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Original Research

The Success of a Simulation-Based Transesophageal Echocardiography Course for Liver Transplant Anesthesiologists

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Introduction

Perioperative management for orthotopic liver transplantation (OLT) involves caring for medically complex patients during a high-risk surgical procedure. Transesophageal echocardiography (TEE) is increasingly used for intraoperative management during OLT. The American Society of Anesthesiologists and Society of Cardiac Anesthesiologists recommend TEE as an intraoperative monitor when severe hemodynamic changes are anticipated.[1] Data from a survey in 2018 indicated that liver transplant (LT) anesthesiologists are using TEE with increasing frequency[2]; however, proficient TEE use requires skill and knowledge to accurately assess the hemodynamic status and guide clinical management. Although the Society for the Advancement of Transplant Anesthesia recommends that LT anesthesiologists obtain certification with the National Board of Echocardiography (NBE) to attain the essential skill and knowledge, NBE certification rates remain below 50% and only half of centers using TEE for OLT have a team member with cardiac fellowship.[2,3] Given NBE certification is difficult and TEE is commonly used regardless of certification status, calls for on-site practical training have been made.[2] At our institution, a desire to enhance TEE utilization prompted a request for the development of a TEE workshop by our LT anesthesiologists.

Although not meant as a stand-in for formal NBE certification, this simulation-based learning (SBL) course can serve as a model to enhance TEE use for LT anesthesiologists who are on the way to basic certification or who are unable to obtain NBE certification due to existing barriers.

Materials and Methods

This course resulted from a quality initiative to improve LT anesthesiologist TEE knowledge and skill. The initiative resulted in a voluntary 4-hour SBL course using the Vimedix TEE simulator (CAE Healthcare, Montreal, Canada) at our institution's simulation center. The authors were confident a 4-hour timeframe would allow for achieving the provided learning objectives and has been shown to be adequate for retention of a focused TEE protocol in other contexts.[4]

The 2 instructors were fellowship-trained cardiac anesthesiologists with advanced certification for perioperative TEE and either LT experience (JMC) or dual certification with comprehensive adult echocardiography (JAN). Both instructors have 3 years of experience training learners in TEE simulation and developed the teaching plan by consensus before the 4-hour course. A total of 15 LT anesthesiologists without NBE certification attended the course. Three critical care anesthesiologists also attended.

Learning objectives focused on basic image acquisition, relevant anatomy, hemodynamic calculations, and pathology germane to the LT period (Figure 1). The 11 TEE views that were taught included those recommended by the American Society of Echocardiography for a basic perioperative TEE examination, with the exception of the midesophageal ascending aorta long-axis.[5] Instead, we included a nontraditional transgastric inferior vena cava and hepatic vein view to evaluate for caval anastomosis complications.[6] Hemodynamic calculations included right ventricular systolic pressure, stroke volume, stroke volume index, cardiac output, and cardiac index. The course design is outlined in Figure 1. The 4-hour course included 90 minutes of didactic lectures; 30 minutes were provided via recorded video to be reviewed before the course. A 60-minute didactic lecture was provided on the day of the course reviewing pathology germane to OLT with high-volume imaging review. This was conducted in person to allow for real-time discussion with questions and answers.

To assess for improvement in knowledge, the anesthesiologists completed 20-question multiple-choice assessments before and after the course (Table 1). The questions asked were either text based or required TEE image interpretation. The learning objectives served as the basis for the knowledge assessment content. Two additional cardiac anesthesiologists with advanced certification for perioperative TEE and LT experience (AMK and REH) independently reviewed and agreed on the knowledge assessment content. A paired

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t-test was used when data were considered normally distributed, and Wilcoxon Signed Rank tests were performed for nonnormally distributed data; a value <.05 was considered significant. Nonnormally distributed data were reported as median with interquartile ranges. To assess for improvement in skill, the anesthesiologists performed a basic TEE examination in a high-fidelity setting with simulated vital signs consistent with the simulated TEE pathology provided. This setting was intended to represent an operating room environment similar to a live OLT. LT anesthesiologists also answered survey questions before and after the course assessing their comfort level with TEE. Anesthesiologists passed the simulated examination if they correctly identified the pathology as assessed by the course instructors in keeping with prior studies evaluating competence in focused cardiac ultrasound.[7]

Anesthesiologists who completed the course were eligible to receive 4 hours of continuing medical education (American Medical Association Physician's Recognition Award category 1) and Maintenance of Certification in Anesthesiology credits. Institutional review board permission for data gathering was obtained.

