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Original Research

Assessment of Didactic Transesophageal Echocardiography Education During Anesthesia Residency

Sheldon Goldstein, MD
Dennis E. Feierman, MD
Gabriela M. Samayoa, MD
Ram Roth, MD
Ellise Delphin, MD, MPH
Yuriy A. Gubenko, MD
Malka Stohl, MS
Jyotsna Rimal, MD
Andrei Botea, MD
Ronit Zweig, PsyD
Nikolaos J. Skubas, MD, DSc

Introduction

Transesophageal echocardiography (TEE) is used to assess volume status, myocardial contractility, myocardial ischemia, and valvular heart disease. While essentially a standard of care during cardiac surgery, its use has also been documented during noncardiac surgery, to determine the etiology of hemodynamic instability and to guide treatment.[1-4] Indeed, the National Board of Echocardiography (NBE) created the Basic TEE examination, after a request from the American Society of Anesthesiologists, so anesthesiologists not trained in cardiac anesthesia or critical care could document a basic level of TEE expertise, to be used for monitoring during noncardiac surgery. Furthermore, TEE is the only practical option when transthoracic echocardiography (TTE) would violate surgical field sterility. Residents gain some TEE knowledge and expertise during rotations in cardiac anesthesia. However, since performance of TEE during noncardiac surgery may be performed by anesthesiologists without a fellowship in cardiac anesthesia or critical care, it would be useful to provide TEE-related education to residents. Such education would also prepare them for the Objective Structured Clinical Exam in Anesthesiology, which has tested TEE knowledge since 2018. We created a comprehensive longitudinal didactic curriculum to teach TEE to anesthesia residents. We hypothesized that residents who complete a didactic longitudinal TEE curriculum would demonstrate increased scores on the end of year exam as compared with the baseline exam.

Materials and Methods

After Institutional Review Board approval at Rutgers New Jersey Medical School-Newark, a TEE education program was instituted at 2 US-based anesthesia residency programs. Written informed consent was obtained from subjects at 1 site. The Institutional Review Board at Maimonides Medical Center judged the program educational and waived the written consent requirement. Both departments required the education and completion of the exams, but permitting use of their preexam and postexam scores (anonymously) for the purpose of the study was voluntary. All 68 residents volunteered. The study was a 2-year, prospective, observational design. A 41-week curriculum was designed to provide a thorough didactic experience in TEE, similar to what a cardiac anesthesia fellow would learn, except that these 4 advanced topics were excluded: (1) three-dimensional echocardiography, (2) tissue Doppler imaging, (3) advanced assessment of prosthetic heart valves, and (4) advanced congenital heart disease.

The 41-week curriculum, provided to clinical anesthesia (CA)-1 to CA-3 residents simultaneously, consisted of weekly reading, quizzes, and an in-person educational session. Reading was assigned from 2 textbooks, published literature, and the Society of Cardiovascular Anesthesiologists' (SCA) echo course manual. A 5-question quiz, based on the reading and scored immediately, was available online until 11:00 PM the night before education sessions, which centered around the SCA's DVD-based TEE Course (with permission). The DVD-based lectures were proctored by an anesthesiologist skilled in TEE, who provided relevant pointers and answered questions. Rarely, a lecture including TEE videos taught by an expert substituted for a DVD session. Key points were provided to help residents focus on the most important points to learn each week.

Baseline and postcourse knowledge for the 41-week curriculum was assessed with an examination created by 3 authors skilled in TEE. It consisted of 20 video-based questions worth 1.5 points each and 70 multiple-choice text-based questions worth 1 point each, for a maximum possible score of 100 points. The authors primarily responsible for developing the exam (S.G. and N.S.) had each supervised and/or personally performed a large number of TEE exams at the time the exam was created, had both successfully completed the NBE's

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Advanced Examination of Special Competence in Advanced Perioperative Transesophageal Echocardiography (PTEexam), and were actively teaching TEE to residents and cardiac anesthesia fellows. All questions were reviewed for factual accuracy, clarity, and presence of 1 best answer, by 1 of the authors (N.S.), a recognized expert in TEE. The exam was administered at baseline, after year 1, and after year 2. The exam after year 1 served as the post-1-year score and the baseline score for year 2. Residents wrote exams on a nonpostcall day and had 2 hours and 15 minutes to complete them. With a third Institutional Review Board approval from the Albert Einstein College of Medicine, the exam was validated by comparing scores on the educators' TEE exam and the PTEexam, in a group of volunteers who provided written informed consent and wrote both exams in the summer of 2019, within 4 weeks of each other. These individuals had just completed fellowship; 13 in cardiac anesthesia, and 1 in vascular and thoracic anesthesia. A 4-question survey comparing the educators' exam and the PTEexam was completed by these subjects. Volunteers were asked to complete survey questions within 48 hours of writing each respective exam.

It was planned that the 41-week curriculum would be repeated 1 year later with modifications. However, 1 program decided to devote more time to the standard anesthesia curriculum and permitted only 23 hours of TEE education in the second year. To maintain consistency between programs, the course was decreased to 23 weeks at both sites in the second year. The 23-week course consisted of biweekly reading assignments, quizzes, and an in-person education session. The 41-week curriculum began in August 2008 and ended June 2009. The 23-week curriculum began in August 2009 and ended in June 2010. The curricula are detailed in Tables 1 and 2, respectively.

Statistical Analysis

The primary prospective outcomes were a change in exam scores within each class after the 41-week TEE course and a correlation between scores on the educators' exam and the NBE's PTEexam. A secondary outcome was a change in exam scores after the 23-week curriculum. Within classes, scores after TEE education were compared to baseline, with 2-sided paired t test. Scores precourse and postcourse were compared between classes using 2-sample t test. After 41 weeks of education, scores within the groups that passed the exam (≥65%) and did not pass the exam were compared to baseline with paired t test. The change in scores between the group that passed and the group that failed was compared with 2-sample t test. Scores between the educators' exam and the PTEexam were compared with Pearson Correlation Coefficient. Survey questions assessing the exams were compared with paired t test. $P < .05$ was considered significant for all analyses.

