Design of a workshop for focused rescue transesophageal echocardiography in nurse anesthesia: a small-scale mixed methods study

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Research Article

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Abstract

Background

Use of transesophageal echocardiography (TEE) by certified registered nurse anesthetists to assess hemodynamic instability during noncardiac surgery is an emerging trend which has created a need for additional training. Unfortunately, the ideal TEE curriculum has yet to be defined to teach nurse anesthesia providers the cognitive and motor skills that will allow them to efficiently acquire and accurately interpret images for this purpose. The primary aim of this prospective, observational study was to evaluate the feasibility and efficacy of a 2-day workshop to teach this skill set to nurse anesthesia students with no prior TEE experience.

Methods

The workshop was based on a focused rescue TEE protocol employing a limited number of views and using a goal-directed, qualitative assessment of critical physiologic parameters. A cohort consisting of 14 second-year nurse anesthesia students was evaluated following this training by quantitative simulator-based testing during hypothetical clinical scenarios. Thereafter, the workshop was assessed by online questionnaire, and quantitative analysis was performed on the results of this qualitative survey.

Results

Participants acquired appropriate TEE views associated with clinical scenarios 99% of the time and correctly interpreted the pathology in those views 93% of the time. In addition, nurse anesthesia trainees uniformly perceived significant educational value in this workshop and were likely to incorporate TEE in their future clinical practice.

Conclusions

A 2-day workshop to teach focused rescue TEE to nurse anesthesia trainees directed by a streamlined protocol based on a limited number of views is feasible and provides useful beginning competency in this diagnostic modality.

Background

Increasingly, transesophageal echocardiography (TEE) has become a standard monitor to assist with management of severe adverse hemodynamic events during noncardiac surgery [1, 2]. Recommendations for perioperative TEE supported by expert opinion and formulated into guidelines by the American Society of Anesthesiologists include the evaluation of acute, unexplained circulatory perturbations resulting in refractory hypotension or hypoxia [2, 3]. Such assessments define “rescue” TEE, and conditions arising
during noncardiac surgery where this diagnostic intervention can provide insight or definitive answers.

relate to hypovolemia, global and regional ventricular function including right ventricular dysfunction and physiology arising from myocardial ischemia, and cardiac tamponade [2, 4, 5].

Although there is a lack of high-quality studies examining the risk-versus-benefit of intraoperative TEE in noncardiac surgery [6], it is clear that the incidence of serious adverse events associated with this monitoring technique is extremely low [7]. Furthermore, there is a significant quantity of observational data indicating that intraoperative TEE can discern the underlying pathology of hemodynamic compromise when it occurs in this setting and thereby direct appropriate resuscitation [6, 8–11]. Despite these findings, however, most certified registered nurse anesthetists (CRNAs) do not employ TEE in their clinical practice [12], especially with noncardiac surgery cases. To address this condition, the American Association of Nurse Anesthesiology (AANA) has recommended monitoring and interpretation of TEE as a special privilege for CRNAs [13]. Additionally, the Council on Accreditation of Nurse Anesthesia Educational Programs has identified point of care ultrasound—a term that includes “focused” rescue TEE (involving a goal-directed, qualitative assessment technique with a limited number of views chosen to assess for a select number of pathologies; consistent with existing modified TEE protocols [4, 14])—as a desired skill in nurse anesthesia training [15].

Given its relative straightforward role and significant value in patient resuscitation [4, 8], focused rescue TEE represents a competency that is both useful and attainable by practicing CRNAs. In order to achieve this goal, it is important to design educational workshops with learning objectives specifically targeted for this purpose. For example, hypothetically an ideal focused rescue TEE workshop for nurse anesthetists with no previous TEE experience should:

- Teach a limited number of views that can be reproducibly acquired and interpreted with relative ease by the novice provider (i.e., be feasible in a relatively short time span);
- Be “user-friendly,” serving to transform a diagnostic modality that has been shrouded in mystery into a positive educational experience; and
- Provide useful skills that allow nurse anesthesia providers to glean valuable insight into perioperative adverse events (i.e., be competency-based).

The aim of the present study was to determine if a workshop employing a single instructor and a 2-day time span could achieve these goals with nurse anesthesia trainees with no previous TEE exposure. The workshop involved both didactic and simulation instruction. The latter teaching was particularly important to allow students to acquire the haptic experience of image acquisition (not just image interpretation) and thereby promoted the equivalent of the “shows how” level of Miller’s pyramid of clinical competence (Fig. 1) [16, 17]. Furthermore, simulation-based TEE training has been shown to be particularly effective in teaching this skill set to novice users [18].