Results

Overall 17 of 18 anesthesiologists completed the course (94.4%). The median baseline knowledge assessment score was 55.0% (37-70). Of the 17 anesthesiologists who completed the course, 16 completed the posttest and survey. The median postcourse knowledge assessment score improved to 95% (94-100) ($P < .001$). All anesthesiologists were able to identify the TEE pathology during high-fidelity simulation. Survey responses yielded significant median score improvement in all areas assessed using a 5-point Likert scale (Table 2).

Discussion

TEE enhances the anesthesiologist's ability to care for the complicated patient presenting for OLT. In addition to basic assessment of cardiac chamber size and function, which is useful during the hemodynamic changes associated with OLT, TEE has been used to diagnose and aid in the treatment of a wide variety of intracardiac pathologies during OLT.[3] Further, abnormal intraoperative TEE findings have been reported in up to 88% of patients during OLT.[8] Pathologic findings reported during OLT include intracardiac thrombus, pulmonary embolus, acute ventricular dysfunction, atrial level shunting, pericardial effusion, left ventricular outflow tract obstruction with systolic anterior motion of the mitral valve, and stress-induced cardiomyopathy.[8,9] Intraoperative TEE also has been used to identify caval anastomosis complications and guide surgical decision making.[10,11]

To date, no outcome-based study has demonstrated improvement in outcomes; however, survey data show that among current LT anesthesiologists nationwide, 83.9% agreed or strongly agreed that TEE gives information unavailable by other modalities, and only 10.7% disagreed with the statement "TEE in LT gives information that changes outcome."[2] In the same survey that captured centers nationwide accounting for more than half the OLT volume in the country, support existed for pathways to NBE certification; however, there was an equal amount of support among LT anesthesiologists for on-site TEE training, suggesting potential value in training and education pathways in addition to NBE certification.

Our baseline knowledge assessment and survey results confirm there is need for further TEE education for LT anesthesiologists. Traditional perioperative learning methods for practicing physicians consists of on-the-job training in the operating room. SBL models differ by providing a safe learning environment to develop the technical skills to become proficient with TEE. When paired with expert instruction, this learning method can improve TEE proficiency and knowledge.

SBL for TEE training is now common among residency and fellowship training programs. Compared with traditional hands-on training, cardiology fellows who completed simulator training had improved examination proficiency and comfort performing TEE.[12] SBL resulted in significantly higher knowledge and practical scores for novice anesthesiology and critical care trainees compared with online electronic and traditional operating room teaching.[13] There are, however, limited data on the role of SBL for TEE training outside of academic training programs. Arntfield et al.[4] reported the success of a mixed didactic and SBL TEE course for emergency physicians. Following a 4-hour workshop, learners were able to successfully complete a focused TEE protocol, with retention at 6 weeks. A 1-day course for critical care TEE reported significantly improved knowledge and image acquisition scores among critical care physicians.[14] To the authors' knowledge, our paper is the first report of a TEE SBL model for LT anesthesiologists.

Following the SBL course, knowledge assessment scores significantly improved. In addition, all areas assessed with surveys yielded significant improvement. This model was efficient and provided value to the physician learner. Further, this success raises questions on the potential expanded role of SBL for TEE continuing medical education.