Results

The baseline exam indicated greater knowledge with each year of training (Table 3). After the 41-week course, exam scores increased 12% among CA-3's ($P = .03$), 29% among CA-2's ($P = .007$), and 25% among CA-1's ($P = .002$; Table 4). After the 23-week course, the increase in scores in the original CA-1 class were maintained ($P = .004$), but did not increase further ($P = .82$), while scores in the original CA-2 class reverted to baseline ($P = .31$; Table 4). Scores in the CA-0 class, which took the baseline exam as they began their CA-1 year in July 2008, did not change after the 23-week curriculum, ($P = .16$; Table 4).

Descriptive statistics comparing the educators' exam and the PTEexam are indicated in Table 5. Pearson correlation coefficients between the educators' exam score, and the PTEexam percentile rank and scaled score were 0.69 ($P = .006$) and 0.71 ($P = .0045$), respectively. Questions comparing the educators' TEE exam and the PTEexam, and survey results, are listed in Table 6. Respondents' survey scores indicated no differences between knowledge assessment, question clarity, and 1 best answer, between the 2 exams, but they did indicate the educators' exam was less challenging than the PTEexam, $P = .0015$ (see Table 6).

Discussion

This is the first report of a thorough didactic curriculum in TEE offered during anesthesia residency. The importance of didactic echocardiography knowledge should be emphasized. While it is relatively simple to recognize the difference between a normal left ventricle and a left ventricle with a severely decreased ejection fraction, learning to obtain and interpret TEE images requires not only performance and review of many examinations so as to be able to assess gradations in pathophysiology but, in addition, a great deal of didactic knowledge. Improper setting of gain or aliasing velocity can lead to gross misinterpretation, such as reading a mass where none is present, or grading mitral regurgitation as severe when it is mild. Add to this knowing when and how to use the various forms of Doppler, and one can easily imagine errors that could negatively impact patient care. Indeed, 2010 guidelines discussed findings detected with TEE during noncardiac surgery,[7] and proper console settings and use of Doppler are necessary to accurately diagnose and/or grade severity of many of these abnormalities.

Use of DVD-based TEE lectures recorded during a course offered by the SCA assured that each speaker was an expert in the topic. Using expert-delivered lectures in more than 1 location is similar to online education provided by Massive Online Open Courses. Indeed, educational resources such as Truelearn, Learnly, and the Anesthesia Toolbox are shared between multiple departments in the field of Anesthesiology. Similar to our use of the SCA's TEE lectures, these programs permit sharing of high-quality educational resources, eliminating the burden if each department had to create such programs on their own.

Resident education in TEE has been described. One group[8] reported that after 2 rotations in cardiac anesthesia, 12/12 (100%) senior residents received a passing grade on performance of a basic TEE exam, and that automated grading was feasible. Another study[9] compared results of a 25-question exam before and after TEE education in 2 groups of 7 CA-1 residents. One group learned TEE from published guidelines, textbooks, electronic media, and web-based resources, while the second was exposed to a 90-minute simulator-based TEE teaching session. The simulator group performed better on a posttest designed to assess normal echo anatomy and image orientation.[9] Ferrero et al[10] reported that anesthesia residents trained with a TEE simulator performed better on a practical exam where they were called upon to obtain TEE

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views on patients, compared to a group of residents who received didactic education via PowerPoint slides, video clips, and an anatomical heart model. These prior studies mostly assessed resident knowledge of cardiac anatomy and basic TEE views.

Our work is unique because the curriculum included pathologic conditions and provided *a thorough* didactic education in TEE, including physics of ultrasound, all forms of Doppler, and proper console settings often referred to as knobology. Acquisition of knowledge required to be a skilled echocardiographer is a time-intensive and effort-intensive endeavor. Our finding of improved exam scores after the 41-week course is therefore relevant and might be considered as a possible supplement to the current anesthesiology residency curriculum.

Exam scores increased significantly in all CA-classes after the 41-week course, but not after the 23-week course. It is likely that 23 weeks is too brief a time for residents to acquire significant TEE knowledge. After the 41-week course, the rise in exam scores in the group that passed was of a far greater magnitude than in the group that failed, a 73.4% rise in exam scores versus just 10.7%. This suggests the 41-week curriculum provides an effective educational experience, but we would like to understand why some residents failed. It could be that academically stronger residents are better able to add study of TEE to their responsibilities. However, this seems unlikely, as there was no difference between baseline exam scores in these groups, 41 points (7.7) in the group that passed the post-education exam versus 42 points (6.8) in the group that failed, (P = .72) There were no penalties for poor exam performance, nor uncompleted quizzes, as it was felt that penalties for what was a novel curriculum at the time should not be enforced. Had there been penalties, there may have been fewer failing exam scores. Another possibility is that the passing group may have been comprised of residents interested in cardiac anesthesia or critical care, while the lower performing group may have included residents interested in specialties in which the use of TEE is uncommon.

One limitation of our study is that we did not survey residents to obtain feedback about their experiences. Had we done so, we might have learned whether residents who failed were unmotivated and, if so, why. Based on an estimate of 2 hours to complete weekly reading assignments, the 41-week curriculum would require 132 hours of residents' time, including education sessions. Had we surveyed residents to learn how much time was actually required to read weekly assignments, it would have better informed us regarding the practicality of adding such education to the anesthesia curriculum. Another limitation is that we did not track quiz results. They were used solely so residents could assess the knowledge they gained from reading in preparation for the next day's session. A fourth limitation is that selection of 65% as the passing grade on the educators' exam was arbitrary. This was necessary because none of the fellows who wrote both exams failed the PTEexam. Therefore, we could not calculate a Receiver Operating Characteristic curve, using the PTEexam as a gold standard, to determine the passing grade on our exam. Still, there are good correlation coefficients for our exam scores versus both NBE percentile rank and NBE scaled score, which confirms our exam is a useful tool to assess TEE knowledge.

