Effect of Simulation Training on Cognitive Performance Using Transesophageal Echocardiography

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Simulation is used in anesthesia training to reinforce didactic learning. The authors hypothesized that knowledge acquisition in the use of transesophageal echocardiography (TEE) could be accomplished better through the use of a simulator than with online or web-based learning. A total of 71 student registered nurse anesthetists were randomly assigned to either web-based or simulator-based TEE training. Using the same rubric, each group was instructed to use 11 views to identify 12 different cardiac structures. In addition, 15 cardiac abnormalities ("pathologies") were identified through either the simulator or a web-based link. The effect of the interventions were measured using a video-based (ExamSoft) assessment to validate improved knowledge of cardiac structures, recognition of ultrasonographic views, and identification of cardiac pathology. Although both groups demonstrated significant improvement, students who trained with the simulator scored higher than the web-based group, 69.4 vs 42.3 (P < .01). Scores were compared using the Mann-Whitney test and 2-tailed t tests. Implementation of TEE training using either modality improved TEE-related knowledge, and both are recommended as a supplement to conventional didactic training.

Keywords: Anesthesia, simulation, transesophageal echocardiography.

Transesophageal echocardiography (TEE) is recognized as an advanced hemodynamic monitor with utility during cardiac and noncardiac surgery.[1-6] Basic perioperative TEE provides relevant information for vascular, orthopedic, liver transplant, urologic, and neurologic surgery.[7,8] A diversity of assessments may be made, including biventricular function, heart valve competence, filling/preload status, and "rescue" uses such as pericardial effusion and pulmonary embolus.[9-12] Use of TEE by nurse anesthetists has been reported in a variety of settings and uses, including cardiac and noncardiac surgery.[13-17] A 2018 survey by the American Association of Nurse Anesthetists (AANA) demonstrated that 20% to 25% of respondents use TEE in their clinical practice.[18]

In 2019 the AANA recommended monitoring and interpretation of transesophageal echocardiography as a special clinical privilege for nurse anesthetists (special request for scope of practice and clinical privilege).[19] Training for TEE use consists of lectures/presentations, individual study, computerized/web-based simulation, mannequin-based simulation, and operating room practicum. Recommended cognitive skills include knowledge of anatomical structures, TEE windows, and various cardiac structural abnormalities (hereafter called pathologies).[11,20] To assess the utility of TEE simulation options, the authors compared online and simulator instruction by assessing posttraining knowledge of cardiac structures, TEE/ultrasonographic windows and cardiac pathologies, compared with pretest knowledge.

Materials and Methods

After obtaining institutional review board approval, 71 first-year student registered nurse anesthetists consented to participate in the study. All first-year students were to receive both online and simulator-based simulation as part of the curriculum such that there was no benefit or penalty for abstaining or participating. Exclusion criteria included previous cardiac anesthesia or TEE clinical experience, current or previous cardiac anesthesia rotation, or failure to complete the pretest or posttest knowledge assessment. Only first-year students were recruited to maintain consistency in clinical and academic experience. On entering the study, each student undertook a video-based pretest (ExamSoft) designed by a member of the school's faculty experienced in clinical use and instruction of TEE (Figure 1).

The pretest was composed of 25 multiple-choice questions covering cardiac anatomy, TEE ultrasonographic windows, and cardiac pathology. The questions were based on the Toronto General Hospital anesthesia department's Perioperative Interactive Education (PIE) library of assessment questions available on its website (pie.med.utoronto.ca/TEE/index.htm) and HeartWorks pathology modules (Inventive Medical Ltd, London, UK; now owned by MedaPhor Group). The pretest was validated

