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ORIGINAL RESEARCH

A Simulation-based Mastery Learning Curriculum to Address Cardiac Point-of-care Ultrasound Requirements of Anesthesiology Board Certification

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INTRODUCTION

Point-of-care ultrasound (POCUS) protocols allow for the use of portable ultrasonography at the bedside to guide real-time clinical decision making across a variety of perioperative and critical care settings. Focused cardiac ultrasound (FoCUS) is a POCUS protocol that utilizes limited transthoracic echocardiography (TTE) to rapidly assess cardiac function and inform urgent clinical management.^{1,2} In 2021, the American Board of Anesthesiology (ABA) incorporated FoCUS image acquisition into the objective structured clinical examination (OSCE) for board certification, underscoring the growing importance of POCUS competency for anesthesiologists. However, despite the integration of FoCUS into anesthesiology training, published competency-based curricula remain limited. Simulation-based mastery learning (SBML) is a structured educational approach in which learners must meet or exceed a predetermined minimum passing standard (MPS) before completing training.^{3,4} Those who do not initially meet the standard would engage in additional deliberate practice (DP) with feedback until a competency level is demonstrated. DP is a strong, theory-based educational intervention in which highly motivated learners repeatedly engage in focused tasks of appropriate difficulty with rigorous

measurement, informative feedback, and ongoing error correction, continuing until they reach a mastery standard and can advance to the next task.⁴ SBML has been shown to improve procedural performance and patient outcomes across multiple domains,⁴ including surgical techniques,⁵ central venous catheter insertion,^{6,7} thoracentesis,⁸ paracentesis,⁹ difficult conversations,^{10,11} and others.^{12,13} SBML has outperformed nonstandardized methods across a range of ultrasound-based skills, including the extended focused assessment with sonography in trauma,¹⁴ ultrasound-guided intravenous access,^{15–17} and transesophageal echocardiography.^{4,18} A summary of SBML core elements can be found in Supplemental Table 1, and a summary of components of DP can be found in Supplemental Table 2. Given the lack of a standardized national curriculum to teach FoCUS, SBML offers a promising framework to ensure a consistent and high level of competence among anesthesiology trainees and practicing clinicians.¹⁹ In this study, we aimed to develop and implement a FoCUS SBML curriculum. We hypothesized that the curriculum would significantly improve FoCUS image acquisition skills as measured by achievement of a MPS of 85% on a 20-item skills checklist derived from the ABA APPLIED examination OSCE content outline.

MATERIALS AND METHODS

Study Design and Participants

This prospective pretest/posttest study evaluated the effectiveness of an SBML curriculum on improving FoCUS competency among pediatric anesthesiology fellows, regional anesthesiology fellows, and attending anesthesiologists at a single quaternary care pediatric hospital between August 2022 and February 2024. The Ann & Robert H. Lurie Children's Hospital of Chicago Institutional Review Board deemed this study exempt (IRB 2022-5657; 09-12-2022). Pediatric anesthesiology fellows (2022–2023, 2023–2024 classes), regional anesthesiology fellows (2023–2024), and pediatric anesthesiology attendings without prior FoCUS training (board-certified prior to cardiac ultrasound competency requirements) were eligible/invited to participate based on availability. All provided verbal informed consent. Participants were excluded if unable to attend at least 1 scheduled curriculum session and complete the pretest and posttest assessments.

Measurements

FoCUS Skills Checklist

A 20-item FoCUS skills checklist was developed using the ABA OSCE content

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outline as a blueprint to assess participants' ability to obtain 5 standard TTE views and identify relevant cardiac anatomy. A modified Delphi technique was used by a panel of content specialists: board-certified pediatric anesthesiologists (ET, ME, HB), board-certified pediatric cardiologists (AH, NH, SP, PK), and a board-eligible anesthesiologist/board-certified pediatric cardiologist (BR) to refine and finalize the 20 checklist items. Items were scored dichotomously as 1 if performed correctly according to defined criteria and 0 if not performed or performed incorrectly. The checklist was pilot tested on 2 pediatric anesthesiologists prior to study initiation.

MPS

A panel of content specialist physicians comprising 6 pediatric cardiologists (AH, SP, JL, PK, JR, NG), 2 pediatric anesthesiologists (ET, ME), 1 board-eligible anesthesiologist/board-certified pediatric cardiologist (BR), and 1 quadruple board-certified pediatric anesthesiologist/pediatric critical care intensivist (MR) used the Mastery Angoff method⁷ to establish the MPS. Given the wide range of image acquisition standards represented on the content specialist panel, the criterion for an acceptable image was defined as adequate for identification of cardiac structures specific to each view as outlined in the ABA APPLIED Examination OSCE content outline rather than expert-level diagnostic image quality. Acceptable images were required to be anatomically comprehensive and appropriately oriented to permit identification of required cardiac structures from a saved clip, consistent with OSCE grading criteria.

Accordingly, panelists defined a "well-prepared trainee" as a trainee who, after completing the SBML curriculum, could reliably acquire standard TTE views and identify the relevant cardiac anatomy expected at the level of the ABA APPLIED Examination OSCE. For each checklist item, panelists estimated the proportion of well-prepared trainees who would perform the task correctly at posttest, and these item-level estimates were averaged to determine the final MPS. Mastery was

defined as achieving an MPS of $\geq 85\%$ (17/20) on the skills assessment checklist.

Knowledge Assessment

A 40-question, multiple-choice knowledge test was developed to assess participants' understanding of foundational FoCUS concepts, image interpretation, and anatomical correlation. The test blueprint was guided by the ABA OSCE content outline and included questions on ultrasound principles, probe positioning, image interpretation, anatomical identification, and selecting the optimal echocardiographic view to demonstrate relevant pathology. The knowledge assessment can be found in Appendix A.

Self-Reported Confidence and Course Satisfaction

Participant surveys were collected to evaluate overall course satisfaction and self-reported confidence in FoCUS image acquisition. Self-confidence was assessed pretraining and posttraining using a 5-point Likert scale (1 = *not at all confident*, 5 = *extremely confident*). Course satisfaction was assessed posttraining using a separate 5-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*). For pediatric and regional anesthesiology fellows, successful completion of the ABA OSCE was initially self-reported, and their certification status verified using the ABA physician directory.

Study Outcomes

The primary outcome was improvement in performance on a 20-item FoCUS skills checklist assessed at baseline (pretest) and after completion of the scheduled SBML sessions (final posttest). Mastery was defined as meeting or exceeding the MPS.

Each participant's skill performance was evaluated on acquisition of the 5 standard FoCUS TTE views: parasternal long axis (PLAX), parasternal short axis (PSAX), apical 4-chamber (A4C), subcostal 4-chamber (S4C), and subcostal inferior vena cava (IVC). For subcostal views, positioning and optimization maneuvers were assessed as part of acquisition technique; however, learners were not penalized for omission of specific positioning steps if an adequate view meeting image quality and anatomic identification criteria was obtained.

Secondary outcomes included changes in FoCUS knowledge assessment scores, self-reported confidence in performing FoCUS, and participant satisfaction with the SBML curriculum. In addition, successful completion of the ABA OSCE was also evaluated for the anesthesiology fellows.

Internal Scoring Consistency

All testing sessions were live-graded by a board-eligible anesthesiologist/board-certified pediatric cardiologist (BR), and representative FoCUS image clips were saved for each participant. A second pediatric cardiologist (PK) independently rescored a randomly selected subset (25%) of saved FoCUS images comprising all 5 TTE views from both pretest and posttest assessments. Interrater reliability for this subset was assessed using the prevalence- and bias-adjusted kappa (PABAK) on the rescored echocardiogram videos. Checklist items that could not be reliably assessed from stored image clips (eg, probe positioning) were excluded from interrater reliability analysis as these were evaluated live during testing.

Procedure

Baseline Assessment

Baseline demographic information was collected from all participants, including age, sex, training level, years of clinical experience, prior FoCUS education, self-reported confidence, and previous FoCUS scanning experience. Participants completed a baseline multiple-choice knowledge test assessing FoCUS principles and image interpretation, followed by a skills pretest evaluating image acquisition on a standardized patient (SP) using the 20-item checklist. All baseline skills exams were conducted on the same SP.

Pretraining Preparation

Prior to the hands-on sessions, participants were assigned prereading using freely available online FoCUS educational resources, including the POCUS 101 cardiac ultrasound tutorial (<https://www.pocus101.com/cardiac-ultrasound-echocardiography-made-easy-step-by-step-guide/>), the University of Utah anesthesiology POCUS educational repository (<https://echo.>

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anesthesia.med.utah.edu/pocus-content/), and the University of Toronto Focused Transthoracic Echocardiography online simulator (http://pie.med.utoronto.ca/TTE/TTE_content/focus.html).