**Methods**
This small scale, prospective observational investigation was not considered human research by the university Institutional Review Board, and the workshop was a mandatory part of a course in advanced anesthesia techniques for second year nurse anesthesia trainees preceding their period of clinical immersion. All 14 student nurse anesthetists in the course participated in the workshop and constituted the small-scale study cohort. None of the students had previous exposure to ultrasound technology except as it related to their prior care of patients in intensive care units, and none had experience with TEE. The workshop instructor was a board-certified anesthesiologist with approximately 25 years’ clinical experience with TEE in cardiac and noncardiac surgery.

**Structure and Learning Objectives of the Workshop**

The workshop had didactic and simulation components followed by a competency assessment. The didactic component took place over two sessions (sessions 1 and 2), each 3.5 hours in length. There were four broad learning objectives for the workshop:

1. Understand TEE fundamentals including the significance of a select number of TEE views;
2. Interpret four views commonly associated with focused rescue TEE in noncardiac surgery – the transgastric mid-papillary short axis (TG MP SAX) view, the mid-esophageal (ME) 4 chamber (4C) view, ME 2 chamber (2C) view, and ME long axis (LAX) view (a modification of a protocol proposed by Staudt and Shelton [4]);
3. Reproducibly acquire these four rescue TEE views; and
4. Acquire and correctly interpret these same TEE views efficiently in the context of common clinical scenarios in noncardiac surgery that may benefit from rescue TEE (i.e., in-context synthesis of objectives 2 and 3).

The didactic sessions focused on objectives 1 and 2, respectively. Objectives 3 and 4 were undertaken in individual simulation sessions involving 1:1 instruction with the TEE simulator, each session lasting approximately one hour (i.e., each student received one hour of individual instructor time for these purposes). The final 15 minutes of these simulations consisted of an evaluation of learning objective 4 in which students performed focused rescue TEE to diagnose causes of refractory hypotension and/or questionable myocardial ischemia in five hypothetical clinical scenarios.

**Didactic Curriculum**

The curriculum content for the didactic sessions (sessions 1 and 2) is set forth in Figure 2. Students were assigned several hours of introductory TEE reading prior to these sessions, and the in-person classroom instruction involved PowerPoint presentations. A large portion of the didactic teaching was performed using a Socratic technique to promote student dialogue, encourage critical thinking, and determine efficacy of content delivery. Many TEE image snapshots and videos of each TEE view were included in
these two sessions. In addition, through both session 1 and session 2, summary PowerPoint slides were incorporated at intervals in the content delivery.

In session 1, practical TEE concepts were introduced including TEE image orientation and the significance of omniplane angle manipulation. A step-by-step “how to perform” a basic 2-dimension TEE exam was outlined that involved the following steps: powering on and connecting the probe to the machine, entering patient information, selecting the image mode, choosing TEE presets, inserting the probe, acquiring and centering the desired image, adjusting the image processing settings, and choosing the appropriate sector depth. Since a Doppler exam has limited utility in rescue TEE, only basic qualitative continuous wave Doppler was discussed. 12 TEE views (ten mid-esophageal and two transgastric views) were detailed in this first session in order to provide an overview of TEE imaging potential, and for each view, the specifics of how to obtain the view (including a logical flow from view-to-view), the anatomic orientations of those views, and the important structures visible in each view (and therefore the view’s potential clinical utility) were identified.

The Simulator

The simulator employed in this study was the CAE Healthcare Vimedix 3.3 TEE trainer with cardiac module (Figure 3). This device consisted of a mannequin torso with a laptop computer-based 2-dimensional (2D) TEE system that demonstrated simultaneous, continuous ultrasound (US) and augmented reality (AR) images of intrathoracic structures using a motion tracker [19]. The Vimedix TEE probe was nearly identical in configuration to an adult TEE probe, and TEE views were generated in a realistic fashion that varied with probe motion including depth of insertion, anteflexion-retroflexion, lateral flexion, and axial rotation. These views appeared on the laptop screen with a split view layout divided between US and AR displays. All the imaging processing options available for routine 2D TEE were available on the Vimedix trainer, including an image pause option that maintained the probe position and had considerable instructional utility to assist with anatomical orientation, analyzing cut planes, and taking measurements. In addition to normal anatomy, the simulator software allowed display of the anatomy and imagery associated with approximately 60 clinical scenarios with various pathologies that were employed for evaluation purposes in a “hidden” mode, where activity titles were not visible to students (see below)