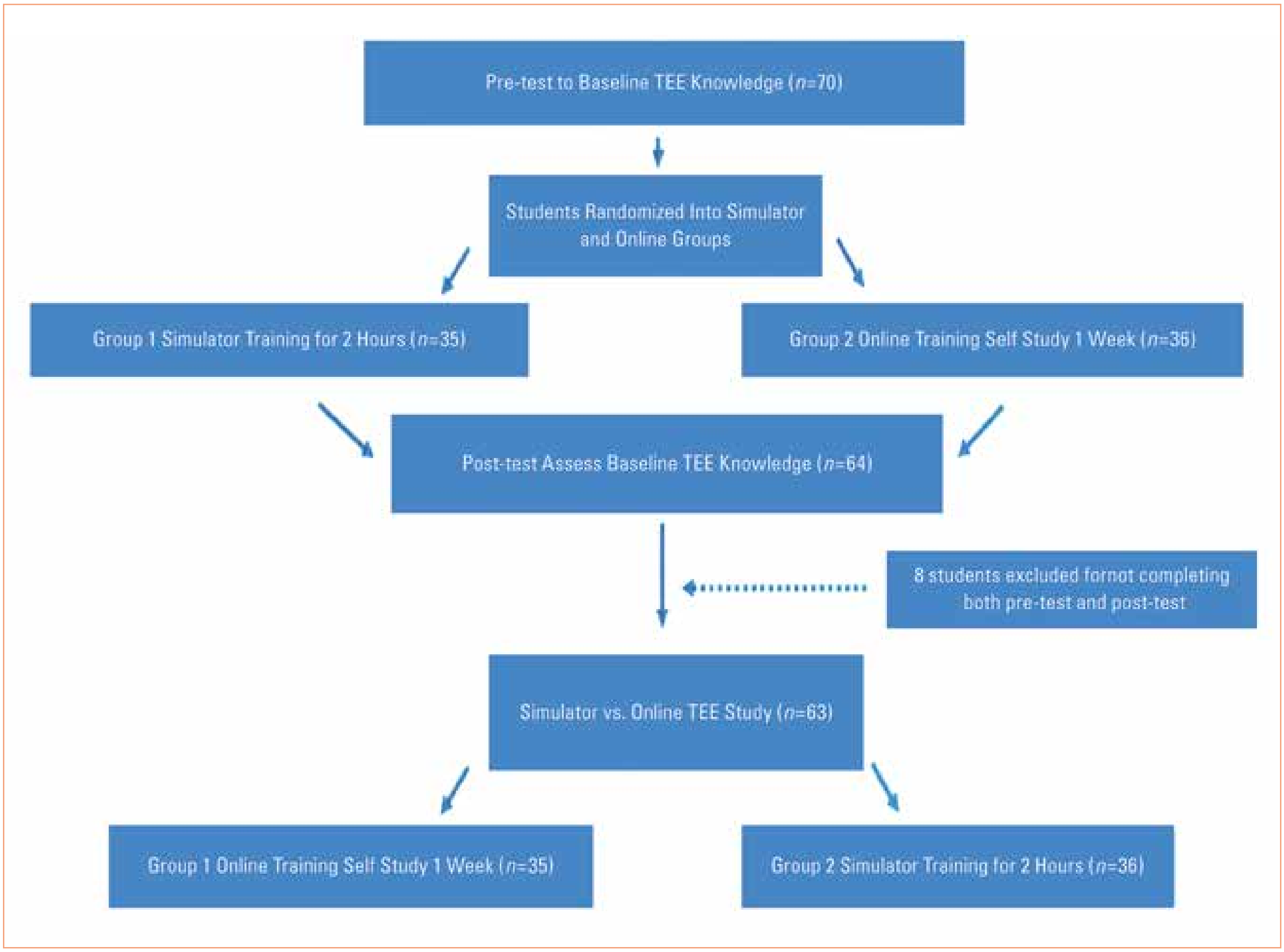

Figure 1. Process for Transesophageal Echocardiography (TEE) Study

in a pilot study the previous year during TEE training for a similar cohort. The students were then randomly assigned by the school's simulation coordinator to receive either simulator-based simulation (HeartWorks simulator, Inventive Medical Ltd) or online simulation using video links to TEE windows, cardiac structures (PIE), and cardiac pathologies through King Abdullah Medical Center, Makkah, Saudi Arabia. Before the start of the study, each group received a standardized rubric focusing on learning objectives specific for its respective simulation but identical in content (Table).