Since the curriculum excluded 4 advanced topics, the educators' exam did not contain questions related to these topics. That is, we intended to create an exam that was somewhat less challenging than the PTEexam. It is therefore noteworthy that the only statistically significant difference among survey questions comparing the 2 exams was that subjects judged the educators' exam to be less challenging. One final limitation is that we could not control for knowledge residents gained during their clinical training. Had we studied TEE education during a brief period, residents who completed cardiac anesthesia rotations immediately prior to an exam would have been at an advantage. However, since our exam assessed knowledge gained from August through June, and most residents rotated through cardiac anesthesia, this is a lesser concern.

We validated our exam against the PTEexam because, as noted, our curriculum and exam only avoided 4 topics cardiac anesthesia fellows are expected to learn. Therefore, we felt our exam was more aligned with the PTEexam than the NBE's Basic TEE exam. Also, individuals who write the basic TEE exam may include attendings who have been learning TEE over several years. We preferred the population of individuals who had just completed fellowship and had spent only 1 additional year learning TEE as compared with CA-3 residents.

Lack of hands-on training was not a weakness of our study. It simply was not our goal. Our goal was to assess effectiveness of a curriculum to impart didactic TEE knowledge. Hands-on training and didactic knowledge in echocardiography are different skill sets, albeit with some overlap. Indeed, even the NBE uses text and video-based exam questions to assess TEE knowledge and presumes hands-on skills based on a roster of exams performed. We would have preferred to incorporate hands-on training, and it is possible this would have resulted in higher exam scores. However, the cardiac surgery caseload at the principal investigator's site was small, and residents received the bulk of their TEE education at a private practice affiliate. Therefore, providing hands-on training was simply not possible. The fact remains that the goal of our study was to determine whether didactic TEE knowledge can be acquired during anesthesia residency, and the data indicates it can be.

Since this study was performed, use of TTE has expanded among noncardiologists. In 2016, the SCA published a call to action regarding training requirements in perioperative ultrasound during anesthesia residency.[11] The 2020 Accreditation Council for Graduate Medical Education Program Requirements in Anesthesiology state that residents must demonstrate competence in TTE, "allowing the evaluation of myocardial function, estimation of central venous pressure, and gross pericardial/cardiac pathology (eg, large pericardial effusion),"[12(p25)] as well as the ability to detect pneumothorax and apply surface ultrasound to facilitate vascular access. Indeed, TTE has been shown to impact management of unstable patients during noncardiac surgery[13] and is useful to assess the etiology of hemodynamic instability and respiratory insufficiency in the postanesthesia care unit. Yet only 40 of 133 US anesthesiology program directors responded to a survey published in 2017 regarding TTE

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education, and just 11/40 (27.5%) indicated formal training in TTE was provided to residents.[14] Of note, The American Board of Anesthesiology has indicated that point-of-care ultrasound, including point-of-care TTE, will be introduced into the Objective Structured Clinical Exam in 2022, making the need to provide such training more acute. How shall such education be imparted to residents? Since the foundational knowledge of echocardiography applies equally to TEE and TTE, modification of our curriculum could be one solution. Decreasing didactics to 40 weeks and adding 8 additional sessions would provide 4 sessions each for hands-on training in TEE and TTE. Hands-on sessions would best be interspersed throughout the year to provide spaced practice. Doing so with simulators would provide a nonrushed environment, uninterrupted by patient care needs. Clinical faculty could supplement the goals of the 48-week curriculum with clinical use of TEE/TTE as appropriate. It would need to be decided whether to provide the curriculum to all residents just once, or perhaps to offer it to residents during both the CA-2 and CA-3 years.

Some may feel only minimal echocardiography education should be provided during residency, and that our curriculum is excessive, but the additional study time needs to be weighed against the benefits of graduating residents with an improved understanding of hemodynamics, and who are better prepared to care for an increasingly older and sicker population. Furthermore, since most residents will not complete cardiac or critical care fellowships, it may be even *more* important to provide echocardiography education during anesthesia residency. Educating residents to perform ultrasound-guided nerve blocks was facilitated by adding rotations in regional anesthesia. Echocardiography might be better learned interspersed throughout a year's time, but it similarly will require dedicated time for residents to learn.

In conclusion, a 41-week didactic TEE curriculum resulted in significant improvement in examination scores among CA-1, CA-2, and CA-3 residents. The 41-week course described could be used as a model curriculum to teach TEE, or it could be modified to teach TEE and TTE side-by-side. TEE/TTE provide superior information to that garnered from vital signs and physical examination. Because of the time and effort required to learn the domain knowledge of echocardiography, and to achieve a significant level of expertise performing TEE/TTE, a year-long curriculum may be superior to a 4-week rotation. Whatever approach is taken, the time to improve echocardiography training for anesthesiology residents has arrived.

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The following authors are in the Department of Anesthesiology, Albert Einstein College of Medicine - Montefiore Medical Center, New York, NY: ***Sheldon Goldstein*** *is an Associate Professor;* ***Gabriela M. Samayoa*** *is a Research Associate;* ***Ellise Delphin*** *is a Professor and Chairman. The following authors are in the Department of Anesthesiology, Rutgers New Jersey Medical School, Newark, NJ:* ***Yuriy A. Gubenko*** *is an Assistant Professor;* ***Jyotsna Rimal*** *is an Assistant Professor;* ***Andrei Botea*** *is an Assistant Professor.* ***Dennis E. Feierman*** *is a Clinical Professor of Surgery, New York Institute of Technology School of Osteopathic Medicine, and Vice-Chairman in the Department of Anesthesiology at Maimonides Medical Center, New York, NY.* ***Ram Roth*** *is an Associate Professor in the Department of Anesthesiology at Icahn School of Medicine at Mount Sinai, New York, NY.* ***Malka Stohl*** *is a Statistician at The New York Psychiatric Institute, New York, NY.* ***Ronit Zweig*** *is a psychologist in New York, NY.* ***Nikolaos J. Skubas*** *is a Professor of Anesthesiology at the Cleveland Clinic Lerner College of Medicine of Case Western Reserve University and Chairman in the Department of Cardiothoracic Anesthesiology at the Cleveland Clinic Anesthesiology Institute, Cleveland, OH. Note: This work was performed at Rutgers-New Jersey Medical School in Newark, NJ and Maimonides Medical Center in New York, NY.*

