The Adequacy of Basic Intraoperative Transesophageal Echocardiography Performed by Experienced Anesthesiologists

Joseph P. Miller, MD*, A.-Stephane Lambert, MD†, William A. Shapiro, MD‡, Isobel A. Russell, MD‡, Nelson B. Schiller, MD§, and Michael K. Cahalan, MD‡

*Department of Anesthesia and Operative Services, Madigan Army Medical Center, Tacoma, Washington; †Department of Anesthesia, St. Michael's Hospital, Toronto, Canada; Departments of ‡Anesthesia and §Medicine, University of California, San Francisco, California

Transesophageal echocardiography (TEE) may improve intraoperative decision-making and patient outcome if it is performed and interpreted correctly. After revising our TEE examination to fulfill the published guidelines for basic TEE practitioners, we prospectively evaluated the ability of our cardiac anesthesiologists (all very experienced with TEE) to record and interpret this revised examination. Educational aids and regular TEE performance feedback were provided to the anesthesiologists. Their interpretations were compared with the independently determined results of experts. Compared with their own historical controls (42% recording rate), all anesthesiologists showed significant improvement in their ability to record a basic intraoperative TEE examination resulting in 81% ($P < 0.0001$) of all required images being recorded: 88% before cardiopulmonary bypass, 77% immediately after bypass, and 64% after chest closure. Seventy-nine percent of the images recorded at baseline were correctly interpreted, 6% were incorrectly interpreted, and 15% were not evaluated. Our attempt to assess compliance with published guidelines for basic intraoperative TEE resulted in a marked improvement in our intraoperative TEE practice. Most, but not all, standard cross-sections are recorded or interpreted correctly, even by highly experienced and motivated practitioners.

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Transesophageal echocardiography (TEE) aids intraoperative management and improves outcome in patients undergoing cardiac valve repairs (1,2), complex congenital heart corrections (3,4), and high-risk patients undergoing coronary artery bypass surgery (5). For these reasons, TEE has become a standard monitor in many cardiac operating rooms. In our hospital, the attending anesthesiologist performs an initial TEE examination in all adults undergoing cardiac surgery and may consult with an attending echocardiographer depending on the findings of that examination. With the publication of TEE guidelines by the American Society of Anesthesiologists (ASA) and the Society of Cardiovascular Anesthesiologists (SCA), we revised our initial TEE examination to meet the goals established by the guidelines for basic intraoperative TEE proficiency (6). However, we are unaware of any published data indicating how attainable these guidelines are in clinical practice. Therefore, we conducted this prospective study to determine how well our attending anesthesiologists, all with considerable experience in TEE, could perform and interpret that examination. To enhance their ability to meet the guidelines, they were provided regular feedback on their results relative to their past performance and the results of their colleagues.

Methods

Before the start of the study, our standard TEE examination consisted of 10 views: 9 different two-dimensional cross-sections plus 1 of these cross-sections recorded during color Doppler assessment of the mitral valve and left ventricular outflow tract (7). After approval from the Committee on Human Research, the principal investigator (JPM) reviewed the recordings from all of our adult cardiac patients having intraoperative TEE during the 6-mo period before

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Address correspondence and reprint requests to MAJ Joseph P. Miller, Department of Anesthesia and Operative Services, Madigan Army Medical Center, Tacoma, WA 98431. Address e-mail to joseph.p.miller@amedd.army.mil.

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our study to determine how completely this standard examination was performed by each cardiac anesthesia faculty member. After publication of the ASA/SCA guidelines for TEE, we revised our standard examination to meet the ASA/SCA guidelines for basic TEE proficiency, including the recognition of myocardial ischemia and infarction, abnormal ventricular function and hemodynamics, air embolism, valvular dysfunction, cardiac masses, thrombi, pericardial effusions, and lesions of the great vessels (6). This revised examination (i.e., the new standard examination) consisted of 12 views: 8 of the original two-dimensional cross-sections plus 4 of these views assessed with color Doppler (Fig. 1). Thus, the revised examination was quite similar to the original one and consisted of the minimum number of standard TEE views necessary to meet the guidelines for basic TEE proficiency. Specific cross-section criteria were developed to guide the faculty in the acquisition of the examination (Fig. 2). After the start of this study, the American Society of Echocardiography and the SCA published recommendations for a comprehensive TEE examination (8). The 8 cross-sections used in this study are among the 20 cross-sections included in that recommended comprehensive examination.