The HeartWorks simulator consists of a torso with a head and mouth, with a reproduction of a functional TEE probe interfaced with a computer-based application featuring more than 15 pathologies (Figure 2). The system is capable of generating thousands of TEE views depending on insertion depth, anteflexion/retroflexion, clockwise or counterclockwise rotation, lateral tilt, rotation, and omniplane. In this manner the simulator may be used to obtain all 11 views used in basic perioperative TEE.[11] The 2-dimensional view is displayed along with either a navigational view with ultrasound plane or a 3-dimensional view of the heart and its structures (Figure 3, top). In this manner, spatial relationships are demonstrated and cardiovascular anatomy, TEE windows, and pathology recognition are distinguished. For the purposes of this simulation, each group of 8 participants were able to visualize each TEE examination and probe manipulation while simultaneously viewing ultrasonographic windows, navigation, and 3-dimensional sections on two 152.4-cm (60-in) screens. Using a different pathology for each examination, the students performed 2 basic TEE studies such that 16 examinations were performed during the simulation.

Participants were randomly assigned to either online or simulator groups by the school's simulation coordinator. All students were instructed not to discuss simulation content or engage in study outside the content outlines provided during their simulation. Any student involved clinically with perioperative TEE during the study was excluded. The online simulation group was assigned the same ultrasonographic windows and anatomy as listed on the rubric using the Toronto General Hospital PIE website (Figure 3, bottom). Comparable to the simulator, the site incorporated interactive 3-dimensional images and videos to translate knowledge of anatomy and window

Category	Objective to be accomplished during simulation
Cardiac anatomy	Identifies structures: • Left atrium (appendage), ventricle including anterior/inferior wall • Right atrium, septum, and ventricle • Aorta (arch, ascending, descending) • Left, right, and main pulmonary arteries • Superior and inferior vena cava • Mitral and tricuspid valves including papillary muscles and leaflets • Aortic and pulmonic valves including aortic valve cusps
TEE windows	Identifies windows: • Midesophageal 4-chamber and 2-chamber views • Midesophageal long axis, bicaval and aortic valve short-axis views • Midesophageal descending aorta short- and long-axis views • Midesophageal ascending aorta short- and long-axis views • Midesophageal right ventricular inflow-outflow view • Deep transgastric midpapillary short-axis view
Valve pathologies	Identifies pathologies: • Aortic stenosis and regurgitation; mitral and tricuspid regurgitation • Atrial septal defect, pulmonary embolus, abnormality of LV wall motion • Aortic dissection, pericardial effusion, hypovolemia/euvolemia • Left and right ventricular failure

Table. Simulation Objectives

Abbreviations: LV, left ventricular; TEE, transesophageal echocardiography.

acquisition. In addition to the imaging, a navigational tool was used to improve the students' ability to acquire the windows and become better oriented to spatial relationships. To demonstrate TEE views of different pathologies, the researchers provided links to web-based videos matching those in the learning rubric available on the King Abdullah Medical Center anesthesiology website.[21] The short videos compared normal TEE anatomy with the same pathologies used with the simulator.

The TEE simulation training for each group took place over a 4-week period, with a group of 8 students trained by simulator and a group of 8 students trained by online simulation each week. Following the training period an unannounced video-based posttest was administered (ExamSoft) with the same content as the pretest. After the examination the groups underwent additional TEE training using the other simulation so that both simulator and conventional training was received by all participants (see Figure 1).

Results

Sixty-three of the 71 students in 8 cohorts participating in TEE sessions entered the study, with 31 in the simulator group and 32 in the online group. One student did not complete the pretest and 7 did not complete the posttest, such that 8 were excluded. The groups' performances on the posttest were compared with their pretest results using Mann-Whitney tests with $P < .01$ considered significant. Pretest scores were similar in each group, averaging 33.5 (SD = 9.57) for the online group and 35.6 (SD = 11.14) in the simulator group. No significant differences were noted for individual categories such as knowledge of anatomy, TEE windows, and cardiac pathologies. Posttest scores were significantly higher in both groups, averaging 42.3 (SD = 11.85) in the online group and 69.4 (SD = 17.93) in the simulator group ($P < .01$).

The groups' improvement after training was compared using Wilcoxon paired *t* tests with $P < .01$ considered significant. Posttest scores were significantly higher (Figure 4) in all 3 cognitive categories in the simulator group compared with the online group ($P < .01$). Changes in pretest and posttest scores were higher in the simulator group than in the online group ($P < .01$). Changes in individual categories (knowledge of anatomy, TEE window recognition, and cardiac pathologies) were all significantly higher in the simulator group ($P < .01$).