Corresponding author: *Sheldon Goldstein, MD, Department of Anesthesiology, Albert Einstein College of Medicine - Montefiore Medical Center, 4th Floor Silver Zone, 111 East 210th Street, Bronx, NY 10467. Telephone: (718) 920-4187*

Email address: *Sheldon Goldstein: shgoldst@montefiore.org*

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Abstract

Background: Transesophageal echocardiography can be a useful monitor during noncardiac surgery, in patients with comorbidities and/or undergoing procedures associated with substantial hemodynamic changes. The goal of this study was to investigate if transesophageal-echocardiography-related knowledge could be acquired during anesthesia residency.

Methods: After institutional review board approval, a prospective observational study was performed in two anesthesiology residency programs. After a 41-week didactic transesophageal-echocardiography-education curriculum residents' exam scores were compared to baseline. The educators' examination was validated against the National Board of Echocardiography's Examination of Special Competence in Advanced Perioperative Transesophageal Echocardiography.

Results: After the 41-week course, clinical anesthesia (CA)-3 exam scores increased 12% compared to baseline (P = .03), CA-2 scores increased 29% (P = .007), and CA-1 scores increased 25% (P = .002). Pearson correlation coefficient between the educators' exam score and the special competence exam percentile rank was 0.69 (P = .006). Pearson correlation coefficient between the educators' exam score and the special competence exam scaled score was 0.71 (P = .0045).

Conclusions: The 41-week course resulted in significant increases in exam scores in all 3 CA-classes. While didactic knowledge can be learned by anesthesiology residents during training, it requires significant time and effort. It is important to educate residents in echocardiography, to prepare them for board examinations and to care for the increasingly older and sicker patient population. Further work needs to be done to determine optimal methods to provide such education.

Keywords: Transesophageal echocardiography, echocardiography, resident education, curriculum

Tables

Table 1. *The 41-Week Curriculum Content*

Week	DVD Topics	Key Points to Learn From Assigned Readings[5,6]
1	Basic TEE: Challenging Cases Probe Manipulations and Scan Planes	1) Know risks of TEE 2) Differentiate posterior and anterior papillary muscles 3) Know location of Eustachian valve 4) Know easiest view to assess LV volume 5) Know what to do if force is required to insert probe 6) Know what to do if a probe that was easy to advance cannot be withdrawn 7) Identify 3 cusps of AV in short axis view 8) Identify anterior and posterior MV leaflets in long axis view 9) Identify interatrial septum 10) Identify interventricular septum
2	Principles of US	1) Know relationship between wavelength and frequency 2) Know factors that determine acoustic impedance 3) Know difference between specular and scattering reflection 4) Know factors that influence attenuation 5) Know the characteristics of a piezoelectric crystal 6) Know difference between the near field and the far field

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3	Knobology for Image Optimization	1) Know difference between axial, lateral, and elevational resolution 2) Understand concept of side-lobe artifacts 3) Understand when high frequency US should be used and when low frequency US is preferred 4) Know benefits and drawbacks of high frequency and low frequency US 5) Understand concept of time-gain compensation 6) Understand why the focus should be set on the region of interest
4	Comprehensive Intraoperative TEE Exam	1) Understand the concept of multiplane imaging 2) Know the grading scale for wall motion 3) Know the segments the MV is divided into 4) Draw from memory the 16 segments of the LV and which coronary artery usually perfuses each segment
5	Imaging Artifacts	1) Know factors that can result in suboptimal image quality 2) Understand *acoustic shadowing* 3) Know how lateral resolution impacts images 4) Understand *reverberation artifact*
6	TEE for CABG Surgery	1) Know most sensitive change with ischemia 2) Differentiate stunning from hibernation 3) Understand *dyskinesis* 4) Understand term contractile reserve 5) Know which coronary arteries perfuse which regions of the myocardium 6) Know mechanisms that cause ischemic MR
7	Anatomic Pitfalls	1) Chiari network 2) Eustachian valve 3) Crista terminalis 4) Coumadin ridge 5) Bubble study to diagnose PFO
8	Assessment of LV Global Systolic Function	1) Know information required to measure CI with TEE 2) Fractional area of change 3) End-systolic cavity obliteration 4) Ejection fraction formula
9	RV Global Systolic Function	1) Tricuspid annular plane systolic excursion 2) Hepatic venous flow patterns 3) RV volume overload 4) RV pressure overload 5) Calculation of pulmonary artery systolic pressure from tricuspid regurgitation jet
10	Diastolic Function	1) IVRT 2) Diastasis 3) Impaired relaxation 4) Abnormal compliance 5) Know where to measure E and A waves