Simulation Curriculum

Simulation sessions were performed following the didactic instruction and students had one hour of individual training with the instructor during 14 separate periods. In these sessions, the trainees were taught how to obtain four common focused rescue TEE views (TG MP SAX, ME 4C, ME 2C, and ME LAX views), and performed these exercises repeatedly with normal and pathologic “patients.” After practicing obtaining these views, they learned a simplified algorithm (Figure 4) that relied on initial acquisition of a TG MP SAX view to diagnose causes of hemodynamic instability in common scenarios amenable to use of focused rescue TEE. This algorithm was predicated on qualitative assessment of critical physiologic
parameters (e.g., visual estimates of left ventricular volumes or changes in ventricular wall thickness). Student findings on this single view were then confirmed by acquisition of an additional view or views from the above focused rescue list (ME 4C, ME 2C or ME LAX views). For example, if they diagnosed anteroseptal myocardial ischemia initially by seeing an appropriate segmental wall motion abnormality on a TG MP SAX view, then they corroborated this finding by obtaining a ME LAX view that visualized the same portion of the left ventricle. Likewise, if they saw evidence of early diastolic collapse of the right ventricle (RV) free wall in the presence of a significant pericardial effusion on TG MP SAX view consistent with cardiac tamponade, they then visualized the RV on the ME 4C view to verify consistent findings.

**Assessment**

After approximately 45 minutes of simulation-based instruction, each student was evaluated using five clinical scenarios associated with appropriate TEE simulator presentations. Scoring of evaluations was divided into scoring of image acquisition and scoring of image interpretation. Although acquisition and interpretation are *a priori* related to each other, the evaluations of the two skills were separated in the following manner:

- For each scenario (with activity titles in a “hidden” mode not visible to the trainee), students were asked to first acquire a TG MP SAX view as the initial step of the desired focused rescue TEE algorithm. They then were instructed to interpret the scenario pathology (i.e., make a diagnosis) and obtain an appropriate second view (either ME 4C, ME 2C, or ME LAX) that corroborated that diagnosis.
- “Acquisition credit” (one point per scenario) was given if students first acquired a clear TG MP SAX view, made the *correct* diagnosis, and then obtained an appropriate clear second view to demonstrate the same pathology, OR if they first obtained a clear TG MP SAX view, made an *incorrect* diagnosis, and then obtained a second view that was appropriate to demonstrate the same (misidentified) pathology. In this manner, “acquisition credit” was possible despite loss of “interpretation credit.” For example, if students correctly or incorrectly interpreted their initial TG MP SAX view as showing inferior wall hypokinesis, they would receive one point for “acquisition credit” if they also acquired a clear view of the inferior wall in a ME 2C view (not ME 4C or ME LAX views that did not show the inferior wall well).
- “Interpretation credit” (one point per scenario) was given if students correctly interpreted the initial TG MP SAX view. Such credit was dependent upon acquisition of this initial view, and as such, hypothetically these skills were not separable if students failed to acquire that view. Fortunately, all students became proficient at TG MP SAX image acquisition.

In this manner, a total of two points was possible for each of the five scenarios, with a total possible score of ten points for the exercise. Students were allowed a maximum time of three minutes per scenario for both acquisition and interpretation of images.
Following the completion of the didactic and simulation curricula, students were emailed surveys (Qualtrics\textsuperscript{XM}) that focused on issues related to the TEE workshop's acceptability and its utility for professional growth, and specifically addressed whether the workshop learning objectives were achieved. These surveys also queried whether students were likely to seek additional TEE training, apply for TEE privileges, and/or employ TEE in their future clinical care as a result of this TEE workshop. Survey data consisted of responses to Likert scale questions as well as descriptive free-style answers.

Data Analysis

For simulation evaluations, performance scores were reported for the entire cohort, and also reported as the percentage of correct view acquisition and correct view interpretation for each scenario. Likewise, errors were grouped as either acquisition errors or interpretation errors. Ranges of scores were compared descriptively.

For the post-TEE survey, mean Likert scale scores were computed for each statement. Qualitative responses to open-ended inquiries were merged and analyzed to generate themes. These themes related to the perceived educational value of the didactic and simulation components of the workshop, to the likelihood of future TEE training and clinical utilization, and to potential improvements in workshop design.