Discussion

The components of basic TEE training include knowledge of cardiac structures, TEE windows, and cardiac pathology.[11] Lecture and readings are conventional methods used in TEE training, but image interpretation, navigation, and structure recognition are limited in availability. The results of this study demonstrate the benefit of simulator and online training in teaching TEE image interpretation, image recognition, and cardiac pathology identification. In this study both online and simulator training offer a navigational and 3-dimensional compo-

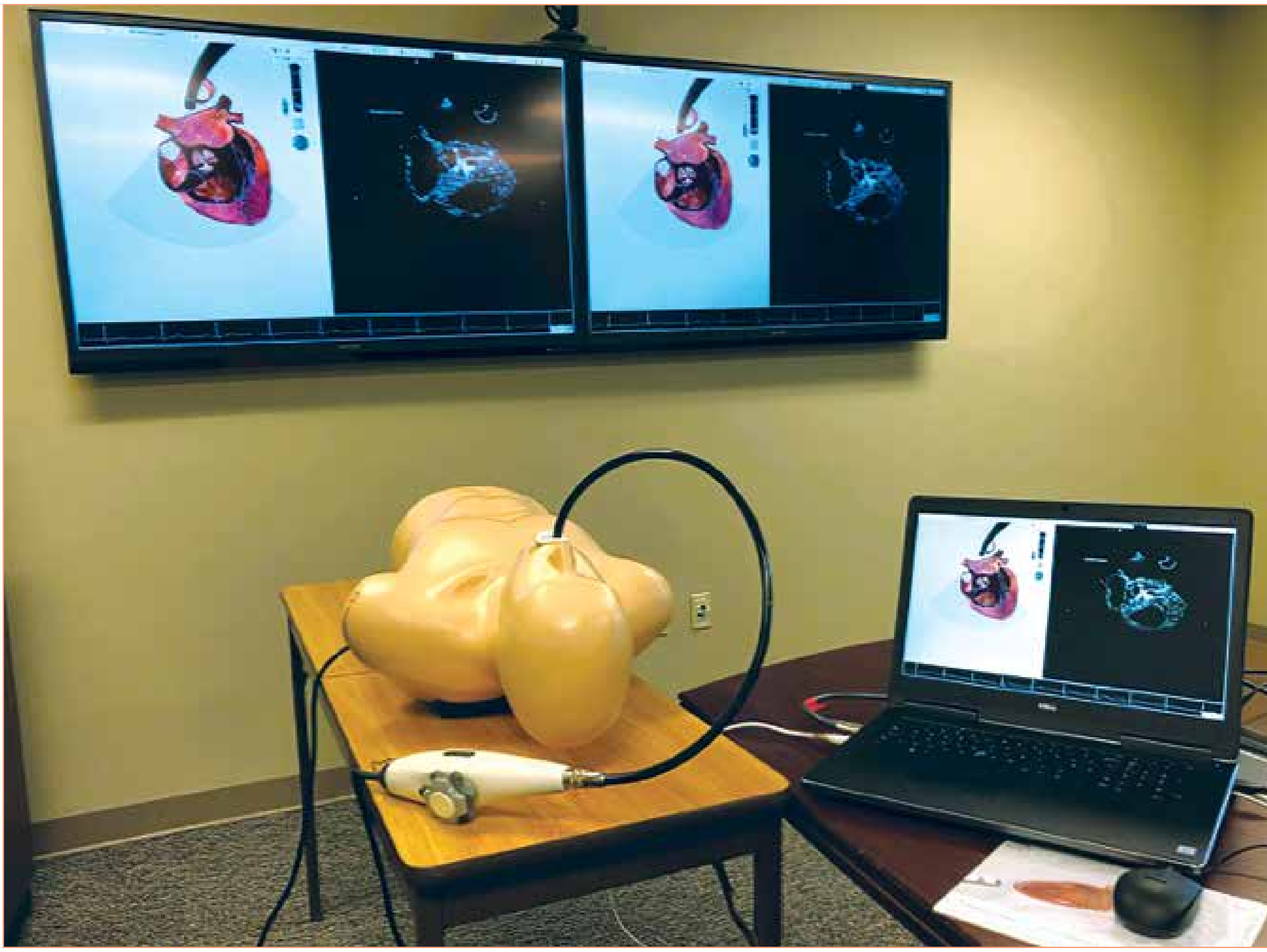

Figure 2. Transesophageal Echocardiography Simulator (HeartWorks)

nent while significantly improving cognitive skills.