Training Sessions

Each participant completed 2 3-hour FoCUS sessions proctored by board-certified pediatric cardiologists with advanced training in transthoracic echocardiography (SP, NH, AH, PK, BR).

General Session Logistics

Each training session was conducted within a single 4-hour block using a staggered group design. Participants were divided into 2 groups with offset arrival times. Group 1 completed didactics, checklist orientation, and simulator-based training prior to SP arrival. Upon the arrival of group 2 and the SPs, group 1 transitioned to SP scanning with additional cardiologist proctors while group 2 began identical didactics and simulator-based training. Group 2 subsequently completed the same SP scanning sequence. This allowed all participants to receive identical instruction, simulator exposure, and SP encounters while enabling efficient use of simulation space, SPs, and faculty proctors.

Session 1: Image Acquisition

Training began on a single high-fidelity TTE simulator (Ultrasound Mentor, Surgical Science), followed by deliberate practice on SPs using a standardized faculty protocol. One participant attempted the checklist at a time while others observed and learned from the demonstration, and this enabled later learners to progress more efficiently. The checklist and faculty coaching focused specifically on FoCUS image acquisition mechanics, including correct probe position and orientation to obtain standard transthoracic views and accurate identification of the corresponding cardiac anatomy. The simulator allowed repeated practice without patient discomfort or challenges related to body habitus and displayed a synchronized cardiac slice alongside the corresponding ultrasound image to illustrate which cardiac structures were being transected. Faculty required trainees to correctly complete

all applicable checklist items sequentially before advancing; items that could not be reliably assessed in the simulator (eg, patient positioning) were not scored. If an item was performed incorrectly, real-time actionable feedback was provided, and the trainee reattempted the full checklist from the beginning until mastery (100% error-free completion of all scored items) was achieved on the simulator. Participants then advanced to live scanning on multiple SPs.

Session 2: Image Interpretation

Prior to the second session, participants completed a brief online knowledge assessment covering content from session 1 and were required to achieve a 100% score before attending the second session. Session 2 focused on image interpretation and deliberate practice on SPs using the same 20-item skills checklist from session 1, now applied within case-based scenarios. Faculty provided real-time feedback on image acquisition quality using the same checklist mastery protocol as session 1. Representative pathological images selected based on the cardiac pathology component of the ABA APPLIED Exam Content Outline²⁰ were embedded into these scenarios requiring participants to both acquire and interpret FoCUS images.

Posttraining Assessment

Posttests were administered between 1 and 2 months after the final deliberate practice session. All posttest assessments were performed on the same SP used for baseline testing. Participants who did not initially meet the MPS engaged in additional DP and retested until mastery was achieved. Participants also repeated the same multiple-choice knowledge exam and completed follow-up surveys assessing their self-confidence in performing FoCUS protocols and overall course satisfaction.

A flow chart summarizing the longitudinal curriculum can be found in Figure 1.

Data Analysis

Categorical variables were summarized as frequencies and percentages, and continuous variables were expressed as mean with standard deviation or median with interquartile range (IQR), depending on normality of the data.

Comparisons between groups were conducted using the Wilcoxon rank-sum test for continuous variables and Fisher exact test for categorical variables. Binary outcomes of image score improvement were evaluated using the McNemar test to compare preintervention and postintervention results. For paired continuous outcomes, including written test scores, performance skills test scores, and self-reported confidence scores, the Wilcoxon signed-rank test was used to assess pre-post changes. All statistical analyses were performed with R software, version 4.3.1. A 2-sided alpha level of 0.05 was considered statistically significant. All participant data were included in the final analysis.

RESULTS

Participant Characteristics

A total of 18 participants completed the SBML FoCUS curriculum, including 12 pediatric or regional anesthesiology fellows (67%) and 6 pediatric anesthesiology attendings (33%) (Table 1). Three fellows initially missed 1 scheduled session due to clinical obligations or unavoidable personal conflicts. The median (IQR) age was 33 years (31–36), and 7 participants (39%) were female. Fellows were younger than attendings (median age 31 vs 36 years) and had fewer years of clinical experience (5 vs 10 years). Despite this difference in general clinical experience, attendings did not have more FoCUS exposure. Most participants in both groups reported only minimal prior didactic exposure, and only 4 participants (22%, all fellows) reported any repeated hands-on FoCUS experience prior to this curriculum. Before SBML training, the most commonly reported barrier to FoCUS use was a lack of training (15 participants, 83%), followed by a lack of equipment (6 participants, 33%). A summary of baseline demographics and FoCUS exposure is listed in Table 1.

Primary Outcome

Skills Checklist

The median (IQR) pretest score improved from 8 (3–11) to 19 (18–20) on the final assessment posttest ($p < .001$; Table 2). Despite lower baseline scores among

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attendings compared with fellows (median: 3.0 vs 9.5), both groups achieved similar assessment posttest scores (19.0 vs 19.5). Among the subset of FoCUS image clips independently scored by both graders, interrater reliability was substantial (PABAK 0.71, 95% CI: 0.46, 0.88).²¹

After completing the curriculum, 12 of 18 participants (67%) achieved mastery on their first assessment posttest attempt. Among participants who completed both scheduled training sessions (15/18), 12 (80%) achieved mastery on their first posttest attempt. The remaining 6 participants (33%) required an additional 30–60 minutes of DP followed by retesting at a later date. By the conclusion of the curriculum, 100% of participants achieved mastery.

All fellows who completed both scheduled sessions (9/12) achieved mastery on their first assessment posttest attempt, whereas fellows who attended only 1 session (3/12) did not achieve mastery on the first attempt and required additional DP prior to retesting. Among attendings, only half (3/6) achieved mastery on the first assessment posttest despite completing both scheduled sessions (Figure 2).

FoCUS Image Acquisition Performance by TTE View

Performance on acquisition of the 5 standard TTE views (PLAX, PSAX, A4C, S4C, and IVC) improved significantly following SBML training ($p < .05$ for all comparisons; Supplemental Table 3). At baseline, fewer than a third of participants were able to obtain most of the required images. The greatest gains were observed in PLAX, A4C, and PSAX, each improving by more than 55 percentage points from pretest to initial posttest. Performance did not differ significantly between attendings and fellows for any of the TTE views (Supplemental Table 4, Supplemental Figure 1).

Secondary Outcomes

Knowledge Test

Participants demonstrated significant improvements in FoCUS knowledge following SBML training (Table 2). The median (IQR) knowledge test score for the

overall cohort increased from 30 (28–34) to 35 (32–37) after training ($p = .001$). Among fellows, scores improved from 31 (28–35) to 36 (35–37) ($p = .004$), whereas attendings improved from 30 (27–30) to 32 (32–35) ($p = .09$), which was not statistically significant.

Self-confidence

Participants' self-confidence in performing FoCUS improved significantly (Table 2) with the overall cohort's median (IQR) confidence score increasing from 2 (1–3) to 4 (4–5) ($p < .001$). Fellows improved from 2 (2–3) to 4 (4–5) ($p = .003$), whereas attendings increased from 1 (1–1) to 4 (4–4) ($p = .031$).

Course Satisfaction

Course satisfaction ratings for the SBML curriculum were high (Table 3). The median (IQR) overall satisfaction score was 5 (5–5). Participants rated the amount of time allotted for hands-on sessions as *sufficient* (median 4 [4–5]) and the use of a standardized checklist as *highly beneficial* (median 5 [4–5]). Satisfaction and perceived benefit did not differ between fellows and attendings; however, fellows reported greater adequacy of training time (median 5 [4–5] vs 4 [4–4], $p = .02$).

Successful Completion of ABA Applied Examination OSCE Component

All fellows ($N = 12$) who participated in the curriculum successfully passed the ABA APPLIED examination OSCE required for board certification on their first attempt.