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11	TEE for AR	1) ME AV long-axis view 2) Ratio AR jet width to LV outflow tract 3) Vena contracta 4) Aortic diastolic flow reversal 5) Slope AR jet decay 6) Pressure half time 7) Why LV diastolic pressure influences slope of regurgitant jet and pressure half time, and why this can give false impression that AR is worse than it really is
12	AS	1) Simplified Bernoulli equation 2) Planimetry of AV 3) LVOT VTI 4) Continuity equation for AV area 5) Why AS underestimated with poor CO 6) Why AS overestimated with high CO (severe AR or sepsis) 7) Which doppler modality used to measure LVOT VTI and why 8) Which doppler modality used to measure peak aortic flow velocity in AS and why 9) What measurement in continuity equation for AS can be significant source of error and why
13	Aortic Aneurysms and Dissections	1) Stanford classification of aortic dissection 2) DeBakey classification of aortic dissection 3) Crawford classification of thoracoabdominal aneurysms 4) Sensitivity and specificity of different diagnostic modalities for aortic dissection 5) Why involvement of the sinus of Valsalva is important 6) Methods to differentiate true and false lumen 7) Grading system for thoracic aortic atheroma
14	Case Conference on Aortic Dissection and AV Disease	1) AS calculation with Bernoulli equation 2) AS calculation with continuity equation
15	Evaluation Regional Wall Motion	1) 17 segment model 2) Coronary artery perfusion to different regions of myocardium 3) Know the temporal relationship of hypokinesis, akinesis, and dyskinesis in relation to coronary artery occlusion 4) Know association of pacemaker and septal bounce 5) Know how to assess if the apex is foreshortened 6) Understand and MEMORIZE figure 7.4 on page 152 of Perrino and Reeves[5]
16	LV Regional Wall Motion	1) Which TEE image/view displays wall motion distribution of all 3 coronary arteries, while also permitting assessment of LV volume?
17	MR	1) MV anatomy (especially Carpentier nomenclature) 2) Causes of MR 3) Meaning of regurgitant volume as it applies to MR 4) Pitfalls in evaluation of MR 5) Know 3 things to look for post-MV repair 6) Know effect functional MR has when found in a patient undergoing CABG

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18	MS	1) 4 components used to score a MV afflicted with rheumatic disease 2) Planimetry to evaluate MS 3) Pressure half-time to evaluate MS 4) Deceleration time to evaluate MS 5) Proximal isovelocity surface area
19	TV and PV	1) Know leaflets of the TV 2) Know views to assess TR 3) Know normal apical displacement of TV in relation to MV 4) Know normal velocity of TV flow 5) Understand why V1 is often ignored in the Bernoulli equation 6) Know the ventricular response to pressure overload 7) Know the atrial response to pressure overload
20	Prosthetic Valves	1) Advantages of TEE over TTE to assess MV disease 2) What information is used to evaluate a prosthetic valve with TEE 3) Degenerative changes in prosthetic valves that lead to pathologic transvalvular regurgitation 4) Causes of paravalvular regurgitation 5) Prosthesis-patient mismatch 6) Know causes of LVOT obstruction after MV surgery 7) Know term SAM 8) Know treatment of LVOT obstruction
21	Basic Congenital Heart Disease	1) 4 types of ASDs 2) Know 4 types of VSDs 3) Know method to detect PFO 4) Know factors that determine physiologic consequences of VSDs 5) Which cardiac chamber is primarily affected in a patient with pulmonic stenosis 6) Describe lesions that comprise tetralogy of fallot 7) Persistent left superior vena cava
22	Overview of Cardiac Anatomy	Describe anatomical relationship between: 1) Aorta and pulmonary artery 2) MV and TV 3) MV and AV 4) Know 3 coronary arteries, their branches, and regions they supply 5) From the midesophagus, which cardiac structure appears in the most views? Note: There is a DVD session entitled *Wet Lab Heart Dissection*, dissection of a porcine heart. It may be very valuable for you to watch.
23	Nonoperating ROOM Applications of TEE (in ICU)	1) Know complications of TEE 2) Know why complications more likely to occur outside the OR 3) Benefits of TEE vs PAC 4) Conditions that make it difficult to obtain good images via transthoracic echo 5) Conditions for which TEE superior to TTE 6) Common indications for TEE in the ICU 7) Where do most intimal flaps originate in aortic dissections?

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24	Epicardial and Epiaortic Echo	1) Know contraindications to TEE 2) Know questions to ask before performing a TEE exam 3) Know why TEE does not visualize the entire ascending aorta 4) Know why an epiaortic exam should be routinely performed prior to cardio-pulmonary bypass 5) Be familiar with the grading systems for aortic atheroma that have been used and the importance of plaque that is 3mm or greater or that is mobile 6) Know why an epicardial exam should be part of an intraoperative echocardiographer's capabilities
25	Intraop Consultant	1) If AS is left untreated, what 3 symptoms are temporally related to mortality, and what is the relationship of each? 2) Know factors to assess when evaluating the AV with 2D echo 3) Know how to obtain the peak AV gradient 4) Planimetry to measure AVA 5) Know how to use the continuity equation to calculate AVA
26	Thoracic Aorta Stents Aortic Atheroma (Cardiac Masses and Sources of Emboli)	1) Know 1-5 grading system for aortic atheroma 2) Know the 6 zones of thoracic aorta 3) Know the association of thoracic atheromatous disease with diffuse atherosclerotic disease 4) Know mechanisms by which aortic plaque can cause distal emboli 5) Know the shunt anatomy(ies) that can result in a paradoxical embolus 6) Myxoma is most likely to obstruct flow across which heart valve? 7) Why is TEE often performed before cardioversion? 8) What is the significance of smoke in the left atrium?
27	Advanced Systolic Function	1) Calculate ejection fraction 2) Calculate Fractional shortening 3) Law of LaPlace 4) Characteristics of various forms of CM
28	Advanced Diastolic Function	1) Risk factors for coronary artery disease 2) Know classification system of diastolic dysfunction used by these investigators 3) Know the relationship these investigators found between LVEF and diastolic filling as measured by E/A 4) Know the relationship these investigators found between LVEF and diastolic filling as measured by deceleration times 5) Of patients with normal LVEF in this study, what percent had diastolic filling abnormalities?
29	Congenital Heart Disease in the Adult	1) Know 4 types of ASD 2) Know how an ASD can lead to pulmonary hypertension 3) Explain the pathophysiology of Eisenmenger syndrome
30	Echo Assessment of Myocardial Viability	1) What principle is evaluation of myocardial viability based on? 2) What echo measurements are the most sensitive indicators of myocardial ischemia, and why? 3) Explain the ability of low dose intraoperative dobutamine stress echo to predict contractile reserve and functional recovery after coronary revascularization