Although agreement exists that TEE use may improve clinical decision making during OLT, attaining TEE knowledge and skill to guide perioperative management is complex; 150 TEE examinations must be performed or a combination of 150 performed and reviewed to obtain basic NBE perioperative transesophageal echocardiography certification focusing on 11 views.[5] However, a study published in 2020 reported 92% of pathological findings most commonly seen with TEE during OLT could be detected using a 5-view examination, suggesting a more limited OLT-specific examination may be beneficial.[15] The 5 views reported included the midesophageal 4-chamber, long-axis, bicaval, right ventricular inflow-outflow, and hepatic vein views. The current SBL model could therefore be beneficial for LT anesthesiologists as part of a more comprehensive program for those seeking NBE certification, for LT anesthesiologists unable to obtain certification, or could be adapted as part of training in other perioperative arenas including the intensive care unit or for focused assessment of the hemodynamically unstable patient under the care of a general anesthesiologist.

There are several limitations with this single-institution quality initiative

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experience. There was no control group for comparison, follow-up retention assessments have not been performed, and simulated TEE examinations were not timed or scored in a structured format. Given these limitations, our model may not be reproducible. Last, this educational course was not comprehensive for perioperative TEE. Anesthesiologists using TEE for perioperative hemodynamic monitoring should recognize their personal limitations when findings guide clinical management. Although further research is needed, we believe the model of a SBL course specifically tailored for the LT anesthesiologist shows promise as a means to address knowledge, skill, and comfort with TEE.

References

1. Thys DM, Abel MD, Brooker RF, et al. Practice guidelines for perioperative transesophageal echocardiography: an updated report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists task force on transesophageal echocardiography. *Anesthesiology.* 2010;112(5):1084-96.
2. Zerillo J, Hill B, Kim S, et al. Use, training, and opinions about effectiveness of transesophageal echocardiography in adult liver transplantation among anesthesiologists in the United States. *Semin Cardiothorac Vasc Anesth*. 2018;22(2):137-45.
3. DeMarchi L, Wang CJ, Skubas NJ, et al. Safety and benefit of transesophageal echocardiography in liver transplant surgery: a position paper from the Society of Advancement of Transplant Anesthesia (SATA). *Liver Transpl*. 2020;26(8):1019-29.
4. Arntfield R, Pace J, McLeod S, et al. Focused transesophageal echocardiography for emergency medicine physicians-description and results from simulation training of a structured four-view examination. *Crit Ultrasound J*. 2015;7(1):10.
5. Reeves ST, Finley AC, Skubas NJ, et al. Basic perioperative transesophageal echocardiography examination: a consensus statement of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. *J Am Soc Echocardiogr*. 2013;26(5):443-56.
6. Meierhenrich R, Gauss A, Georgieff M, Schutz W. Use of multi-plane transoesophageal echocardiography in visualization of the main hepatic veins and acquisition of Doppler sonography curves. Comparison with the transabdominal approach. *Br J Anaesth*. 2001;87(5):711-7.
7. Gibson LE, White-Dzuro GA, Lindsay PJ, et al. Ensuring competency in focused cardiac ultrasound: a systematic review of training programs. *J Intensive Care*. 2020;8(1):93.
8. Shillcutt SK, Ringenberg KJ, Chacon MM, et al. Liver transplantation: intraoperative transesophageal echocardiography findings and relationship to major postoperative adverse cardiac events. *J Cardiothorac Vasc Anesth*. 2016;30(1):107-14.
9. Dalia AA, Flores A, Chitilian H, et al. A comprehensive review of transesophageal echocardiography during orthotopic liver transplantation. *J Cardiothorac Vasc Anesth*. 2018;32(4):1815-24.
10. 1Aubuchon J, Maynard E, Lakshminarasimhachar A, et al. Intraoperative transesophageal echocardiography reveals thrombotic stenosis of inferior vena cava during orthotopic liver transplantation. *Liver Transpl*. 2013;19(2):232-4.
11. Khurmi N, Seman M, Gaitan B, et al. Nontraditional use of TEE to evaluate hepatic vasculature and guide surgical management in orthotopic liver transplantation. *Case Rep Transplant*. 2019;2019:5293069.
12. Damp J, Anthony R, Davidson MA, Mendes L. Effects of transesophageal echocardiography simulator training on learning and performance in cardiovascular medicine fellows. *J Am Soc Echocardiogr*. 2013;26(12):1450-6.
13. Weber U, Zapletal B, Base E, et al. Resident performance in basic perioperative transesophageal echocardiography. *Medicine (Baltimore)*. 2019;98(36):e17072.
14. Silva Restrepo M, Boivin MA, Kory P, et al. Effectiveness of a transesophageal echocardiography course. *J Intensive Care Med*. 2020;35(11):1148-52.
15. Vanneman MW, Dalia AA, Crowley JC, et al. A focused transesophageal echocardiography protocol for intraoperative management during orthotopic liver transplantation. *J Cardiothorac Vasc Anesth*. 2020;34(7):1824-32.