Results

Feasibility

All students completed the study, indicating that a workshop with the parameters (one instructor; 10–20 trainees; two days) and curriculum of the present endeavor is feasible with nurse anesthesia providers with no previous TEE exposure. The workshop design was associated with a significant instructor time burden (21 hours: 14 trainees). More than half of this time was devoted to 1:1 simulation instruction.

Efficacy

All post-TEE surveys were completed and returned (14/14). The responses to questions 1–10 in this survey demonstrate that attendees perceived significant benefit from this workshop (Table 1). This was true for both the didactic and simulation portions: “The TEE didactic exercise was extremely useful as it will allow us as future clinicians to utilize TEE in assessing patients for any number of ...abnormalities;” “Having the hands-on experience helped solidify what we learned in the didactic session.” The Likert-scale responses to these same survey questions (in particular, question 10) also made it clear that the workshop served to ease some of the intimidating aura surrounding TEE: “Putting our hands on the TEE simulator was one of the most engaging, educational, yet low-stress simulations we've had.”

The effectiveness of this workshop was also assessed quantitatively by students’ performances on the simulation evaluations (Table 2). These exercises judged whether students could correctly acquire and
interpret TEE data applicable to five hypothetical clinical scenarios in real time (three minutes per scenario). Students correctly performed both tasks in mock clinical situations in real time during 64/70 (91%) endeavors. They acquired images correctly 69/70 (99%) of the time and interpreted images correctly 65/70 (93%) of the time. The lowest score (10/14 [71%]) occurred with scenario 3 and related to incorrect interpretation of TEE images showing RV dysfunction.

The lowest student cumulative score was eight points (out of ten possible points); four students scored nine points, and the remainder (nine students) had a score of ten points. Six responses were judged inadequate and received no credit. Five of the six inadequate responses (83%) related to incorrect interpretations; one related to an incorrectly performed assessment. The latter event occurred because a student did not recall that the left ventricle (LV) inferior wall is better examined in a ME 2C rather than a ME LAX view. All students successfully acquired an initial clear TG MP SAX view, and in the five instances of misinterpretation of this initial view, students acquired an appropriate second image of the same anatomical area of “misdiagnosis.”

**Likelihood of Future TEE Training and Clinical Utilization**

All students agreed or strongly agreed that they were “likely to seek opportunities to improve” their TEE skills and “request further instruction in TEE” in the future. Furthermore, nearly all students strongly agreed that they were “likely to seek TEE privileges and employ TEE” in their clinical practice. These findings clearly suggest that students appreciated the value of TEE as an intraoperative monitor for patients with unstable hemodynamics.

**Areas for Improvement**

Students recommended that the simulator be incorporated into the didactic portion of the workshop as an adjunct method to demonstrate acquisition and interpretation of images. Most students were not averse to the entire TEE didactic experience occurring on one day and therefore being “content dense.” The mean Likert scale response to “The TEE didactic experience would be better if it occurred over more than one day” was 3.6 (0.7). A common sentiment was that “It was a really, long day, but by the end we really did know how to read TEEs! I feel like if there was a gap in the days of didactic, I might have forgotten certain pieces and not felt as prepared. We took good breaks and the different use of video, pictures and lecture helped break up the day. I think the whole day didactic was the best way to do it.”

**Discussion**

Despite the lack of randomized controlled studies comparing the benefit (both for intraoperative clinical outcomes and for 30-day postoperative recovery) to the risk of TEE in noncardiac surgery [6], there is a large volume of observational evidence to suggest a vital role of TEE in this setting [8–11, 20]. For these reasons, and possibly because of diminishing use of pulmonary artery catheters, anesthesia providers have made increasing use of TEE as a real-time dynamic monitor to guide resuscitation and optimize perioperative hemodynamic interventions in noncardiac surgery patients [5, 8]. Despite this fact, a
relatively recent AANA survey showed that only 20–25% of CRNAs incorporate TEE in their clinical practice [12].