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continued from previous page

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31	Echo for Heart Failure and CM	1) Definition of *cardiomyopathy* 2) Order dilated, hypertrophic, and restrictive/infiltrative CM from most common to least common 3) Why is development of LV hypertrophy initially beneficial in dilated CM? 4) Where are cardiac thrombi most commonly found? 5) What is the normal wall thickness of the LV? 6) Describe the pathologic process in restrictive and infiltrative CM 7) What is the relationship between wall thickness and survival in patients with cardiac amyloidosis?
32	Case Presentation: MR	1) False tendon 2) 2 reasons pulmonary venous waveform may be normal in the setting of moderate MR 3) Know anatomic classification (cm^2) for normal, mild, moderate, and severe MS 4) Know criteria to evaluate severity of TR
33	History of Echo: from M-Mode to 3D Intro to New Technologies	1) In patients with a prosthetic MV, why is TEE better at assessing MR than TTE? 2) What problems prevent clear imaging of prosthetic heart valves? 3) Know steps required to evaluate prosthetic heart valves by TEE 4) What is the most common finding on TEE to confirm a diagnosis of endocarditis? 5) Know risk factors for prosthesis-patient mismatch after AV replacement
34	Pericardial Disease	1) How much fluid does the pericardial space normally contain? 2) Under conditions of acute volume increase in cardiac chambers or within the pericardial space, how does the pericardium affect chamber dilation? 3) What are the causes of pericarditis? 4) In the CVP tracing what change is characteristic of cardiac tamponade? 5) If a large amount of blood acutely enters the pericardial space, it will appear as what color on echocardiography? 6) What echo finding is most sensitive and most specific for pericardial tamponade? 7) What are the echocardiographic findings associated with constrictive pericarditis?
35	Timing of Surgery in Patient with Asymptomatic AS	1) What are the factors that determine when to replace the AV in patients with AS? 2) Why does decreased LV function make the determination about the need for surgery more difficult? 3) What are the valve areas that correlate with mild, moderate, and severe AS? 4) What 3 symptoms correlate temporally with time to death if AS is untreated? And how?
36	Advanced MV: What to Do with 2+MR?	1) What is the most common cause of MR requiring surgical correction? 2) How does endocarditis lead to MR? 3) How does ventricular dilatation lead to MR? 4) Why are atrial and mitral pressures transmitted to the pulmonary veins? 5) What are the sequelae of significant MR after coronary revascularization?

continued on next page

continued from previous page

Tables *continued*

37	Advanced Hemodynamics: Review of Principles and Quantitative Doppler	1) Know the concept and the formula of the Bernoulli equation 2) Know the concept and the formula of the continuity equation 3) Know formula to calculate the PA systolic pressure, and under what conditions this calculation may be in error 4) Know formula to calculate the left atrial pressure and under what condition it may be inaccurate 5) Know the pressure half time formula to calculate MV area
38	No DVD session. Use time to practice calculations.	1) Know how to calculate the gradient across the TV in a patient with TR 2) Know how to calculate pulmonary artery systolic pressure in a patient with TR 3) Know how to calculate left atrial pressure in a patient with MR 4) Know how to determine the pressure gradient across the AV from peak Doppler velocity 5) Know how to calculate the AVA using the continuity equation
39	Ischemic MR	1) Understand the dilemma regarding the addition of unexpected MV surgery to CABG surgery 2) What percent of patients who sustain an MI develop ischemic MR? 3) Which papillary muscle is more likely to become ischemic and why? 4) In theory, why does a ring annuloplasty decrease MR? 5) What are the advantageous of MV repair rather than replacement? 6) Explain the preferred hemodynamic profile to be maintained prebypass in patients undergoing MV surgery for severe MR 7) Explain the anatomic/physiologic reason why patients who have severe MR and do not need inotropic support before bypass, may need inotropic support after MV repair or replacement (assuming the MV surgery has gone very well). THINK!
40	Surgical Repair of MV	1) What is the best echocardiographic technique to screen for MR? 2) Understand the difference between central MR jets and jets that hug the wall of the LA 3) What questions regarding the MV should be answered when performing intraoperative examination of the MV? 4) Understand why 3D echo can help the surgeon decide what operation to perform in a patient with MR
41	Using Echo to Wean from Bypass	1) Understand why myocardial dysfunction influences the success of weaning from bypass 2) Understand how to rapidly assess ventricular volume using TEE 3) Understand the importance of monitoring for air before weaning from bypass 4) Know how to use TEE to determine if therapy to improve ventricular systolic function is efficacious

Abbreviations: 2D, 2-dimensional; 3D, 3-dimensional; AV, aortic valve; AR, aortic regurgitation; AS, aortic stenosis; ASD, atrial septal defect; AVA, aortic valve area; CABG, coronary artery bypass graft; CI, cardiac index; CM, cardiomyopathy; CO, cardiac output; CP, constrictive pericarditis; CVP, central venous pressure; ICU, intensive care unit; IVRT, isovolumic relaxation time; LA, left atrium; LV, left ventricle; LVEF, left ventricular ejection fraction; LVOT, left ventricular outflow tract; ME, midesophageal; MI, myocardial infarction; MR, mitral regurgitation; MS, mitral stenosis; MV, mitral valve; OR, operating room; PA, pulmonary artery; PAC, pulmonary artery catheter; PFO, patent foramen ovale; PV, pulmonic valve; RV, right ventricle; SAM, systolic anterior motion; SVC, superior vena cava; TR, tricuspid regurgitation; TV, tricuspid valve; US, ultrasound; VTI, velocity time integral.