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Abstract

Introduction: Transesophageal echocardiography (TEE) is increasingly used for intraoperative management during orthotopic liver transplantation. Proficient TEE use requires skill and knowledge to accurately assess the hemodynamic status and guide clinical management. Currently there are no TEE educational tracks specifically focused on perioperative liver transplant management and barriers to obtaining basic certification exist.

Methods: A 4-hour simulation-based learning (SBL) course was provided to improve liver transplant anesthesiologist TEE knowledge and skill. Learners received training and education using a TEE simulator in small groups focusing on basic image acquisition, relevant anatomy, hemodynamic calculations, and pathology germane to the liver transplant period. Knowledge assessment and survey responses were assessed at the beginning and completion of the course. Learners completed TEE examinations with simulated pathology during high-fidelity simulations following the course.

Results: Seventeen anesthesiologists completed the course. The median baseline knowledge assessment score was 55.0% (37-70). The median postcourse knowledge assessment score improved to 95.0% (94-100) ($P < .001$). All anesthesiologists were able to identify TEE pathology during high-fidelity simulation. Survey responses yielded significant median score improvement in all areas assessed using a 5-point Likert scale.

Conclusions: A small group, simulation TEE course delivered over 4 hours can increase knowledge and skill in TEE use for liver transplant anesthesiologists.

Keywords: Transesophageal echocardiography, simulation-based learning, orthotopic liver transplantation, perioperative management, continuing medical education.