DISCUSSION

Our study demonstrated that an SBML curriculum incorporating both TTE simulation and SPs significantly improved FoCUS image acquisition of the 5 standard TTE views in a simulated setting and increased knowledge and self-confidence in performing FoCUS. Despite wide variability in baseline experience, no participant met the MPS at baseline; however, 100% achieved mastery after limited DP, demonstrating the curriculum's efficiency across learner levels. Defining competency in POCUS and establishing minimum training standards for anesthesiologists, residents, and fellows has become a priority for several professional societies and accrediting bodies.^{22,23}

Despite this growing attention, few guidelines outline a standardized approach to POCUS education and assessment.^{22–24} A survey of Accreditation Council for Graduate Medical Education–accredited anesthesiology residency programs found that most incorporate a combination of informal bedside instruction, lectures, online modules, and simulation. Notably, 60% of respondents reported no formal assessment of POCUS knowledge or skills, and among those that did, assessment methods varied widely (eg, hands-on skills evaluation, written examination, or completion of a minimum number of scans).²⁴

The indication, acquisition, interpretation, and medical decision making (I-AIM) framework provides a structured approach for performing and applying POCUS examinations.^{2,24,25} Educational programs that incorporate a combination of modalities aligned with the I-AIM model can help ensure competency across all 4 domains. Our curriculum builds upon this framework by offering an integrated education and assessment tool that facilitates rapid development of image acquisition proficiency, an essential milestone along the continuum of POCUS competency, while laying the foundation for advancing to image interpretation and clinical application.

Our participants' performance on individual TTE views highlighted areas in which focused educational resources may be most beneficial. Whereas participants demonstrated significant improvement across all 5 views, PLAX and A4C were acquired most reliably, often reaching mastery after the initial posttest. Consistent with prior observations in cardiac ultrasound training,^{26,27} the subcostal views (S4C, IVC) were more challenging, showing lower acquisition rates initially and requiring additional DP to achieve mastery. These findings may reflect real-world clinical difficulty and suggest that SBML curricula should prioritize structured teaching and extended hands-on time for these technically demanding views.

Our curriculum is unique in combining high-fidelity simulation with SP scanning,

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ensuring that participants achieved mastery on the simulator before advancing to more complex, real-time imaging. This approach guaranteed that all participants began SP assessments at a consistently high competency standard. To our knowledge, SBML has not been utilized to prepare anesthesiologists for the FoCUS component of the ABA APPLIED board examination. Baseline skills assessment required approximately 12–15 minutes per learner, and each hands-on training session was delivered in a single 3-hour block with a faculty-to-learner ratio of 1:2. Additionally, baseline skills assessments can be performed asynchronously, further enhancing scheduling flexibility and scalability across training programs.

Despite lower baseline performance, attendings achieved comparable mastery rates to fellows by the conclusion of training, supporting the effectiveness of SBML across varying levels of experience.^{11,12,16} This approach enables attendings to efficiently achieve uniform FoCUS image acquisition proficiency and provides a structured method to teach the trainers, bridging POCUS competency gaps among earlier ABA Diplomates. Additionally, this curriculum offers a framework to assess skill retention, identify learning decay, and support ongoing proficiency through periodic deliberate practice refresher sessions.

However, attendings were less likely than fellows to achieve mastery on their first posttest attempt despite completing both scheduled sessions. This difference may reflect variation in learner context, including perceived relevance of FoCUS skills, motivation, engagement during training, and recency of prior cardiac ultrasound exposure. Among fellows, completion of 2 scheduled sessions appeared sufficient to support first attempt mastery, whereas some attendings required additional DP beyond the scheduled sessions to achieve mastery. These observations should be interpreted cautiously given the small sample size but highlight the importance of considering learner motivation when implementing SBML curricula across mixed-experience groups.

Our study adds to the growing body of literature demonstrating that SBML improves procedural skills across multiple domains.^{5,8,9,13,14,16,28,29} Consistent with prior studies,^{3,4,6,30} clinical experience (years in practice as opposed to experience with cardiac ultrasound) did not predict performance as anesthesiology fellows achieved mastery after an average of 2 DP sessions, whereas half of attendings required 1 additional session. These results are consistent with prior SBML curricula demonstrating that most learners, regardless of baseline experience, achieve mastery after limited additional DP.^{9,15,16,28} None of the fellows achieved mastery at baseline despite most (83%) reporting prior didactic exposure and 22% reporting repeated hands-on ultrasound training during residency. The wide range of baseline scores highlights the ongoing lack of standardization in POCUS education across anesthesiology training programs. The variability in baseline performance despite prior formal instruction underscores the limitations of nonstandardized educational approaches in achieving procedural competency and supports the effectiveness of SBML in producing more consistent outcomes.^{3,15,16,28,30}

This study has several limitations. It was conducted at a single pediatric institution with a relatively small sample size, which may limit generalizability. Training occurred in a simulated environment that may not fully reflect perioperative conditions. However, whereas the same SP was intentionally used for baseline and posttest assessments to control for anatomic variability, practice sessions incorporated multiple SPs with varying degrees of difficulty to introduce variability and better approximate clinical practice. The use of a single simulator alongside multiple SPs created a bottleneck, despite staggered learner start times. While additional simulators would improve efficiency, there remains value in non-scanning learners observing a peer's standardized, checklist-driven progression under 1:1 expert supervision. This logistical constraint, however, should be addressed in future implementations. Interrater reliability was assessed using a randomly selected subset of saved image clips rather than the full data set, reflecting

a balance between methodological rigor and feasibility given the use of extradepartmental content experts.

The skills curriculum focused on image acquisition using SPs with normal anatomy and did not directly assess real-time interpretation of pathology. However, interpretation was indirectly evaluated through the written knowledge assessments in which participants demonstrated significant improvement. The same multiple-choice knowledge assessment was used for both pretesting and posttesting, and this introduces potential recall bias and may overestimate learning gains. To mitigate this, the question order was varied, and assessments were separated by a substantial interval (August pretest, February posttest), but we cannot exclude the possibility that prior exposure to test items contributed to improved scores. There are other components that likely additionally contributed to the improvements measured, including the readings following the pretest. Learning decay was partially addressed by having posttests administered at least 1 month after training. However, long-term durability of FoCUS skills and translation to clinical practice remain unknown. Time, scheduling constraints (for both trainees and faculty), and limited internal expertise were additional limitations. Because there were limited qualified faculty within the anesthesiology department to teach this curriculum, we collaborated with pediatric cardiologists to serve as instructors and administer the skills curriculum.

CONCLUSIONS

In summary, this SBML curriculum enabled rapid and reliable mastery of FoCUS image acquisition across participants with varying levels of prior experience, meeting the competency standard expected for FoCUS image acquisition on the ABA APPLIED exam. These findings support the use of SBML not only for FoCUS training but also as a framework for expanding POCUS education to other domains, including lung, abdomen, and airway ultrasound, which are being incorporated into ABA certification requirements.

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Abbreviations:

SBML, simulation-based mastery learning

POCUS, point-of-care ultrasound

FoCUS, focused cardiac ultrasound

ABA, American Board of Anesthesiology

OSCE, objective structured clinical examination

TTE, transthoracic echocardiography

MPS, minimum passing standard

SP, standardized patient

Abstract

Background: Focused cardiac ultrasound (FoCUS) is increasingly recognized as an essential competency for anesthesiologists and appears in the American Board of Anesthesiology (ABA) APPLIED exam. Standardized training approaches remain limited. This study evaluated a simulation-based mastery learning (SBML) curriculum for achieving FoCUS image acquisition competency among anesthesiology fellows and attending anesthesiologists.

Methods: In this single-center, pretest/posttest study (August 2022–February 2024), 12 fellows and 6 attending anesthesiologists participated in a curriculum consisting of 2 3-hour sessions combining transthoracic echocardiography (TTE) simulation and standardized patient scanning. Performance was assessed using a 20-item checklist derived from the ABA objective structured clinical examination (OSCE) content outline. A minimum passing standard (MPS) of 85% was set using the Mastery Angoff method. Posttests were administered ≥ 1 month after training. The primary outcome was improvement in FoCUS image acquisition skills, defined by achievement of the MPS on posttest assessment. Secondary outcomes included FoCUS knowledge on a written exam, confidence, course satisfaction, and OSCE success.

Results: Eighteen participants completed the curriculum. At baseline, 0/18 (0%) participants achieved the MPS. Among participants who completed both scheduled training sessions (15/18), 12 (80%) achieved mastery on their first posttest attempt, including all fellows who completed both sessions (9/9). The remaining participants required additional deliberate practice before achieving the MPS on a subsequent posttest. Performance improved significantly across all TTE views ($p < .01$).

Conclusion: This SBML curriculum enabled rapid mastery of FoCUS image acquisition across learners with varying experience levels and achieved competency aligned with expectations for FoCUS image acquisition on the ABA APPLIED examination. SBML can be utilized to create effective curricula addressing evolving certification requirements and clinical needs.