One reason for this low prevalence is likely the lack of adequate TEE training in nurse anesthesia education. A 1-day combined didactic and hands-on training in focused transthoracic echocardiography for anesthesia and critical care physicians (not CRNAs) has been shown to correlate with improvement on a multiple-choice test [21], a testing modality that fails to assess higher order critical thinking and correlates poorly with competence [22, 23]. There is even less-convincing data in the nurse anesthesia population that similar workshop training positively impacts clinical performance. Shields and Gentry studied two cohorts of nurse anesthesia students and showed that the group trained in basic TEE with a HeartWorks simulator in-person performed better than a comparable group who underwent web-based training [24]. Unfortunately, this latter investigation does not help address the question as to whether a relatively short TEE workshop can provide an effective basis for use of focused rescue TEE by novice nurse anesthetists in a clinical setting since: (1) the study cohort consisted of first year students with incomplete didactic foundations; (2) both student groups in the study performed poorly (the higher scoring group averaged 69% in their post-course evaluation); (3) the training occurred over four weeks; and (4) outcome parameters relied on multiple-choice testing. As such, although a workshop for CRNAs that can provide beginning expertise in TEE image acquisition and interpretation is needed, it is important initially to establish the feasibility and efficacy of any such planned endeavor.

We chose to study a workshop designed to teach focused rescue TEE because of its relative lack of complexity and significant value in patient resuscitation during noncardiac surgery [4, 8]. Hypothetically, desired aspects of such a workshop include:

- **Concentrating on the practical aspects of rescue TEE.** For example, since focused rescue TEE is a qualitative process, the details of quantitative TEE data collection largely can be avoided. Furthermore, most issues related to significant hemodynamic instability (e.g., hypovolemia, impaired contractility, vasodilation, tamponade, etc.) do not require a finely detailed understanding of cardiac anatomy, and as such, the didactic component of the workshop should assume a basic knowledge of this subject and only focus on such information when it is relevant to the goal of image acquisition and interpretation of intraoperative cardiovascular perturbations.

- **Teaching a limited number of TEE views as part of a focused rescue protocol.** Most perioperative issues benefiting from rescue TEE in noncardiac surgery can be addressed with four TEE views (TG MP SAX, ME 4C, ME 2C, and ME LAX views). Teaching a larger subset of the 28 comprehensive views [25] can be confusing and intimidating. This is consistent with a focused rescue TEE protocol recently advocated by Staudt and Shelton for noncardiac surgery patients [4]. The latter protocol involved five views and used a ME Bicaval and Ascending Aorta views rather than a ME 2C view.

- **Using an uncomplicated algorithm to guide diagnosis of major hemodynamic problems.** Since a normal examination (or possibly a hyperdynamic presentation consistent with vasodilation) or hypovolemia were the findings in approximately 60% of rescue TEE studies performed for noncardiac surgery patients [4], and working recall of the protocol details is important for real time
responses to intraoperative crises often under stressful circumstances that may impair memory retrieval [26], this algorithm should be as streamlined as much as possible. More involved echocardiographic protocols for preoperative assessment of high-risk patients represent expert approaches, but they likely are too complex for routine use by novices [27, 28]. Furthermore, while greater than one diagnosis is sometimes possible (e.g., refractory hypotension due to hypovolemia in a patient with LV dysfunction), such situations are less common (an example of Occam’s razor). Also, it should be emphasized that unlike nonoperative TEE, perioperative TEE is not usually performed just at one point in time (a hemodynamic “snapshot”), but rather consists of viewing sequential images after interventions are performed. As such, repeated application of this algorithm to the same patient at successive times is important, and such use should be encouraged.

The present study utilized the aforementioned elements in its design. A basic familiarity with cardiac anatomy, physiology, and pathophysiology was assumed, and didactic sessions focused largely on the “how to” of TEE performance and provided a practical guide to TEE image analysis. Although 12 TEE views initially were discussed in the didactic curriculum, only four views were emphasized and described in detail as part of image acquisition and interpretation to address focused rescue TEE issues. The algorithm employed with these views (Fig. 4) started with a single view (TG MP SAX) and used one or more of the remaining three views for confirmation of the diagnosis. This protocol for initial focused rescue TEE is comparable to a simplified version of other recommended approaches [29], employing views that usually are relatively easy to acquire. Given the limited number of views mastered for focused rescue TEE in this process, workshop-trained nurse anesthetists should understand the importance of requesting assistance when additional views and/or expertise may be useful.

Possibly related to these design considerations, participants in this small-scale study performed very well. Like the cohort in Shields and Gentry’s study [24], these nurse anesthesia students had no previous exposure to TEE, and in this regard, they were reasonable surrogates for many CRNAs in practice. Unlike that previous study cohort, however, the mean score (for all scenarios) for all students tested in the present investigation on a simulation-based exam of image acquisition and interpretation associated with hypothetical rescue TEE scenarios was well-above passing: 95%. There were only 6/70 (9%) occurrences when students either failed to acquire an appropriate image or misinterpreted an image (mostly the latter) i.e., 91% of the time, students acquired and interpreted images correctly within three minutes. Also, although our specific evaluation process has not been verified, simulation-based exams as employed in the current workshop test the third level of Miller’s pyramid model of competence (“shows how”) (Fig. 1), and as such, they provide an improved assessment of workshop goal effectiveness compared with standard multiple-choice exams [17, 23].