Although the practice guidelines do not specify how frequently or completely the examination should be repeated during surgery, we reasoned that the views most likely to reveal important changes in the heart should be repeated at least once early after separation from cardiopulmonary bypass and once after closure of the chest. We picked the cross-sections to repeat based on our previous experience and the published literature (9–11). Thus, a complete basic intraoperative examination required a minimum of 22 views recorded on videotape at the appropriate times: 12 after induction, 6 after bypass, and 4 after chest closure (Fig. 3). Additional views or required views recorded at nonrequired intervals were not analyzed.

The revised examination was introduced to the attending cardiac anesthesiologists at a group meeting, and the principal investigator of the study assisted in the first two revised examinations conducted by each faculty to ensure a full understanding of the required views and recording intervals. At the same time, laminated TEE guide sheets attached to the ultrasonographs at our institution were replaced with new guide sheets containing the revised examination and recording intervals. Thereafter, the prospective data collection began. All faculty members received monthly reports on their TEE performance relative to their past performance and the results of their colleagues.

After 3 mo of experience with the new examination, we began systematically comparing our faculty's interpretations of their recorded examination with the interpretations of experts. Before this time, the faculty

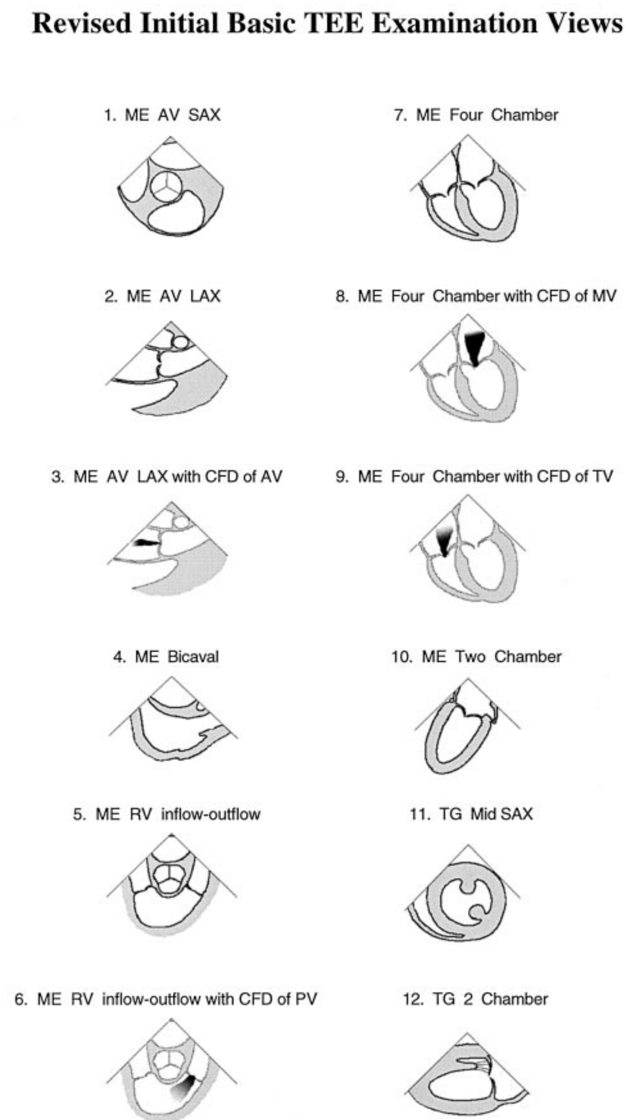


Figure 1. The 12 views of the initial precardiopulmonary bypass transesophageal echocardiography (TEE) examination. Please see Figure 2 for criteria for cross-sections. ME = midesophageal; AV = aortic valve; SAX = short axis; LAX = long axis; CFD = color flow Doppler; MV = mitral valve; TV = tricuspid valve; RV = right ventricle; TG = transgastric; PV = pulmonic valve.