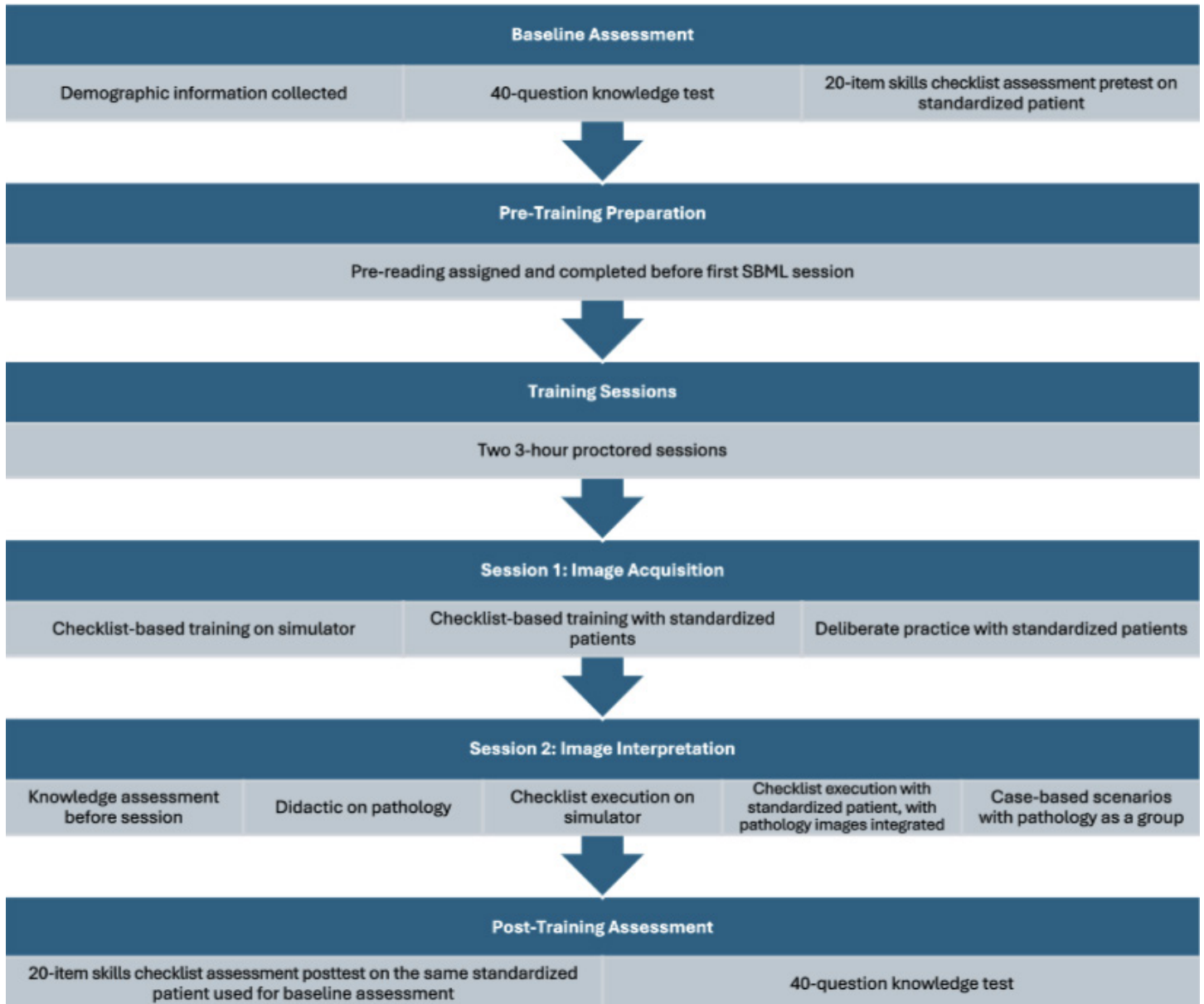
Keywords: Simulation-based mastery learning (SBML), focused cardiac ultrasound (FoCUS), point-of-care ultrasound (POCUS), perioperative education, anesthesiology board certification, competency-based medical education, simulation training

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Figures

Figure 1. Summary of longitudinal curriculum

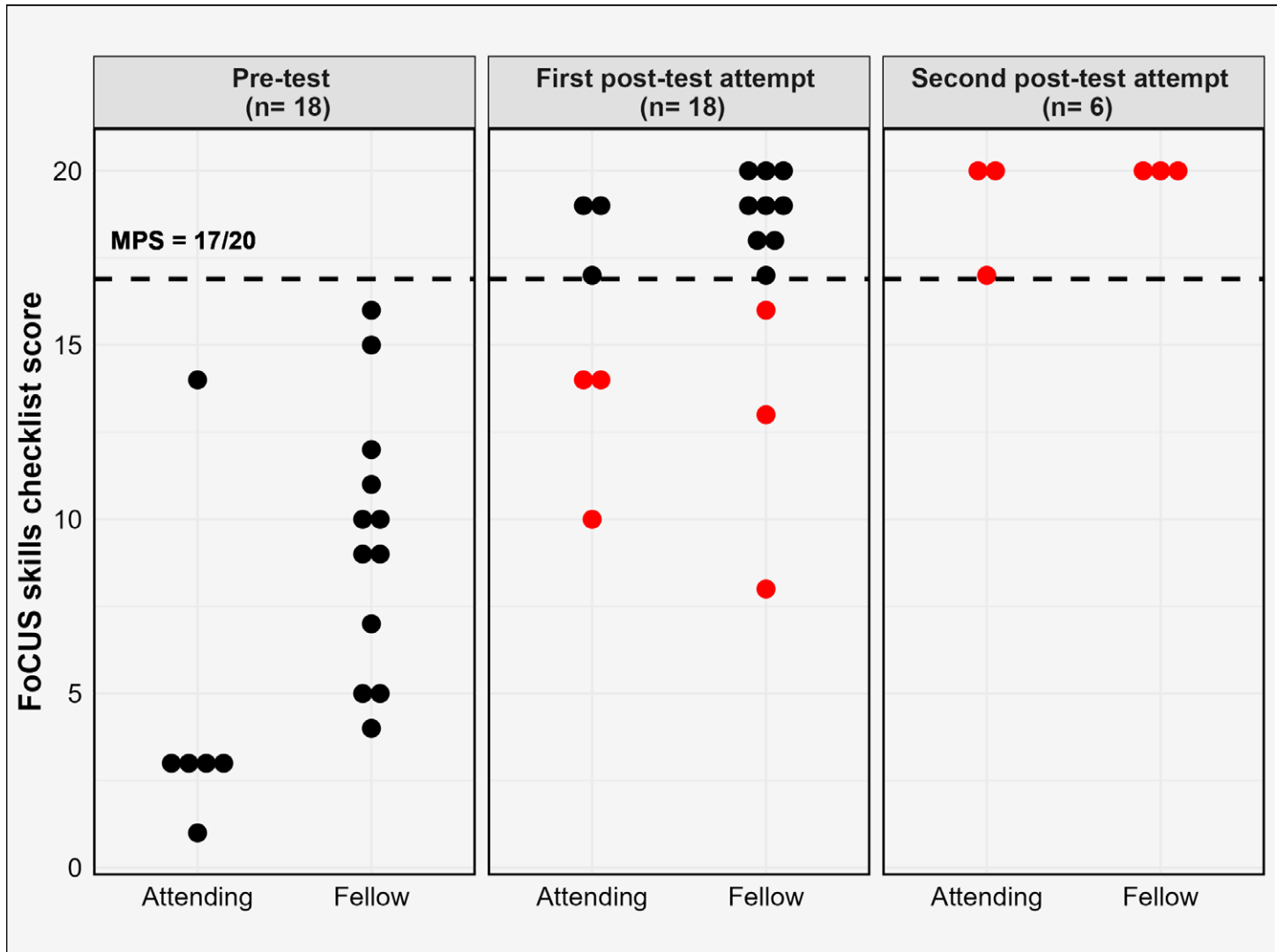


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Figures

Figure 2. Individual participant scores. Individual participant scores on the 20-item FoCUS skills checklist at baseline (pretest); their first attempt at a mastery posttest after completion of the scheduled SBML sessions; and for those that did not achieve the MPS, a second posttest following additional deliberate practice if required. Results are shown separately for attendings and fellows. The dashed line denotes the minimum passing standard (MPS = 17/20).