Uniformly, these nurse anesthesia trainees believed that both the didactic and simulation components of the workshop were valuable educational experiences that prepared them for common significant perioperative adverse events (hypovolemia, hypotension, and myocardial ischemia). Their perception that they learned to acquire and interpret specific rescue TEE views accurately is consistent with their simulation-based evaluation scores. Importantly, all the students (14/14) also believed that the workshop
had “de-mystified” TEE and all students strongly agreed (12/14) or somewhat agreed (2/14) that they will seek TEE privileges in their future clinical practice.

**Limitations**

This investigation involved a small cohort and should be repeated on a larger scale. Although the immediate results of the workshop suggest that it was effective, the study did not assess retention of content, and future investigations could be designed to address this element. We also did not include an assessment in the clinical setting with practicing CRNAs, which represents the ultimate goal of this type of workshop (the top level of Miller’s pyramid of competence).

**Conclusions**

The present study suggests that an effective 2-day workshop for nurse anesthesia providers to teach acquisition and interpretation of appropriate views during focused rescue TEE in noncardiac surgery is achievable predicated on competency-based evaluative findings and survey results. The critical design elements for this workshop include concentrating on practical rather than esoteric aspects of TEE performance, teaching a limited number of TEE views as part of a focused rescue protocol, and using an uncomplicated algorithm to guide diagnosis of major hemodynamic problems. One of the weaknesses of the current workshop construct, however, is that there is a significant teaching burden on the sole instructor (21 hours for 14 students). This burden could be reduced significantly with the introduction of additional instructors, especially for the 1:1 simulation sessions. In addition to making use of multiple instructors, future studies should examine the feasibility and efficacy of similar endeavors for larger cohorts, including practicing CRNAs desiring to achieve focused rescue TEE competence.

**Abbreviations**

2C
two chamber
2D
two dimensional
4C
four chamber
AANA
American Association of Nurse Anesthesiology
AR
augmented reality
CRNA
certified registered nurse anesthetist
LAX
long axis
LV
left ventricle
ME
mid-esophageal
MP
mid-papillary
RV
right ventricle
SAX
short axis
TEE
transesophageal echocardiography
TG
transgastric
US
ultrasound

Declarations

Ethics approval and consent to participate

The study was carried out under the auspices of the Oregon Health & Science University Institutional Review Board who determined that the investigation was not research involving human subjects and provided a letter stating as such (IRB Study #00024517). All methods were performed in accordance with the ethics guidelines outlined in the Declaration of Helsinki.

Consent for publication

Consent for reproduction of Figure 3 in published format was obtained from CAE Healthcare, Inc.

Availability of data and materials

The raw data sets generated and analyzed during the current study are not publicly available due to concerns related to participants' confidentiality but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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**Authors’ contributions**

Study design: All authors. Data collection: B.S. Data analysis: All authors. Writing manuscript text: All authors. Review and approval of final manuscript: All authors.

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None

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**References**


Tables

Table 1 and 2 are available in the Supplementary Files section.
Figure 1
Miller’s Pyramid for Clinical Assessment. Higher levels of the pyramid model are associated with increasing professional competence which can be assessed by different means. For example, “knows” can be evaluated by multiple choice questions, “knows how” by oral examination, “shows” by simulation performance, and “does” by clinical performance.
Figure 2

Curriculum for the Didactic Sessions I and II of the TEE Workshop. See text for discussion. TEE = transesophageal echocardiography; SAX = short axis; SWMAs = segmental wall motion abnormalities; LVOT = left ventricular outflow tract.
Figure 3

Transesophageal Echocardiography (TEE) Simulator (CAE Healthcare Vimedix). Trainer includes mannequin torso, TEE probe, and laptop with a split screen demonstrating simultaneous ultrasound and augmented reality displays. External motion tracker is not shown. See text for details. From CAE Healthcare with permission.
Figure 4

Focused Rescue TEE Algorithm. See text for discussion. TEE = transesophageal echocardiography; LVEDV = left ventricular end-diastolic volume; LVESV = left ventricular end-systolic volume; SWMA = segmental wall motion abnormality.

* includes ischemic cardiomyopathy

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.pdf
- Table2.pdf