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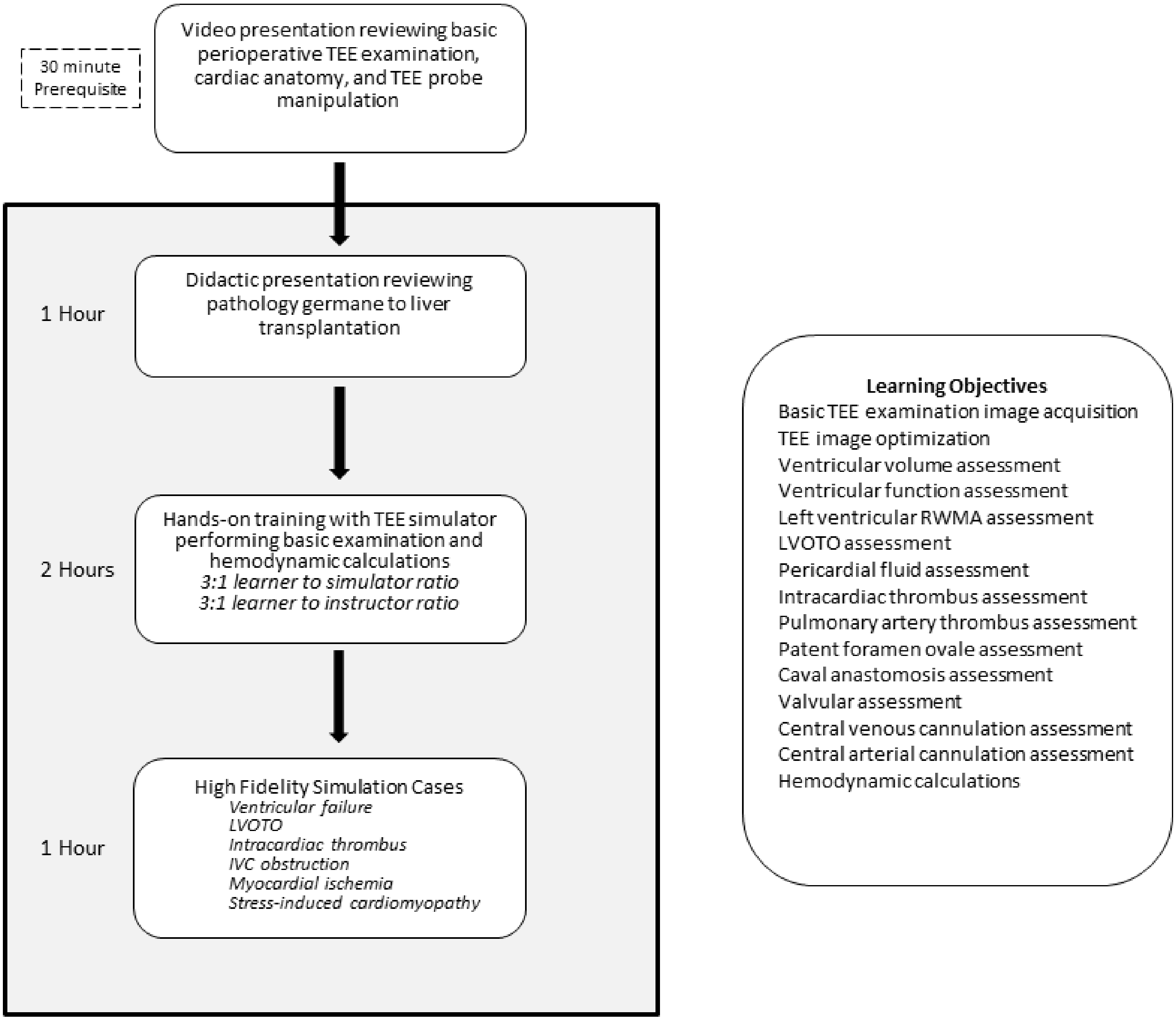
Figure

Figure 1. *Learning objectives and course design. IVC, inferior vena cava; LVOTO, left ventricular outflow tract obstruction; RWMA, regional wall motion abnormalities; TEE, transesophageal echocardiography.*