Transesophageal echocardiography is invaluable in decision making during cardiothoracic surgery and may be useful in guiding intraoperative management to restore cardiopulmonary stability during surgery.[3,5,7,9] To this end, basic TEE training has evolved across the spectrum of specialties, including perioperative anesthesia, emergency department, obstetrics, and the intensive care unit.[22,23] The American Society of Anesthesiologists and the American Society of Echocardiography have established functional levels of TEE ranging from basic perioperative TEE to interventionalist, with focused transthoracic echocardiography part of 36% of surveyed residency programs.[11,12,23,24] The Society of Cardiovascular Anesthesiologists has called for basic competency in TEE in all anesthesiologist residency training along with transthoracic echocardiography.[25] Transesophageal echocardiography has been used and reported clinically in nurse anesthesia as well, and the AANA recognizes TEE to be a special clinical privilege for nurse anesthetists.[19]

Previous studies have examined the role of simulator training in different settings in improving TEE knowledge and TEE performance. Image acquisition and identification of cardiac structures was improved with didactic and simulator training in emergency medicine physicians.[22] Cardiac anatomy and ultrasonographic window identification was demonstrated to be superior with simulators compared with operating room–based training.[26] Other comparisons between didactic and simulation demonstrated similar results in anesthesia residents, anesthesia fellows, anesthesiologists, internal medicine physicians, intensive care unit physicians, and medical students.[27-42] Comparable to transthoracic echocardiography, training using a TEE simulator was not inferior to training in the operating room.[43,44] This study demonstrated that, although knowledge was significantly improved using online resources, simulators improved performance to a greater extent than did online simulation in 3 separate cognitive categories.

A potential limitation of this study was the sample population of first-year student registered nurse anesthetists. First-year students have very limited exposure to cardiac surgery and TEE, as well as limited didactic training. However, in selecting first-year students, bias and previous TEE experience was eliminated and created

