawyer T. Simulation-based medical education in pediatrics. *Acad Pediatr.* 2015;15(2):134–142.

[19] Cheng A, Lang TR, Starr SR, Pusic M, Cook DA. Technology-enhanced simulation and pediatric education: a meta-analysis. *Pediatrics.* 2014;133(5):e1313–e1323.

[20] Adler MD, Trainor JL, Siddall VJ, McGaghie WC. Development and evaluation of high-fidelity simulation case scenarios for pediatric resident education. *Ambul Pediatr.* 2007;7(2):182–186.

[21] Brett-Fleegler MB, Vinci RJ, Weiner DL, Harris SK, Shih MC, Kleinman ME. A simulator-based tool that assesses pediatric resident resuscitation competency. *Pediatrics.* 2008;121(3):e597–e603.

[22] Eppich WJ, Adler MD, McGaghie WC. Emergency and critical care pediatrics: use of medical simulation for training in acute pediatric emergencies. *Curr Opin Pediatr.* 2006;18(3):266–271.

[23] Hunt EA, Walker AR, Shaffner DH, Miller MR, Pronovost PJ. Simulation of in-hospital pediatric medical emergencies and cardiopulmonary arrests: highlighting the importance of the first 5 minutes. *Pediatrics.* 2008;121(1):e34–e43.

[24] Surcouf JW, Chauvin SW, Ferry J, Yang T, Barkemeyer B. Enhancing residents' neonatal resuscitation competency through unannounced simulation-based training. *Med Educ Online.* 2013;18: 1–7.

[25] Campbell DM, Barozzino T, Farrugia M, Sgro M. High-fidelity simulation in neonatal resuscitation. *Pediatr Child Health.* 2009;14 (1):19–23.

[26] Malakooti MR, McBride ME, Mobley B, Goldstein JL, Adler MD, McGaghie WC. Mastery of status epilepticus management via simulation-based learning for pediatrics residents. *J Grad Med Educ.* 2015;7(2):181–186.

[27] McBride ME, Waldrop WB, Fehr JJ, Boulet JR, Murray DJ. Simulation in pediatrics: the reliability and validity of a multiscenario assessment. *Pediatrics.* 2011;128(2):335–343.

[28] Kessler DO, Arteaga G, Ching K, et al. Interns' success with clinical procedures in infants after simulation training. *Pediatrics.* 2013;131 (3):e811–e820.

[29] Green SM, Klein AJ, Pancholy S, et al. The current state of medical simulation in interventional cardiology: a clinical document from the

Society for Cardiovascular Angiography and Intervention's (SCAI) Simulation Committee. *Catheter Cardiovasc Interv*. 2014;83(1): 37–46.

[30] Westerdahl DE. The necessity of high-fidelity simulation in cardiology training programs. *J Am Coll Cardiol*. 2016;67(11): 1375–1378.

[31] Mohan S, Follansbee C, Nwankwo U, Hofkosh D, Sherman FS, Hamilton MF. Embedding patient simulation in a pediatric cardiology rotation: a unique opportunity for improving resident education. *Congenit Heart Dis*. 2015;10(1):88–94.

[32] Costello JP, Olivieri LJ, Su L, et al. Incorporating three-dimensional printing into a simulation-based congenital heart disease and critical care training curriculum for resident physicians. *Congenit Heart Dis*. 2015;10(2):185–190.

[33] Fossel M, Kiskaddon RT, Sternbach GL. Retention of cardiopulmonary resuscitation skills by medical students. *J Med Educ*. 1983;58 (7):568–575.

[34] Bjornard K, Riehle-Colarusso T, Gilboa SM, Correa A. Patterns in the prevalence of congenital heart defects, metropolitan Atlanta, 1978 to 2005. *Birth Defects Res A Clin Mol Teratol*. 2013;97(2): 87–94.

[35] Oster ME, Lee KA, Honein MA, Riehle-Colarusso T, Shin M, Correa A. Temporal trends in survival among infants with critical congenital heart defects. *Pediatrics*. 2013;131(5):e1502–e1508.

[36] Mai CT, Riehle-Colarusso T, O'Halloran A, et al. Selected birth defects data from population-based birth defects surveillance programs in the United States, 2005–2009: Featuring critical congenital heart defects targeted for pulse oximetry screening. *Birth Defects Res A Clin Mol Teratol*. 2012;94(12):970–983.

[37] Penk JS, Loke YH, Waloff KR, et al. Unplanned admissions to a pediatric cardiac critical care unit: a review of 2 years' experience. *Pediatr Crit Care Med*. 2015;16(2):155–160.

[38] Norman G. Likert scales, levels of measurement and the "laws" of statistics. *Adv Health Sci Educ Theory Pract*. 2010;15(5):625–632.

[39] Kane MT. Validating the interpretations and uses of test scores. *J Educ Meas*. 2013;50(1):1–73.