members were not required to write down their intraoperative interpretations. Again, we used the ASA/SCA guidelines for basic TEE proficiency to define the necessary diagnoses and listed them on a standardized evaluation sheet supplied for each patient (Fig. 4,5). We confined this part of our study to the initial examination (i.e., the first 12 views recorded after induction of anesthesia) because, in most patients, subsequent views do not reveal new diagnoses. After surgery, all of the recordings were independently evaluated by two experts (JPM and WAS). If the independent reviewers did not agree on a diagnosis, they met and attempted to reach a consensus evaluation. In

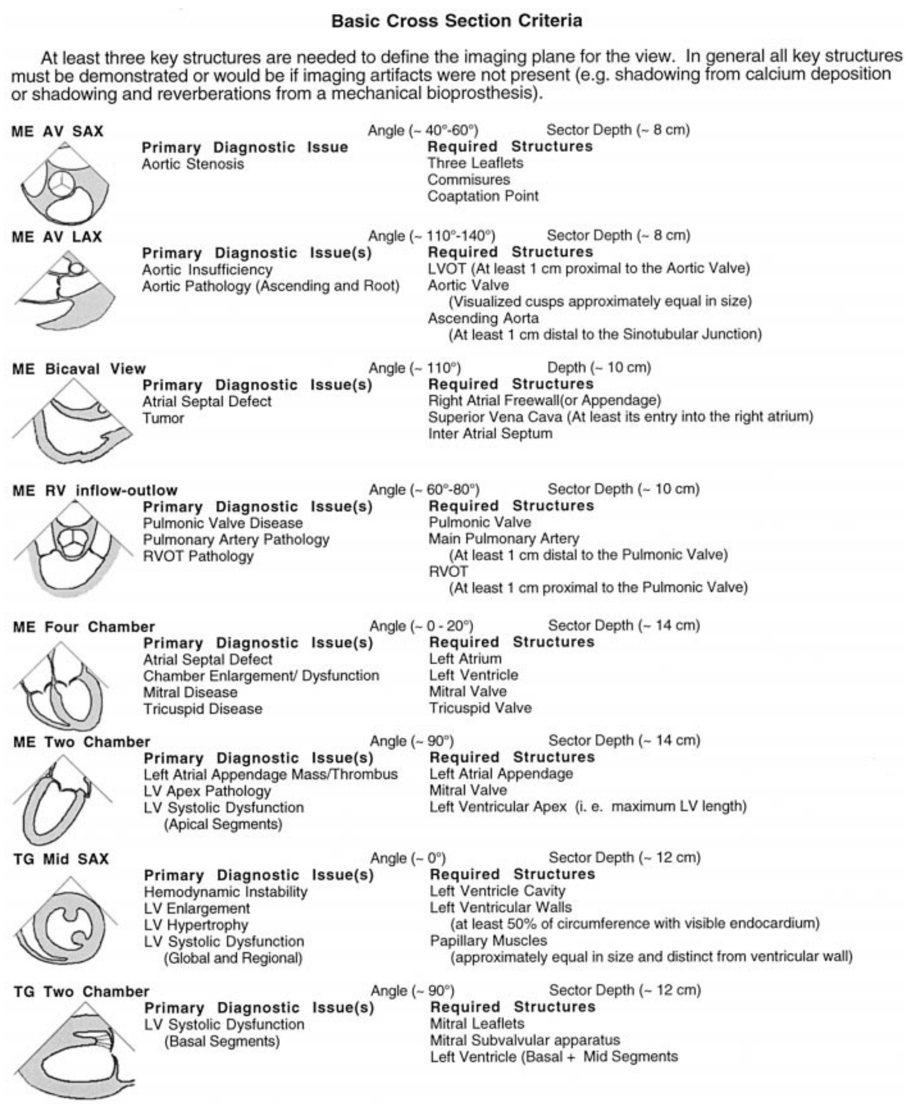


Figure 2. Descriptions of the basic cross-section criteria and related information distributed to the study subjects to assist them in adequate image acquisition. ME = midesophageal; AV = aortic valve; SAX = short axis; LAX = long axis; RV = right ventricle; TG = transgastric; LVOT = left ventricular outflow tract; RVOT = right ventricular outflow tract.

addition, any disagreement in diagnosis was reviewed independently by a third expert (NBS). If the third expert's diagnosis confirmed the consensus interpretation, then the diagnosis was considered valid. If not, or if consensus was not reached, then the corresponding recording was defined as uninterpretable.