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Tables

Table 1. Demographics and Clinical Experience

Variable	Overall (N = 18)	Attending (N = 6)	Fellow (N = 12)
Age (years, IQR)	33 (31, 36)	36 (35, 37)	31 (31, 34)
Sex¹			
Female	7 (39%)	3 (50%)	4 (33%)
Male	11 (61%)	3 (50%)	8 (67%)
Years of clinical experience (Years, IQR)	5 (5, 10)	10 (9, 11)	5 (5, 5)
Prior didactic FoCUS exposure^a			
None	3 (17%)	1 (17%)	2 (17%)
Minimal	13 (72%)	5 (83%)	8 (67%)
Formal Curriculum	2 (11%)	0 (0%)	2 (17%)
Prior Hands-On FoCUS Experience^a			
None/Minimal	14 (78%)	6 (100%)	8 (67%)
Repeated	4 (22%)	0 (0%)	4 (33%)
Expert/Certification	0 (0%)	0 (0%)	0 (0%)

Abbreviations: FoCUS, focused cardiac ultrasound; IQR, interquartile range.

¹n (%).

Table 2. Pretest and Posttest Performance on Knowledge, Skills, and Self-Confidence

Variable	Pretest Score	Posttest Score	Score Change (95% CI)	Wilcoxon P ^a
Knowledge assessment				
Attending (N = 6)	30 (27, 30)	32 (31, 35)	[-1.09, 8.09]	0.090
Fellow (N = 12)	31 (28, 35)	36 (35, 37)	[2.52, 6.57]	0.004*
Overall (N = 18)	30 (28, 34)	35 (32, 37)	[2.4, 5.95]	0.001*
Hands-on skills checklist				
Attending (N = 6)	3 (3, 3)	19 (18, 20)	[9.32, 19.02]	0.035*
Fellow (N = 12)	9.5 (7, 11)	19.5 (19, 20)	[6.99, 12.51]	0.003*
Overall (N = 18)	8 (3, 11)	19 (18, 20)	[8.83, 13.61]	0.000*
Self-confidence				
Attending (N = 6)	1 (1, 1)	4 (4, 4)	[1.62, 3.38]	0.031*
Fellow (N = 12)	2 (2, 3)	4 (4, 5)	[1.51, 2.82]	0.003*
Overall (N = 18)	2 (1, 3)	4 (4, 5)	[1.8, 2.75]	0.000*

Abbreviation: CI, confidence interval.

^aWilcoxon signed-rank test.

*Significance at $P < .05$.

Values are reported as Median (IQR). Knowledge assessment consisted of 40 multiple-choice questions. Hands-on skills were evaluated using a 20-item checklist. Self-confidence was rated on a 5-point Likert scale (1 = *not at all confident*, 5 = *extremely confident*).

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Tables

Table 3. Participant Satisfaction with Curricular Elements and Overall Satisfaction

Question	Overall (N = 18 ^a)	Attending (N = 6 ^a)	Fellow (N = 12 ^a)	P Value ^b
Using a standardized checklist helped me advance my technical skills.				0.790
Median (IQR)	5.0 (4.0, 5.0)	4.5 (4.0, 5.0)	5.0 (4.0, 5.0)	
The amount of time allowed at hands-on sessions was sufficient to master FoCUS skills.				0.020
Median (IQR)	4.0 (4.0, 5.0)	4.0 (4.0, 4.0)	5.0 (4.0, 5.0)	
The overall objectives of the course were achieved.				0.076
Median (IQR)	5.0 (5.0, 5.0)	4.5 (4.0, 5.0)	5.0 (5.0, 5.0)	

Abbreviations: FoCUS, focused cardiac ultrasound; IQR, interquartile range; SD, standard deviation.

^an (%).

^bWilcoxon rank sum test, Fisher exact test; *Scored as 1 = *strongly disagree* to 5 = *strongly agree*;

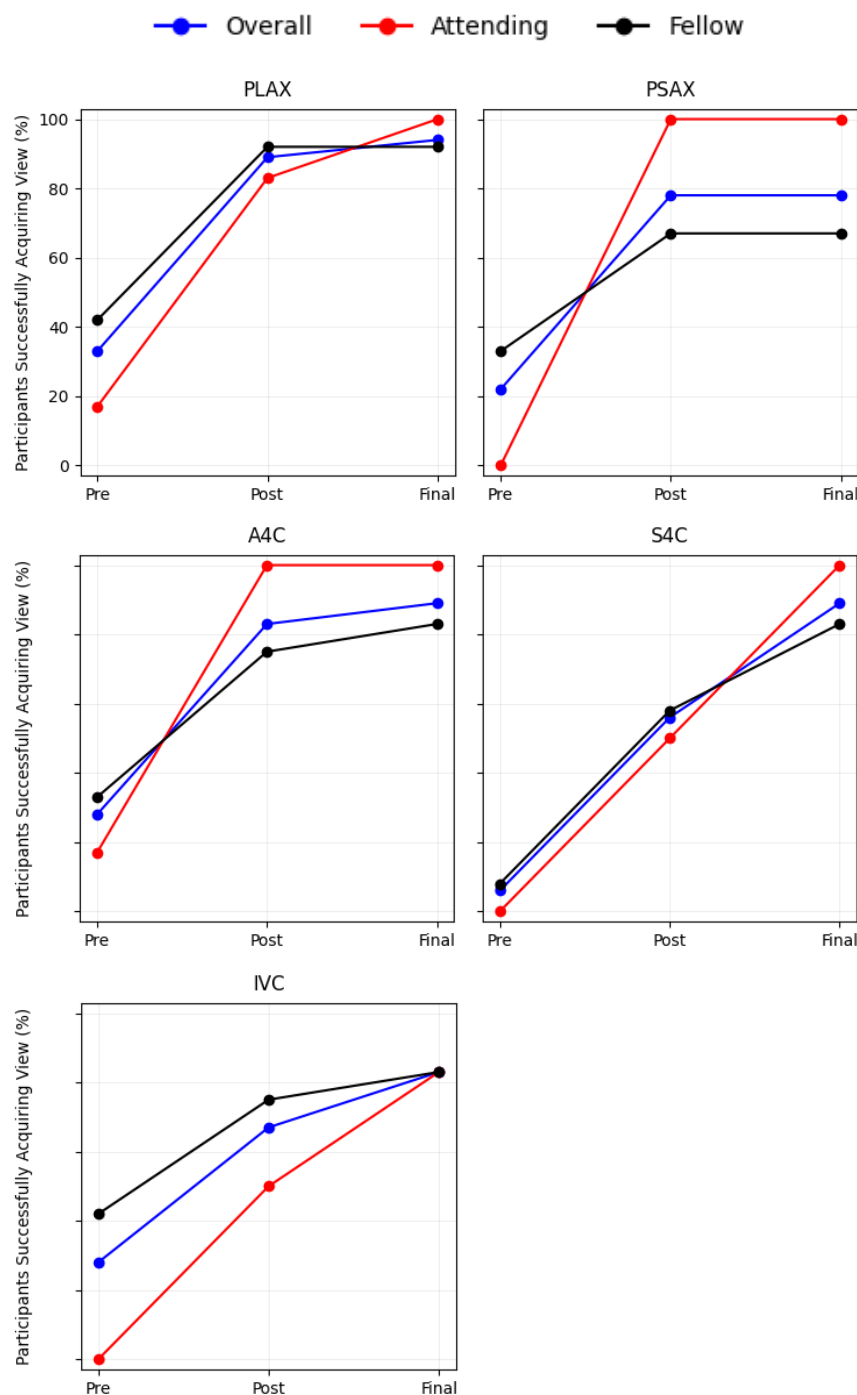
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Supplemental Figure 1. FoCUS image acquisition scores by transthoracic echo view. PLAX, parasternal long axis; PSAX, parasternal short-axis; A4C, apical 4-chamber; S4C, subcostal 4-chamber; IVC, inferior vena cava.