SUPPORTING INFORMATION

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

APPENDIX S1 Learning objectives for narrated computer presentation

APPENDIX S2 Detailed curriculum scenarios and scoring items

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Appendix A- Learning Objectives for Narrated Computer Presentation

At the end of this module, participants will be able to:

- Identify a classification system for four basic pathophysiologies of acute congenital heart disease presentations: Left-to-Right Shunts, ductal dependent-Systemic Blood Flow, Low Cardiac Output, and Hyper-cyanotic Spells
- Demonstrate understanding of the underlying pathophysiology of each class of acute congenital heart disease
- Describe the representative lesions of each class of acute congenital heart disease
- Summarize the typical presentation of each class of acute congenital heart disease
- Describe the initial steps in the acute management of each class of acute congenital heart disease
- Describe the elements and steps that lead to effective communication with a subspecialist over the phone when transferring an ill patient

Appendix B- Detailed Curriculum Scenarios and Scoring Items

Scenario	Description and Construct	Main Scoring Items
Left-to-Right Shunt • VSD- 4 month old, 4.5 kg	Infant with profound pulmonary over circulation -Vital Signs- RR 60 HR 165 T 36.5 BP 75/48 100% -Exam- increased work of breathing, crackles, holosystolic murmur, liver 4 cm below RCM, <2 sec cap refill -History- poor oral intake, weight loss, progressive increase in work of breathing, fatigue, sweating	Asks about weight, feeding, WOB Notes tachypnea, tachycardia Notes murmur, HSM, WOB Interprets ECG with sinus tachycardia and ventricular hypertrophy Interprets CXR with cardiomegaly and pulmonary edema Obtains IV access, considers diuretic, avoids O2 and IVF Explains diagnosis and plan to parent
• AVSD- 2 month old, 4 kg	Vital Signs- RR 65 HR 72 T 36.4 BP 70/48 98% Exam- increased WOB, crackles, holosystolic murmur, liver 4 cm below RCM, <2 sec cap refill History- poor oral intake, weight loss, progressive increase in work of breathing, fatigue, sweating, Trisomy 21 diagnosis	Same as above case
Ductal Dependent-Systemic Blood Flow • Coarctation of the Aorta- 1 week old, 3.5 kg	Newborn in shock due to ductal closure and arch lesion Vital Signs- RR 45, T 36.2 HR 185 RUE BP 103/48 97%, LLE BP 45/23 79% Exam- lethargic, tachypneic, no murmur, HSM, delayed cap refill, 3+ right brachial pulse, no femoral pulses History- poor oral intake, lethargic, no UOP x24 hours Improves with correct dose PGE but with apnea	Asks about AMS, feeding, UOP Notes abnormal 2 extremity BPs and saturations and tachycardia Notes delayed cap refill, WOB, HSM and lack of femoral pulses Interprets ECG with sinus tachycardia and diffuse T wave changes Interprets CXR with cardiomegaly and pulmonary edema Obtains IV access, ordered PGE STAT at dose >0.05 mcg/kg/min, anticipates apnea, provides appropriate supportive care
• Interrupted Aortic Arch- 5 day old, 3 kg	Vital Signs- RR 50, T 36.2 HR 175 RUE BP 96/38 100%, LLE BP unobtainable Exam- lethargic, tachypneic, no murmur, HSM, delayed cap refill, 3+ right brachial pulse, no femoral pulses History- poor oral intake, lethargic, no UOP x24 hours, known 22q11 deletion Improves with correct dose PGE but with apnea	Same as above case
Low Cardiac Output • Myocarditis- 10 month old, 10 kg	Infant with decompensating cardiogenic shock and poor perfusion and systolic dysfunction Vital Signs- RR 40 HR 190 T 38.2 BP 70/57 98% Exam- ill-appearing, tired, weak, increased WOB, gallop, HSM, delayed cap refill, weak pulses History- low-grade fever, URI symptoms, emesis w/o diarrhea, fatigue, poor oral intake, poor UOP, diffuse abdominal pain	Asks about mental status, feeding, UOP, GI symptom Notes tachycardia, hypotension, fever Notes delayed cap refill, gallop, HSM Interprets ECG with sinus tachycardia, low voltage, ST/T wave changes Interprets CXR with cardiomegaly and pulmonary edema Obtains IV access, orders appropriate labs, gives antibiotics, O2, fever control, small boluses with frequent reassessment, avoids >20ml/kg of IVF, prepares for decompensation
• ALCAPA- 4 month old, 8 kg	Vital Signs- RR 40 HR 185 T 37.8 BP 72/57 97% Exam- ill-appearing, tired, weak, increased WOB, gallop, HSM, delayed cap refill, weak pulses History- 2 weeks of fatigue and sleepiness, 2 days of poor oral intake, emesis, irritability, No UOP, AMS	Same as above case with addition of Q waves on ECG
Hyper-cyanotic Spell • Tetralogy of Fallot- 3 month old, 5 kg	Infant with history of unclear CHD presenting with cyanosis in the setting of dehydration Vital Signs- RR 45 T 37 HR 180 BP 95/60 65% Exam- cyanotic, crying, clear to auscultation bilaterally, no murmur, no HSM, normal perfusion History- 2 days of poor oral intake, diarrhea, now irritable/crying. Seen by cardiology for murmur with plan for surgery in 1 month	Asks about feeding, irritability, cardiac history Notes tachycardia, cyanosis, hypoxia without O2 response Notes lack of murmur, normal lung/perfusion exam Interprets ECG with sinus tachycardia, RVH, RAD Interprets CXR with clear lungs, boot-shaped heart Obtains IV access, O2 placed, knees to chest done, attempts to calm patient, gives bolus of at least 20ml/kg, Orders medications (narcotic, beta-blocker, phenylephrine) Explains diagnosis and plan to parent
• Double Outlet Right Ventricle- 3 month old, 5kg	Vital Signs- RR 50 T 37 HR 185 BP 90/60 60% Exam- cyanotic, crying, CTAB, no murmur, no HSM, normal perfusion History- 2 days of poor oral intake, diarrhea, now irritable/crying. Seen by cardiology for DORV with plan for surgery in 2 weeks	Same as above case