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Table 2. *The 23-Week Curriculum Content*

Week	DVD Topics	Key Points to Learn From Assigned Readings[5,6]
1	Basic TEE: Challenging Cases Probe Manipulations and Scan Planes	1) Know risks of TEE 2) Differentiate posterior and anterior papillary muscles 3) Know location of Eustachian valve 4) Know easiest view to assess LV volume 5) Know what to do if force is required to insert probe 6) Know what to do if a probe that was easy to advance cannot be withdrawn 7) Identify 3 cusps of AV in short axis view 8) Identify anterior and posterior MV leaflets in long axis view 9) Identify atrial septum 10) Identify ventricular septum
2	Principles of US	1) Know relationship between wavelength and frequency 2) Know factors that determine acoustic impedance 3) Know difference between specular and scattering reflection 4) Know factors that influence attenuation 5) Know the characteristics of a piezoelectric crystal 6) Know difference between the near field and the far field
3	Knobology for Image Optimization	1) Know difference between axial, lateral, and elevational resolution 2) Understand concept of side-lobe artifacts 3) Understand when high frequency US should be used and when low frequency US is preferred 4) Know benefits and drawbacks of high frequency and low frequency US 5) Understand concept of time-gain compensation 6) Understand why the focus should be set on the region of interest
4	Comprehensive Intraoperative TEE Exam	1) Understand the concept of multiplane imaging 2) Know the grading scale for wall motion 3) Know the segments the MV is divided into 4) Draw from memory the 16 segments of the LV and which coronary artery usually perfuses each segment
5	Imaging Artifacts	1) Know factors that can result in suboptimal image quality 2) Understand *acoustic shadowing* 3) Know how lateral resolution impacts images 4) Understand *reverberation artifact*
6	TEE for CABG Surgery	1) Know most sensitive change with ischemia 2) Differentiate stunning from hibernation 3) Understand *dyskinesis* 4) Understand term contractile reserve 5) Know which coronary arteries perfuse which regions of the myocardium 6) Know mechanisms that cause ischemic MR

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continued from previous page

Tables *continued*

7	Anatomic Pitfalls	1) Chiari network 2) Eustachian valve 3) Crista terminalis 4) Coumadin ridge 5) Bubble study to diagnose PFO
8	Assessment of LV Global Systolic Function	1) Know information required to measure CI with TEE 2) Fractional area of change 3) End-systolic cavity obliteration 4) Ejection fraction formula
9	RV Global Systolic Function	1) Tricuspid annular plane systolic excursion 2) Hepatic venous flow patterns 3) RV volume overload 4) RV pressure overload 5) Calculation of pulmonary artery systolic pressure from TR jet
10	Diastolic Function	1) IVRT 2) Diastasis 3) Impaired relaxation 4) Abnormal compliance 5) Know where to measure E and A waves
11	TEE for AR	1) ME AV long-axis view 2) Ratio AR jet width to LV outflow tract 3) Vena contracta 4) Aortic diastolic flow reversal 5) Slope AR jet decay 6) Pressure half time 7) Why LV diastolic pressure influences slope of regurgitant jet and pressure half time, and why this can give false impression that AR is worse than it really is
12	AS	1) Simplified Bernoulli equation 2) Planimetry of AV 3) LVOT VTI 4) Continuity equation for AV area 5) Why AS underestimated with poor CO 6) Why AS overestimated with high CO (severe AR or sepsis) 7) Which doppler modality used to measure LVOT VTI and why 8) Which doppler modality used to measure peak aortic flow velocity in AS and why 9) What measurement in continuity equation for AS can be significant source of error and why
13	Aortic Aneurysms and Dissections	1) Stanford classification of aortic dissection 2) DeBakey classification of aortic dissection 3) Crawford classification of thoracoabdominal aneurysms 4) Sensitivity and specificity of different diagnostic modalities for aortic dissection 5) Why involvement of the sinus of Valsalva is important 6) Methods to differentiate true and false lumen 7) Grading system for thoracic aortic atheroma

continued on next page

continued from previous page

Tables *continued*

14	Case Conference on Aortic Dissection and AV Disease	1) AS calculation with Bernoulli equation 2) AS calculation with continuity equation
15	Evaluation Regional Wall Motion	1) 17 segment model 2) Coronary artery perfusion to different regions of myocardium 3) Know the temporal relationship of hypokinesis, akinesis, and dyskinesis in relation to coronary artery occlusion 4) Know association of pacemaker and septal bounce 5) Know how to assess if the apex is foreshortened 6) Understand and MEMORIZE figure 7.4 on page 152 of Perrino and Reeves[5]
16	LV Regional Wall Motion	1) Which TEE image/view displays wall motion distribution of all 3 coronary arteries, while also permitting assessment of LV volume?
17	MR	1) MV anatomy (especially Carpentier nomenclature) 2) Causes of MR 3) Meaning of regurgitant volume as it applies to MR 4) Pitfalls in evaluation of MR 5) Know 3 things to look for post-MV repair 6) Know effect functional MR has when found in a patient undergoing CABG
18	MS	1) 4 components used to score a MV afflicted with rheumatic disease 2) Planimetry to evaluate MS 3) Pressure half-time to evaluate MS 4) Deceleration time to evaluate MS 5) Proximal isovelocity surface area
19	TV and PV	1) Know leaflets of the TV 2) Know views to assess TR 3) Know normal apical displacement of TV in relation to MV 4) Know normal velocity of TV flow 5) Understand why V1 is often ignored in the Bernoulli equation 6) Know the ventricular response to pressure overload 7) Know the atrial response to pressure overload
20	Prosthetic Valves	1) Advantages of TEE over TTE to assess MV disease 2) What information is used to evaluate a prosthetic valve with TEE 3) Degenerative changes in prosthetic valves that lead to pathologic transvalvular regurgitation 4) Causes of paravalvular regurgitation 5) Prosthesis-patient mismatch 6) Know causes of LVOT obstruction after MV surgery 7) Know term SAM 8) Know treatment of LVOT obstruction
21	Basic Congenital Heart Disease	1) 4 types of ASDs 2) Know 4 types of VSDs 3) Know method to detect PFO 4) Know factors that determine physiologic consequences of VSDs 5) Which cardiac chamber is primarily affected in a patient with pulmonic stenosis? 6) Describe lesions that comprise tetralogy of fallot 7) Persistent left superior vena cava