FoCUS Image Acquisition Scores by Transthoracic Echo View



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Supplemental Table 1: Core Elements of Simulation-Based Mastery Learning

Core Elements	Description
1. Baseline assessment of learner performance	Initial assessment to determine learners' starting competence
2. Clearly defined learning objectives	Explicit, measurable skills and behaviors that define expected performance
3. Minimum passing standard (MPS) set by a panel of content specialists	Criterion-referenced benchmark for mastery established by expert consensus
4. Educational activities with deliberate practice and feedback	Repetitive, focused practice paired with immediate, specific, and actionable feedback
5. Formative assessment	Ongoing assessment used to guide learning and identify gaps relative to the MPS
6. Continued practice until mastery achieved	Learners repeat deliberate practice and reassessment until performance meets or exceeds the MPS
7. Summative assessment & clinical transfer	Final verification that the learner meets the MPS with expectation of real-world performance improvement

Supplemental Table 2: Components of Deliberate Practice in FoCUS Training

Deliberate Practice Components	Description	FoCUS-Specific Example
1. Repetitive performance of targeted skill	High-frequency repetition of clearly defined tasks	Repeated acquisition of parasternal, apical, and subcostal views
2. Immediate feedback from instructors	Real-time expert guidance during or immediately after performance	Probe positioning, depth/gain adjustments, window optimization
3. Focused correction of errors	Targeted remediation of identified deficiencies	Correcting foreshortened apical views or misidentification of effusion
4. Gradual increase in complexity	Progressive advancement from simple to challenging scenarios	Normal anatomy → pathology → technically limited or critically ill patients
5. Defined goals and performance benchmarks	Explicit criteria for acceptable performance	Image quality checklists, view completeness, interpretation accuracy

Supplemental Table 3: FoCUS Image Acquisition Success Rates by View

View	Pre (%)	Post (%)	Final ² (%)	Δ Pre to Post	Δ Pre to Final	P Value (Pre to Post) ¹	P Value (Pre to Final) ¹
A4C	27.8	83.3	88.9	55.5	61.1	0.009	0.006
IVC	27.8	66.7	83.3	38.9	55.5	0.046	0.009
PLAX	33.3	88.9	94.4	55.6	61.1	0.004	0.003
PSAX	22.2	77.8	77.8	55.6	55.6	0.009	0.009
S4C	5.6	55.6	88.9	50.0	83.3	0.016	0.000

¹McNemar's test for paired binary outcomes; values represent the proportion of participants (%) who successfully obtained each transthoracic view at pretest, initial posttest, and final performance; Δ, absolute percentage-point improvement; PLAX, parasternal long-axis; PSAX, parasternal short-axis; A4C, apical four-chamber; S4C, subcostal four-chamber; IVC, inferior vena cava. ²"Final" reflects each participant's last available assessment (first posttest for participants who met the MPS on their initial attempt, and second posttest only for those who required additional deliberate practice and retesting). View-specific values may therefore remain unchanged between posttest and final if retesting was not performed or did not alter that item.

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Supplemental Table 4: FoCUS Image Acquisition Scores by Group³

Transthoracic Echo View	Overall (N=18 ¹)	Attending (N=6 ¹)	Fellow (N=12 ¹)	P Value ²
PLAX (Pre-test)	6 (33%)	1 (17%)	5 (42%)	0.60
PLAX (First Post-test)	16 (89%)	5 (83%)	11 (92%)	>0.99
PLAX (Final)	17 (94%)	6 (100%)	11 (92%)	>0.99
PSAX (Pre-test)	4 (22%)	0 (0%)	4 (33%)	0.25
PSAX (First Post-test)	14 (78%)	6 (100%)	8 (67%)	0.25
PSAX (Final)	14 (78%)	6 (100%)	8 (67%)	0.25
A4C (Pre-test)	5 (28%)	1 (17%)	4 (33%)	0.61
A4C (First Post-test)	15 (83%)	6 (100%)	9 (75%)	0.51
A4C (Final)	16 (89%)	6 (100%)	10 (83%)	0.53
S4C (Pre-test)	1 (5.6%)	0 (0%)	1 (8.3%)	>0.99
S4C (First Post-test)	10 (56%)	3 (50%)	7 (58%)	>0.99
S4C (Final)	16 (89%)	6 (100%)	10 (83%)	0.53
IVC (Pre-test)	5 (28%)	0 (0%)	5 (42%)	0.11
IVC (First Post-test)	12 (67%)	3 (50%)	9 (75%)	0.34
IVC (Final)	15 (83%)	5 (83%)	10 (83%)	>0.99

¹n (%); ²Fisher's exact test; PLAX, parasternal long axis; PSAX, parasternal short-axis; A4C, apical four-chamber; S4C, subcostal four-chamber; IVC, inferior vena cava; ³ Scores represent the number (%) of participants who successfully demonstrated acquisition of the specified TTE view, defined as obtaining a focused image meeting checklist criterion for that view (maximum score = 1 per view). These values reflect view-specific acquisition only and do not represent total points earned across the full checklist section. "Final" reflects each participant's score at the time they first achieved the MPS, incorporating first posttest scores for those who passed initially and second posttest scores for those who required additional DP and retesting.

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Appendix A: 40 Question Knowledge Test

Demographics 1. Please enter your name

Demographics 2. Please enter your Email Address

Demographics 3. What formal TTE or Focused Cardiac Ultrasound (FoCUS) didactic exposure do you have previously?

- ☐ No formal didactics
- ☐ Minimal formal didactics (i.e. intermittent powerpoints during residency)
- ☐ Formal didactics curriculum completed (i.e. residency had repeated formal didactics to address TTE component of ABA oral board examination)
- ☐ Other

Demographics 4. What hands-on experience in TTE or Focused Cardiac Ultrasound (FoCUS) do you have previously?

- ☐ Minimal hands-on experience (i.e. scanning the IVC for respiratory variation in an ICU patient)
- ☐ Repeated hands-on experience (i.e. scanning standardized patients as part of a curriculum, or assessing patients for pathology to make a diagnosis)
- ☐ Expertise in TTE or Focused Cardiac Ultrasound
- ☐ Other

Demographics 5. How often do you use Focused Cardiac Ultrasound (FoCUS)?

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- ☐ Never
- ☐ Once a year
- ☐ Once a month
- ☐ Once a week
- ☐ Daily

Demographics 6. What barriers exist for your use of Focused Cardiac Ultrasound (FoCUS) (choose all that apply)?

- ☐ Lack of training
- ☐ Lack of equipment
- ☐ Not useful for my patients
- ☐ Other

Demographics 7. To what extent do you agree or disagree with the following statement?

I understand the indications for Focused Cardiac Ultrasound (FoCUS) in perioperative care.

- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

Demographics 8. To what extent do you agree or disagree with the following statement?

I am confident that I could perform Focused Cardiac Ultrasound (FoCUS) on my patients.

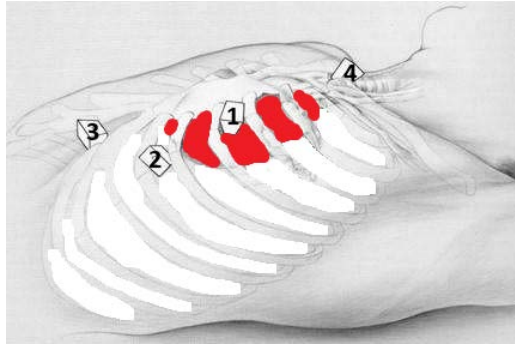
- ☐ Strongly Agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly Disagree

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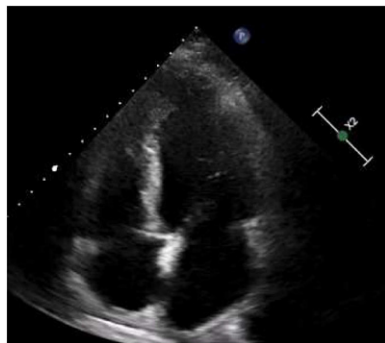
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Q1. Which probe position is correct to acquire a parasternal view?



- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4

Q2. Which view is depicted in this image?