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Tables

Table 1. *Knowledge Assessment Questions With Multiple-Choice Answers*

Questions	Multiple-Choice Answers
The lower reference value (abnormal) for fractional area of change for right ventricular systolic function is:	A. <35% B. <45% C. <55% D. <65%
Which pathologic state is suggested by the following transesophageal echocardiogram images? (midesophageal long-axis view showing reduced systolic excursion of the aortic valve with high-velocity turbulent color-Doppler flow originating at the aortic valve level)	A. Dynamic left ventricular outflow tract obstruction B. Aortic dissection C. Aortic stenosis D. Systolic anterior motion of the mitral valve
Calculate the estimated right ventricular systolic pressure given the following variables: right atrial pressure 10 mm Hg, tricuspid regurgitation max velocity 3.3 m/s, end diastolic pulmonary regurgitation velocity 2.0 m/s (round to nearest whole number)	A. 54 mm Hg B. 34 mm Hg C. 26 mm Hg D. Not enough data to determine
Which of the following clinical scenarios is suggested based on the midesophageal 4-chamber view? (midesophageal 4-chamber view showing right ventricular free wall akinesis with apical sparing, with an underfilled and hyperdynamic left ventricle)	A. Left anterior descending coronary artery ischemia B. Acute pulmonary embolism C. Hypovolemia D. Hypervolemia
The structure indicated by the arrow is which of the following? (midesophageal right ventricular inflow-outflow view with indicator arrow pointing at right ventricular thrombus)	A. Right atrial thrombus B. Moderator band C. Eustachian valve D. Right ventricular thrombus
Identify the transesophageal echocardiography view and the structure indicated by the arrow: (midesophageal bicaval view with indicator arrow pointing at superior vena cava)	A. Midesophageal bicaval view, superior vena cava B. Midesophageal right ventricular inflow-outflow view, right ventricular outflow tract C. Midesophageal bicaval view, inferior vena cava D. Midesophageal right ventricular inflow-outflow view, right ventricular inflow
What pathology is indicated by the following midesophageal long-axis view? (midesophageal long-axis view demonstrating systolic anterior motion of the mitral valve)	A. Aortic stenosis B. Systolic anterior motion of the mitral valve C. Mitral valve stenosis D. Mitral valve prolapse
Which of the following pathologic states is suggested by the following midesophageal long-axis view? (color compare midesophageal long-axis view showing systolic anterior motion of the mitral valve, color-Doppler with turbulent, high-velocity flow through the left ventricular outflow tract, and posterior directed mitral regurgitation)	A. Aortic valve stenosis B. Myocardial ischemia C. Left ventricular outflow tract obstruction D. Mitral stenosis
Which pathologic state is suggested by the following midesophageal 4-chamber view? (midesophageal 4-chamber view demonstrating prominent epicardial adipose with no pericardial effusion or tamponade physiology)	A. Pericardial effusion without tamponade physiology B. Pericardial effusion with tamponade physiology C. Pericarditis with constrictive physiology D. Normal physiology without pericardial effusion

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Which finding below from the modified midesophageal 4-chamber view suggests pericardial tamponade physiology? (modified midesophageal 4-chamber view demonstrating pericardial effusion with right ventricular collapse)	A. Left atrial collapse B. Right ventricular collapse C. Ventricular interdependence D. Mitral valve inflow variation >25%
During emergent peripheral veno-arterial extracorporeal membrane oxygenation cannulation via the right femoral artery and vein, the following view is obtained. The findings confirm which of the following? (midesophageal bicaval view demonstrating a wire being directed from the inferior vena cava through the right atrium and into the superior vena cava)	A. Severe right ventricular dysfunction B. Wire successfully placed in central venous circulation C. Atrial septal defect D. Successful arterial cannulation
Coronary artery ischemia in which of the following distributions is most likely? (transgastric midpapillary view with regional wall motion abnormalities in the inferior wall of the left ventricle)	A. Left anterior descending coronary artery B. Circumflex coronary artery C. Right coronary artery D. No regional wall motion abnormalities present
Identify the transesophageal echocardiography view and the structure indicated by the arrow: (midesophageal ascending aorta short-axis with indicator arrow pointing to right pulmonary artery)	A. Midesophageal ascending aorta short-axis, right pulmonary artery B. Midesophageal bicaval view, inferior vena cava C. Midesophageal ascending aorta long-axis, right pulmonary artery D. Midesophageal ascending aorta short-axis, left pulmonary artery
Calculate the stroke volume index based on the following variables: left ventricular outflow tract diameter 2.2 cm, left ventricular outflow tract pulsed-wave Doppler velocity time integral 20 cm, body surface area 2 m^2, heart rate 80 beats per minute.	A. 30 mL/m^2 B. 76 mL/m^2 C. 48 mL/m^2 D. 38 mL/m^2
Calculate the cardiac index based on the following variables: left ventricular outflow tract diameter 2.2 cm, left ventricular outflow tract pulsed-wave Doppler velocity time integral 20 cm, body surface area 2 m^2, heart rate 80 beats per minute.	A. 3 $L/min/m^2$ B. 6 $L/min/m^2$ C. 3.8 $L/min/m^2$ D. 7.8 $L/min/m^2$
Identify the transesophageal echocardiography view and associated findings: (midesophageal bicaval view revealing a patent foramen ovale with left-to-right shunting)	A. Midesophageal bicaval view, no patent foramen ovale B. Midesophageal right ventricular inflow-outflow view, tricuspid regurgitation C. Midesophageal bicaval view, patent foramen ovale with left-to-right shunt D. Midesophageal bicaval view, patent foramen ovale with right-to-left shunt
Identify the finding indicated by the arrow: (zoomed in midesophageal bicaval view revealing Eustachian valve)	A. Right atrial thrombus B. Right atrial vegetation C. Crista terminalis D. Eustachian valve
Coronary artery ischemia in which of the following distributions is most likely? (transgastric midpapillary view with regional wall motion abnormalities in the anteroseptal wall of the left ventricle)	A. Left anterior descending coronary artery B. Circumflex coronary artery C. Right coronary artery D. No regional wall motion abnormalities present