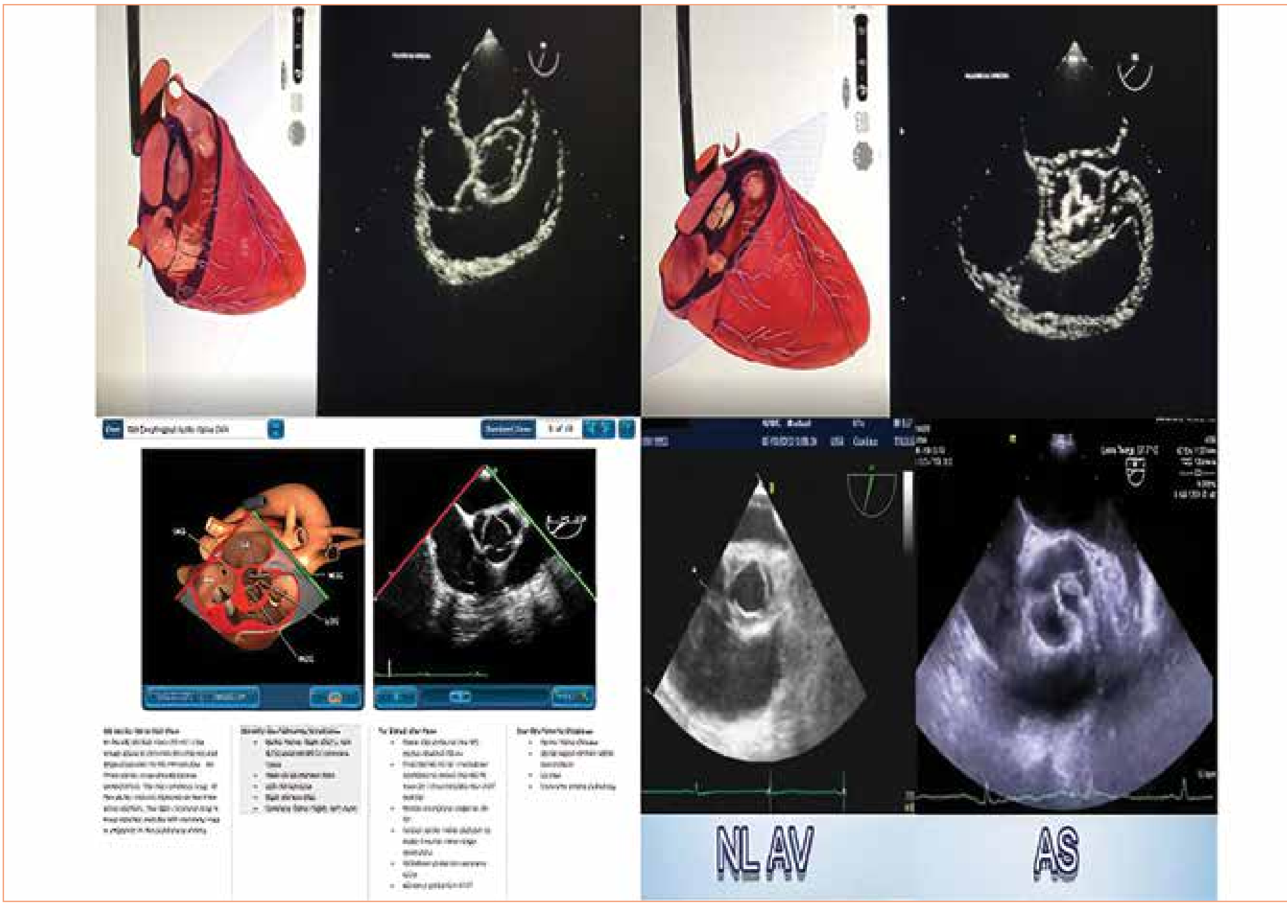

Figure 3. Online and Simulator Views of Aortic Stenosis
Top, Simulator views of normal aortic valve (left) and aortic stenosis (right). Bottom, Online views of normal aortic valve (NLAV, left side of right image) and aortic stenosis (AS, far right).

a more homogeneous sample. Different intervals existed between training and the posttest (between 1 and 4 weeks) such that retention may have been inconsistent. Although this period was uniform between groups, the assessment was performed within a month of training, so there is no account for any potential knowledge decay. Simulation offers many advantages in clinical education, but several limitations exist. Clinical conditions can be reproduced only to a limited extent, including TEE images and clinical presentations. Similar to airway simulators, mannequin anatomy is not identical to human anatomy, such that anatomical variation and mechanical skills may not be as transferrable.[45,46] Also, the use of gain and depth for image optimization is not available with current simulators. However, simulators and simulation offer the benefit of probe manipulation with less time constraint and better teaching conditions.[47]

Future studies should focus on clinical outcomes and an integrated curriculum on knowledge acquisition. Along with improved cognitive performance, image acquisition and interpretation in the operating room should be enhanced. An ideal follow-up to this study would be to assess the impact on the ability to recognize structures, windows, and pathology in the operating room and intensive care unit. Additionally, image optimization with "knobology" and probe manipulation was not evaluated and should be assessed in the clinical setting. Additional studies would compare this translation, as well as the effect of probe manipulation. A more realistic curriculum would involve online study before TEE simulator use, as well as a more extensive training period. Because TEE simulation has been demonstrated to discriminate between expert and novice competencies, it may be used to demonstrate competence in perioperative echocardiography.[48] The true value of intraoperative TEE is its use in decision making when used as a cardiopulmonary monitor, such that any measurement of outcomes would involve specific assessments of biventricular function, heart valve competence, preload, and "rescue" component identification.