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22	Overview of Cardiac Anatomy	Describe anatomical relationship between: 1) Aorta and pulmonary artery 2) MV and TV 3) MV and AV 4) Know 3 coronary arteries, their branches, and regions they supply 5) From the midesophagus, which cardiac structure appears in the most views? Note: There is a DVD session entitled *Wet Lab Heart Dissection*, dissection of a porcine heart. It may be very valuable for you to watch.
23	Nonoperating ROOM Applications of TEE (in ICU)	1) Know complications of TEE 2) Know why complications more likely to occur outside the OR 3) Benefits of TEE vs PAC 4) Conditions that make it difficult to obtain good images via transthoracic echo 5) Conditions for which TEE superior to TTE 6) Common indications for TEE in the ICU 7) Where do most intimal flaps originate in aortic dissections?

Abbreviations: AR, aortic regurgitation; AS, aortic stenosis; ASD, atrial septal defect; AV, aortic valve; CABG, coronary artery bypass graft; CI, cardiac index; CO, cardiac output; ICU, intensive care unit; IVRT, isovolumic relaxation time; LV, left ventricle; LVOT, left ventricular outflow tract; ME, midesophageal; MR, mitral regurgitation; MS, mitral stenosis; MV, mitral valve; PAC, pulmonary artery catheter; PFO, patent foramen ovale; PV, pulmonic valve; RV, right ventricle; SAM, systolic anterior motion; SVC, superior vena cava; TEE, transesophageal echocardiography; TR, tricuspid regurgitation; TTE, transthoracic echocardiography; TV, tricuspid valve; US, ultrasound; VSD, ventricular septal defect; VTI, velocity time integral.

Table 3. *Baseline Exam Scores Between Classes*

	Baseline Exam Scores[a]	*P* Value
CA-III	45.9 (4.0) n = 17	CA-III vs CA-II, $P = .032$ CA-III vs CA-I, $P < .001$ CA-III vs CA-0, $P = .0001$
CA-II	41.2 (8.1) n = 19	CA-II vs CA-III, P .032 CA-II vs CA-I, $P = .14$ CA-II vs CA-0, $P = .067$
CA-I	37.7 (5.5) n = 16	CA-I vs CA-III, $P < .001$ CA-I vs CA-II, $P = .14$ CA-I vs CA-0, $P = .54$
CA-0	36.3 (7.2) n = 16	CA-0 vs CA-III, $P = .0001$ CA-0 vs CA-II, $P = .067$ CA-0 vs CA-I, $P = .54$

Abbreviation: CA, clinical anesthesia.

[a] Data are mean (SD).

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Table 4. *Post TEE Education Exam Scores Within Classes Versus Baseline*

Class on July 1, 2008	Exam Scores Baseline: (2008 for I, II, III; 2009 for CA-0)[a]	Exam Scores Post 41-Week Course (2009)[a]	Exam Scores Post 23-Week Course (2010)[a]	*P* Post 41-Week Course vs Baseline (2009 vs 2008)	*P* Post 23-Week Course (2010) vs Baseline: (2008 for I, II, III; 2009 for CA-0)
CA-III	45.9 (4.0) n = 17	51.5 (10.8) n = 17	NA	.03	NA
CA-II	41.2 (8.1) n = 19	53.2 (15.7) n = 19	43.4 (9.6) n = 17	.007	.31
CA-I	37.7 (5.5) n = 16	47.1 (11.2) n = 15	47.2 (12.7) n = 14	.002	.004
CA-0	36.3 (7.2) n = 16	NA	41.4 (7.5) n = 14	NA	.16

Abbreviations: CA, clinical anesthesia; NA, not applicable.

[a] Data are mean (SD); decreased follow up sample sizes due to medical leave and, in one case, leave from the training program.

Table 5. *Descriptive Statistics Comparing the Educators' TEE Exam and the PTEexam*

Variable	n	Mean	SD	Minimum	Maximum
Educator's exam score	14	88.25	5.06	81.0	96.5
PTEexam scaled score	14	694.1	71.3	584.0	803.0
PTEexam percentile rank	14	66.50	23.84	26.0	97.0

Abbreviations: PTEexam, Perioperative Transesophageal Echocardiography exam; TEE, transesophageal echocardiography.

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Table 6. *Results of Survey Comparing Educators' TEE Exam and NBE's PTEexam, and Survey Questions*

	Educator's Exam		PTEexam		Paired *t* Test
	Mean (SD)	**Min, Max**	**Mean (SD)**	**Min, Max**	***P* Value**
Question 1	4.1 (0.7)	3,5	3.8 (0.8)	2,5	.22
Question 2	4.1 (0.8)	2,5	4.1 (0.5)	3,5	.78
Question 3	4.1 (0.8)	2,5	4.1 (0.8)	2,5	.79
Question 4	2.7 (0.9)	2,4	3.8 (0.6)	3,5	.0015

Question 1: The questions on the Educator's TEE Exam and the PTEexam I just completed are a good reflection of knowledge required to perform and interpret TEE in patients:

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1	2	3	4	5

Question 2. The questions on the Educator's TEE Exam and the PTEexam I just completed were clearly understood:

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1	2	3	4	5

Question 3: The questions on the Educator's TEE Exam and the PTEexam I just completed seemed to have one best answer:

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1	2	3	4	5

Question 4: Please rate how challenging the Educator's TEE Exam and the PTEexam were for you:

Very Easy	Somewhat Easy	Neither Easy nor Difficult	Somewhat Difficult	Very Difficult
1	2	3	4	5

Abbreviations: NBE, National Board of Echocardiography; PTEexam, Perioperative Transesophageal Echocardiography exam; TEE, transesophageal echocardiography.