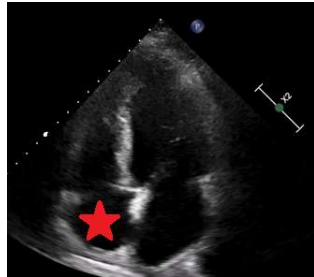
- ☐ Parasternal Long Axis
- ☐ Apical Four Chamber
- ☐ Parasternal Short Axis
- ☐ Subcostal IVC View
- ☐ Subcostal Four Chamber

Q3. In the image shown, the star is in/on the

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- ☐ Right Atrium
- ☐ Left Atrium
- ☐ Left Ventricle
- ☐ Mitral Valve
- ☐ Right Ventricle

Q4. In the image shown, the star is in/on the:



- ☐ Aortic Valve Leaflet
- ☐ Anterior Mitral Valve Leaflet
- ☐ Posterior Mitral Valve Leaflet
- ☐ Left Ventricle
- ☐ Left Atrium

Q5. In the image shown, the star is in/on the:

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- ☐ Right Ventricle
- ☐ Interventricular Septum
- ☐ Pericardium
- ☐ Left Ventricle
- ☐ Aortic root

Q6. In the image shown, the star is in/on the:



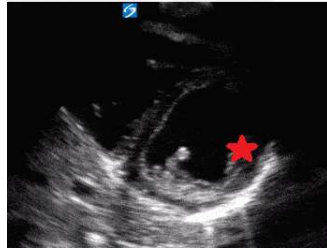
- ☐ Anterior Leaflet of the Mitral Valve
- ☐ Right Ventricle
- ☐ Interventricular Septum
- ☐ Posterior Leaflet of the Mitral Valve
- ☐ Right Atrium

Q7. In the image shown, the star is in/on the:

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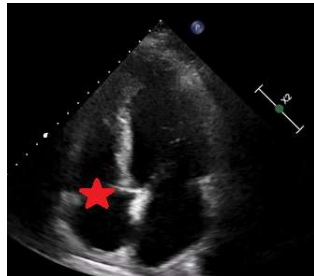
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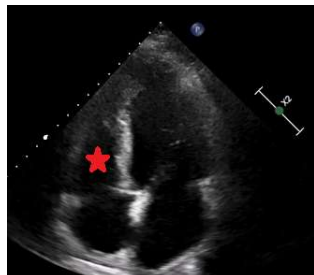
- ☐ Posterior Leaflet of the Mitral Valve
- ☐ Posteromedial Papillary Muscle
- ☐ Anterolateral Papillary Muscle
- ☐ Septal Tricuspid Valve Leaflet
- ☐ Interventricular Septum

Q8. In the image shown, the star is in/on the:



- ☐ Interventricular Septum
- ☐ Left Ventricle
- ☐ Tricuspid Valve
- ☐ Aortic Valve
- ☐ Mitral Valve

Q9. In the image shown, the star is in/on the:



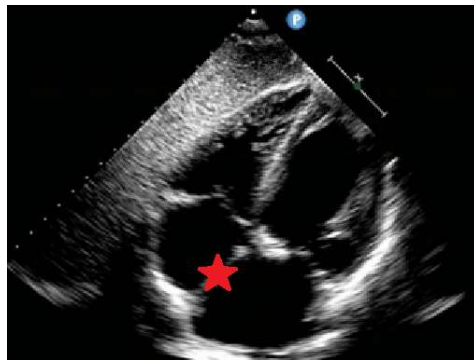
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- ☐ Right Ventricle
- ☐ Left Atrium
- ☐ Right Atrium
- ☐ Left Ventricle
- ☐ Mitral Valve

Q10. In the image shown, the star is in/on the:



- ☐ Right Ventricle
- ☐ Tricuspid Valve
- ☐ Left Atrium
- ☐ Interatrial Septum
- ☐ Right Atrium

Q11. In the image shown, the star is in/on the:



- ☐ Left Ventricle
- ☐ Right Atrium
- ☐ Right Ventricle
- ☐ IVC
- ☐ SVC

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Q12. Which of the following views is pictured in this image?



- ☐ Subcostal IVC View
- ☐ Parasternal Short Axis
- ☐ Subcostal 4 Chamber
- ☐ Parasternal Long Axis
- ☐ Apical 4 Chamber

Q13. Which of the following is NOT assessed with FoCUS?

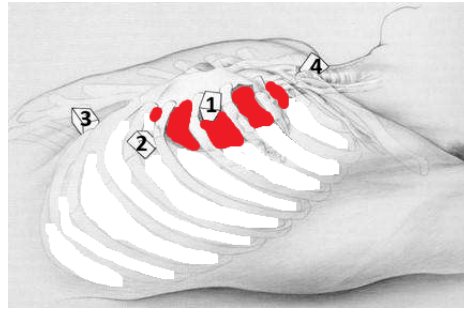
- ☐ Ventricular Function
- ☐ Chamber Size
- ☐ Effusion
- ☐ Pneumothorax

Q14. Which probe position is correct to acquire an Apical 4 Chamber view?

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- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4

Q15. What anatomic structures are commonly visualized in the apical 4 chamber view?

- ☐ The LV, AV, MV, and LA
- ☐ All 4 chambers (LV, RV, LA, RA) and all 4 valves (AV, MV, TV, PV)
- ☐ The LV, LA, MV, RV, RA, and TV
- ☐ The LV, AV, MV, LA, RVOT, and PV
- ☐ The LV, AV, MV, LA, RVOT, PV, and TV

Q16. The IVC is best seen in which view?

- ☐ Parasternal Short Axis
- ☐ Apical 4 chamber
- ☐ Parasternal Long Axis
- ☐ Subcostal 4 Chamber
- ☐ Subcostal IVC View

Q17. Which statement is CORRECT concerning standard echo views?

- ☐ RV size is visually estimated as enlarged if its area is larger than the area of the left ventricle in the parasternal short axis view
- ☐ In normal hearts there is asymmetric thickening of the left ventricular myocardium and septum in addition to systolic anterior motion of the mitral valve
- ☐ The interatrial septum is best interrogated in the parasternal long axis view

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- ☐ Both pericardial fluid and pleural fluid appear white but epicardial adipose tissue appears black
- ☐ The three leaflets of the aortic valve are best visualized in the parasternal long axis view

Q18. Ventricular systolic function in this view is:



- ☐ Abnormal
- ☐ Normal

Q19. Ventricular systolic function in this view is:



- ☐ Abnormal
- ☐ Normal

Q20. Left ventricular function in this view is:

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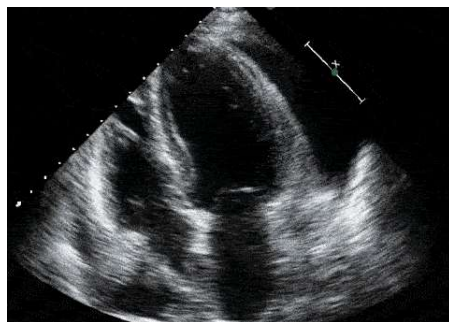
- ☐ Abnormal
- ☐ Normal

Q21. This image shows:



- ☐ Poor ventricular function
- ☐ An atrial septal defect
- ☐ Unicuspid Aortic Valve
- ☐ A large pericardial effusion
- ☐ Aortic dissection

Q22. The MOST CRITICAL finding in this image is:



- ☐ Left atrial collapse
- ☐ A large pericardial effusion

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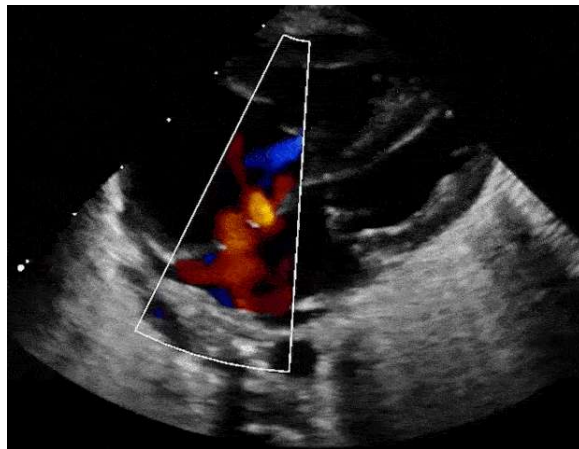
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- ☐ Aortic dissection
- ☐ Poor left ventricular function
- ☐ Unicuspid aortic valve

Q23. Pericardial effusion causing RA chamber collapse causes:

- ☐ Increased LV filling
- ☐ Increased RV filling
- ☐ Decreased RV filling
- ☐ Reduced LV contractility

Q24. This image shows:



- ☐ An ASD with left to right flow
- ☐ An ASD with right to left flow
- ☐ A VSD
- ☐ AR
- ☐ MR

Q25. Which lesion is the MOST LIKELY cause of a DILATED RV?

- ☐ A large ASD
- ☐ Systemic hypertension
- ☐ A large PDA
- ☐ Aortic stenosis
- ☐ Aortic valve regurgitation

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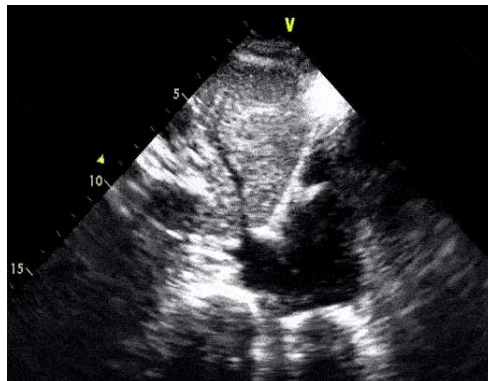
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Q26. This image suggests hypovolemia:



- ☐ True
☐ False

Q27. This image suggests hypovolemia:



- ☐ False
☐ True

Q28. Which of the following pathologies is suggested by this image?