In summary, the current and future role of TEE in the modern operating room dictates a thorough understanding of cardiac anatomy, pathology recognition, and TEE ultrasonographic windows. This study was designed to test and compare the ability of TEE training modalities to improve TEE knowledge. Both modalities improved scores significantly on a validated examination and demonstrate the

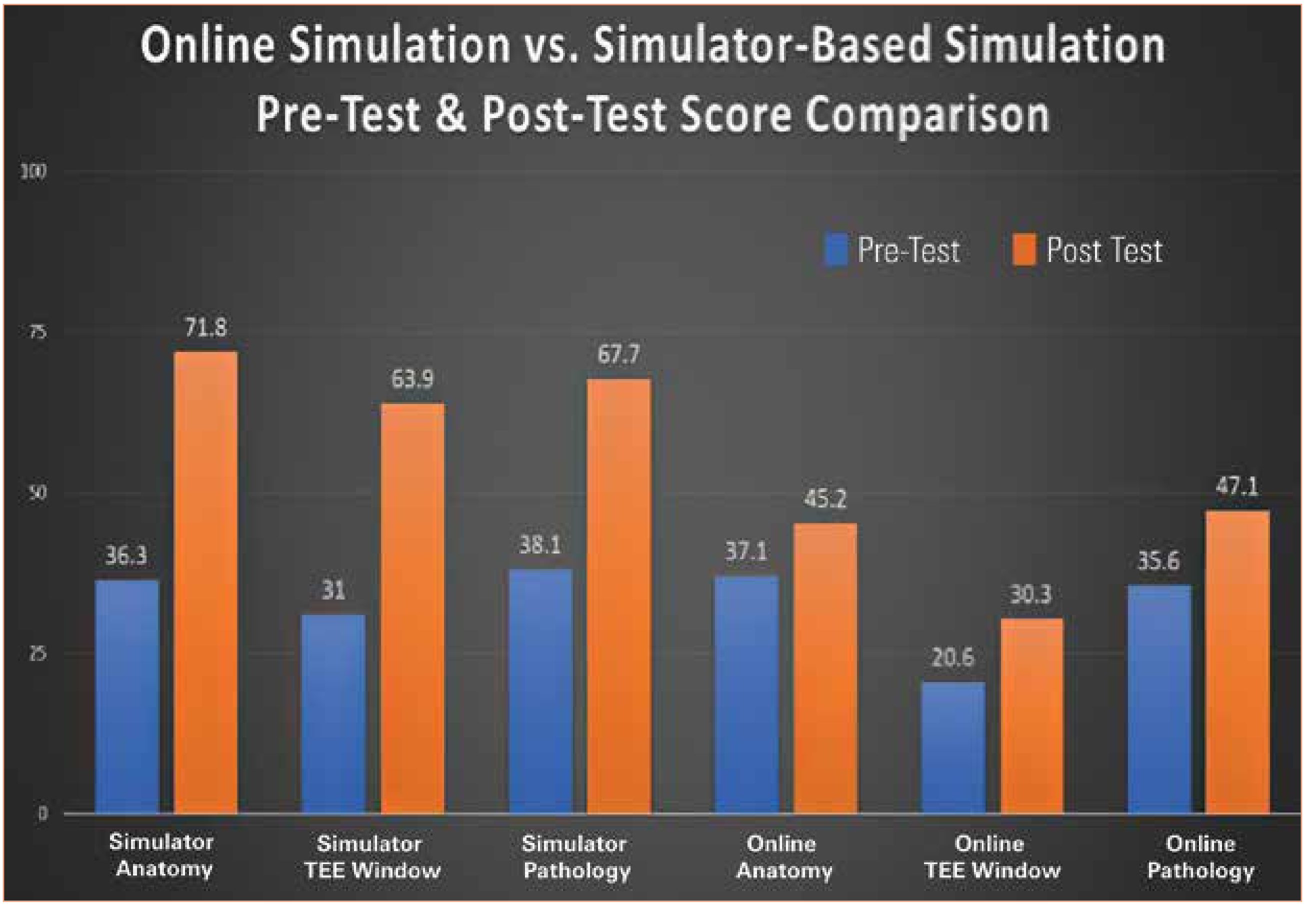

Figure 4. Simulator versus Online Comparison of Pretest and Posttest Scores
Abbreviation: TEE, transesophageal echocardiography.

utility of simulation in TEE training for nurse anesthetists.

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