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A specific criterion for diagnosing severe tricuspid valve regurgitation is which of the following?	A. Large central regurgitation jet covering >20% of the right atrium B. Large central regurgitation jet covering >30% of the right atrium C. Large central regurgitation jet covering >40% of the right atrium D. Large central regurgitation jet covering >50% of the right atrium
Each of the following are relative contraindications to performing a transesophageal echocardiogram except for:	A. Recent upper gastrointestinal bleed B. Esophageal varices C. Esophageal diverticulum D. Hiatal hernia

Table 2. *Anesthesiologist Survey Responses Reported as Median Based on a Likert Scale of 1 to 5*

	Precourse Result	Postcourse Result	*P* Value
What is your overall comfort level performing the technical aspects of TEE?	2 (2-3)	4 (3-4)	<.001
What is your overall comfort level interpreting a normal TEE examination?	2 (2-3)	4 (3-4)	<.001
What is your overall comfort level interpreting an abnormal TEE examination?	2 (2-3)	4 (3-4)	<.001
How would you rank your ability to perform a complete basic TEE examination?	2 (1.75-2.25)	3 (3-4)	<.001
How would you rank your ability to identify cardiac anatomy for a basic TEE examination?	3 (2-3)	4 (3-4)	<.005
What is your comfort level assessing ventricular function with TEE?	2 (2-3)	4 (3-4)	<.001
What is your comfort level assessing ventricular volume with TEE?	2 (2-3)	4 (3-4)	<.003
What is your comfort level assessing for left ventricular RWMA with TEE?	2 (2-3)	3.5 (3-4)	<.001
What is your comfort level assessing for left ventricular RWMA with TEE from midesophageal views?	2 (1.75-3)	3 (3-4)	<.001
What is your comfort level performing hemodynamic calculations with TEE?	2 (1-2)	3 (3-4)	<.001
What is your comfort level assessing for cardiac thrombus with TEE?	2 (2-3)	4 (3.75-4)	<.001
What is your comfort level assessing for pulmonary artery thrombus with TEE?	2 (1-2)	4 (3-4)	<.001
What is your comfort level assessing for LVOTO with TEE?	2 (1-2.25)	4 (3-4)	<.001
What is your comfort level assessing for pericardial tamponade with TEE?	2 (2-3)	3.5 (3-4)	<.001
What is your comfort level assessing for valvular abnormalities with TEE?	2 (1-2)	3 (3-4)	<.003
What is your comfort level assessing IVC and hepatic venous anatomy with TEE?	1 (1-2)	3 (3-3.25)	<.001

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What is your comfort level assessing for a patent foramen ovale with TEE?	2 (1-2)	3 (3-3.25)	<.001
This course met my expectations for TEE training germane to liver transplantation.		5 (5-5)	
I am satisfied I completed this course.		5 (5-5)	

Results for precourse and postcourse survey reported based on a Likert scale of 1 to 5, with 1 representing strong disagreement of lower comfort levels and 5 representing strong agreement of higher comfort levels. Data are reported as median values of the 16 respondents with interquartile ranges and *P* values obtained using the Wilcoxon Signed Rank test for nonnormally distributed data.

Abbreviations: IVC, inferior vena cava; LVOTO, left ventricular outflow tract obstruction; RWMA, regional wall motion abnormalities; TEE, transesophageal echocardiography.