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- ☐ Hypertrophic Cardiomyopathy
- ☐ Pulmonary Embolism
- ☐ Normal Echocardiogram
- ☐ Left Anterior Descending Coronary Artery Ischemia

Q29. The differential of a large, poorly functioning RV includes ALL OF THE FOLLOWING EXCEPT:

- ☐ Congenital heart disease
- ☐ Severe pulmonary hypertension
- ☐ Pericardial tamponade
- ☐ A large pulmonary embolism

Q30. Which coronary artery supplies blood flow to the following area?

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- ☐ Left Anterior Descending Artery (LAD)
- ☐ Left Circumflex Artery (LCx)
- ☐ Either LAD or LCx
- ☐ Posterior Descending Artery

Q31. This image shows:



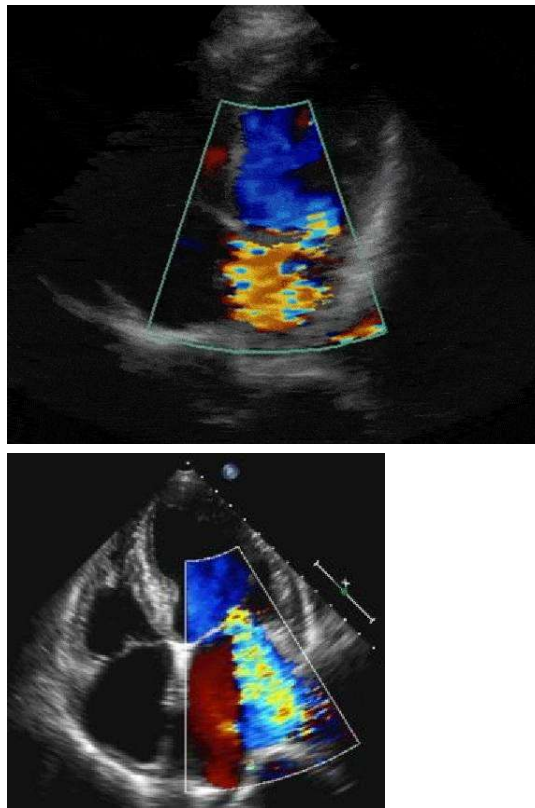
- ☐ Intracardiac air bubbles
- ☐ Poor RV function
- ☐ Valve regurgitation
- ☐ Poor LV function
- ☐ Pericardial tamponade

Q32. These images show what lesion?

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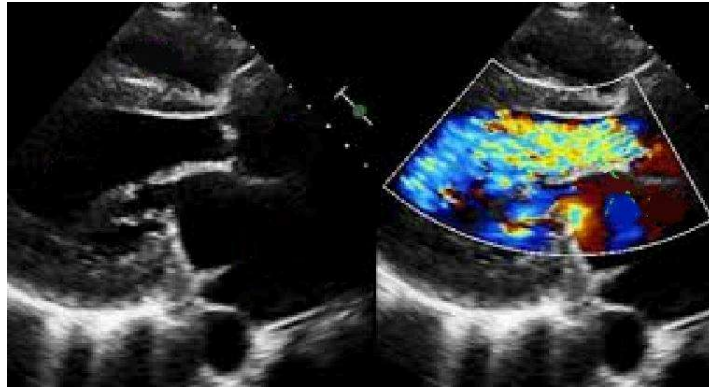
- ☐ No evidence of severe valve pathology
- ☐ Severe pulmonary stenosis
- ☐ Severe tricuspid valve regurgitation
- ☐ Aortic regurgitation
- ☐ Severe Mitral Regurgitation

Q33. These images show what lesion?

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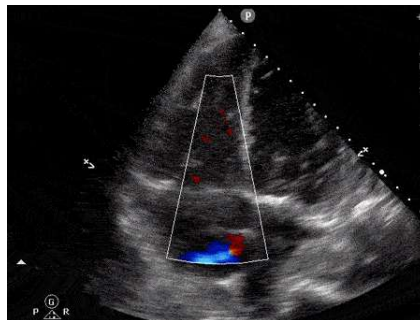
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- ☐ No evidence of severe valve pathology
- ☐ Severe Tricuspid stenosis
- ☐ Severe tricuspid valve regurgitation
- ☐ Severe Mitral Stenosis
- ☐ Severe Aortic regurgitation

Q34. This image shows what lesion?



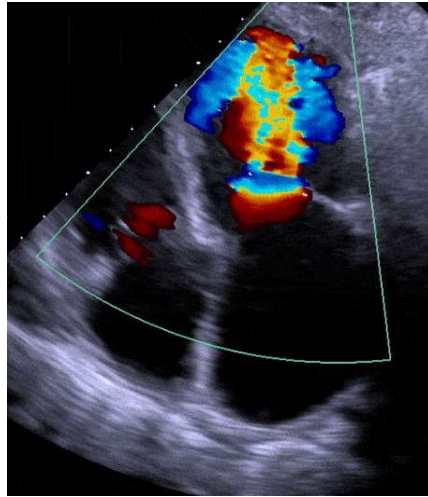
- ☐ Tricuspid Regurgitation
- ☐ Aortic Regurgitation
- ☐ Mitral Regurgitation
- ☐ No evidence of severe valve pathology
- ☐ Tricuspid Stenosis

Q35. This image shows what lesion?

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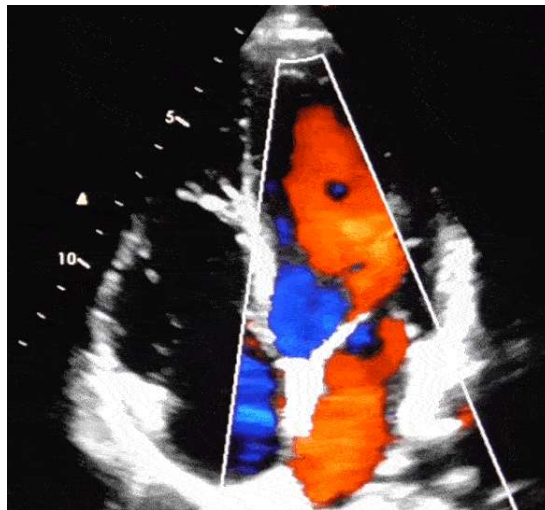
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- ☐ Severe Aortic regurgitation
- ☐ Severe tricuspid valve regurgitation
- ☐ No evidence of severe valve pathology
- ☐ Severe Tricuspid stenosis
- ☐ Severe Mitral stenosis

Q36. This image shows what lesion?



- ☐ Severe Mitral Stenosis
- ☐ Severe tricuspid valve regurgitation
- ☐ No evidence of severe valve pathology
- ☐ Aortic regurgitation

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- ☐ Significant Tricuspid stenosis

Q37. Assessment for a Type A Aortic Dissection can be made in which view?

- ☐ Parasternal Long Axis
☐ Subcostal IVC View
☐ Apical 4 Chamber
☐ Subcostal 4 Chamber

Q38. Assuming typical machine settings, which statement is correct about color doppler?

- ☐ Air around the heart improves the color Doppler signal
☐ Blue flow is away from the transducer and Red is toward
☐ Blue is toward the transducer and Red is away
☐ Flow may not be detected if the transducer is at an angle of zero degrees.
☐ Both Red and Blue flow are toward the transducer by varying with systole and diastole

Q39. Which coronary artery perfuses the territory indicated by the star?



- ☐ SA Nodal Branch
☐ Left Anterior Descending
☐ Left Circumflex
☐ Right Coronary Artery

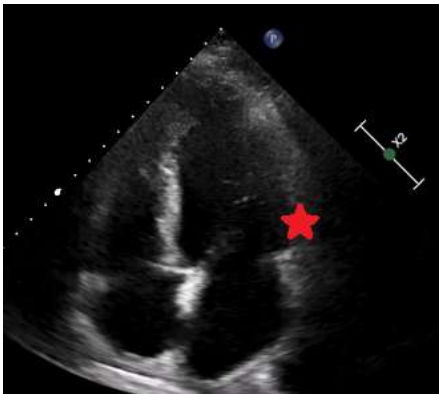
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Supplemental Online Materials

☐ Left Anterior Descending or Circumflex

Q40. Which coronary artery perfuses the territory indicated by the star?



- ☐ Right Coronary Artery
- ☐ Left Anterior Descending or Left Circumflex
- ☐ Left Anterior Descending
- ☐ Left Circumflex
- ☐ SA Nodal Branch

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