Reproducibility in image evaluation was verified with the kappa statistic (12–14). Comparisons between retrospective and prospective results were evaluated with a χ^2 analysis with α and β set at 0.05 and 0.2, respectively.

Results

During the historical control period, 8 cardiac anesthesia faculty performed 144 intraoperative TEE studies. Five studies were excluded from analysis because the study tapes could not be located. During the prospective study period, the same 8 cardiac anesthesia faculty members performed 135 intraoperative TEE examinations. One study was excluded because of a technical ultrasound probe malfunction. Three additional studies were excluded because the faculty member did not perform the TEE examinations. Ultimately, the historical control group consisted of 139 examinations and the study group of 131 examinations.

Compared with historical controls, the rates of image acquisition increased for all views and by all providers. The increase occurred during the first month of the study ($P < 0.0001$) and was sustained throughout the prospective study period (Fig. 6). Image acquisition was largest in the precardiopulmonary bypass examination (88.0%) and decreased sequentially in the separation (77.0%) and postchest closure periods (64.2%).

Fifty-three intraoperative TEE examinations were performed during the interpretation phase of the study (the last 3 mo of the prospective study period).

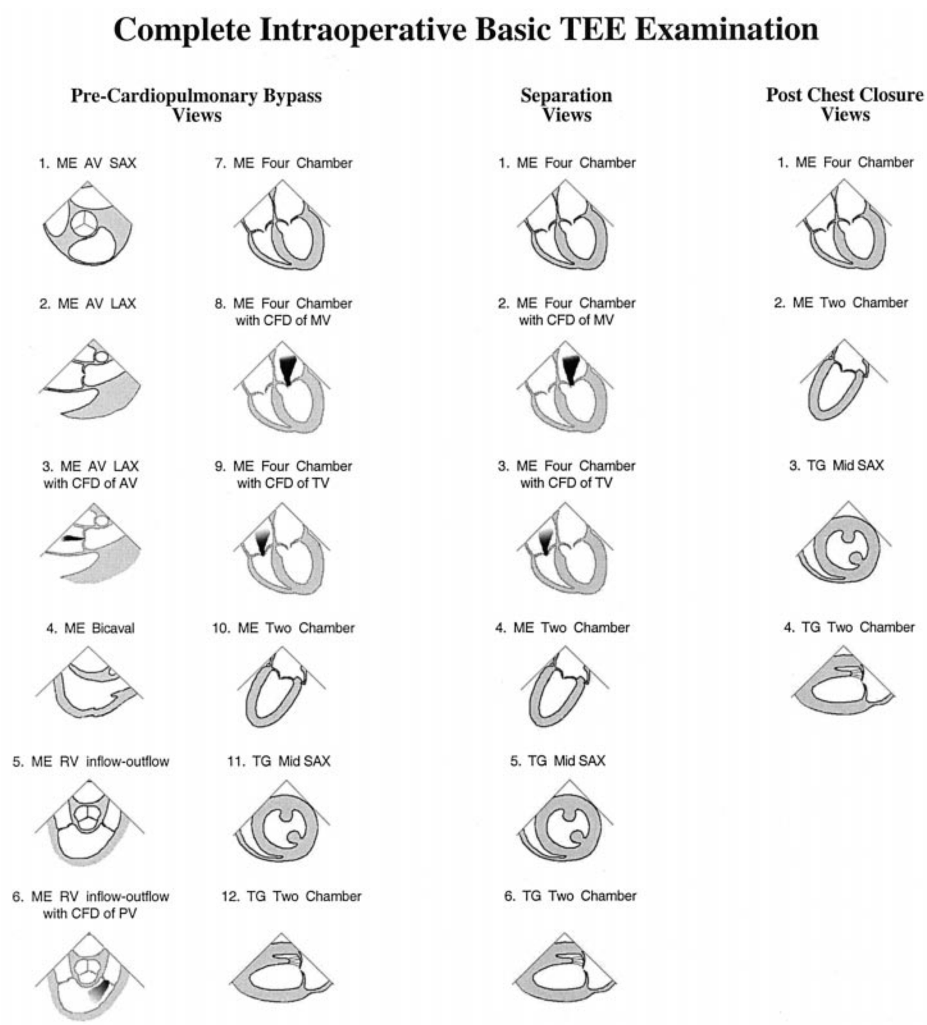
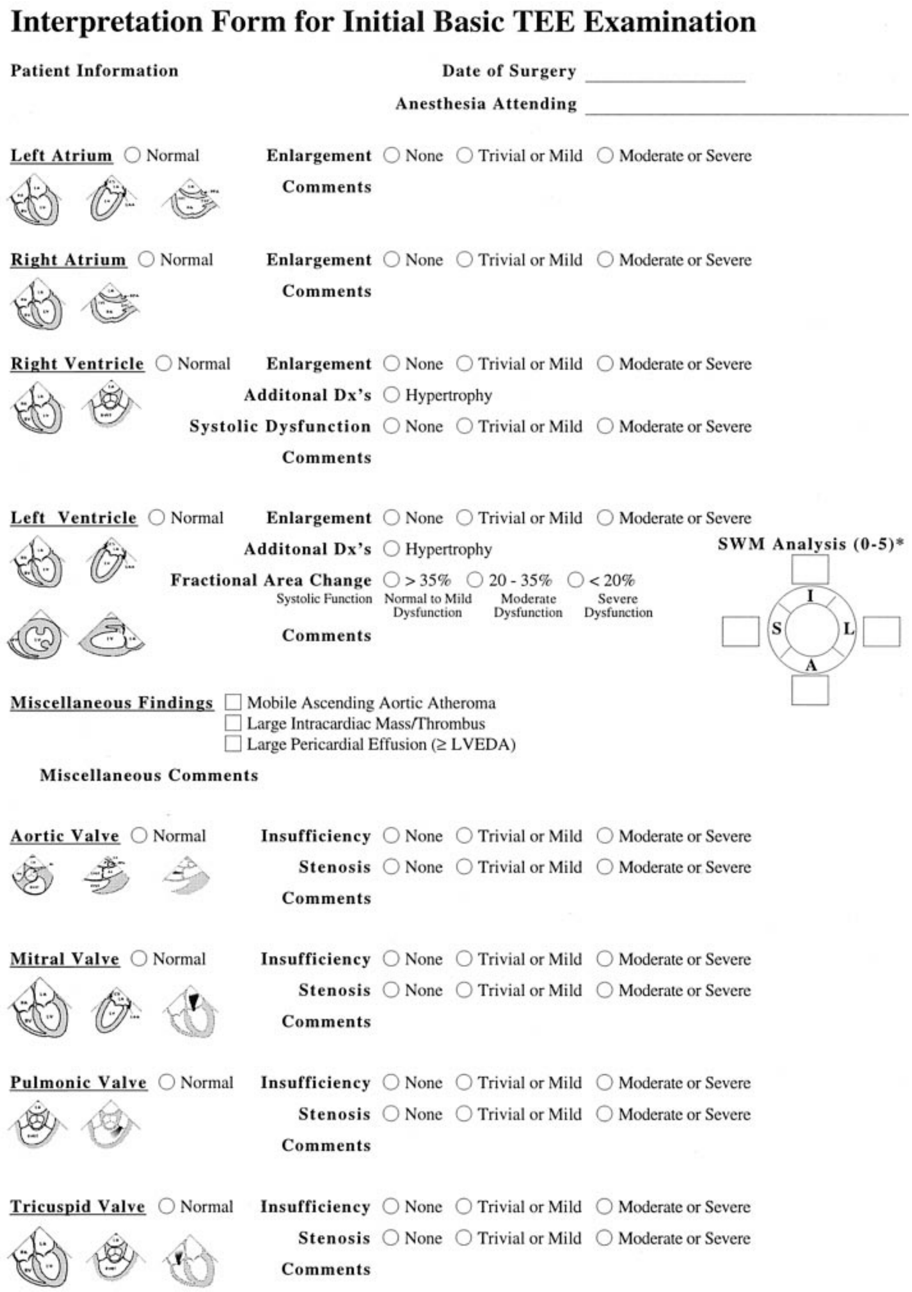


Figure 3. Twelve views are required before cardiopulmonary bypass (usually obtained before skin incision). Six of these views are required immediately after separation from bypass and four of these views again after chest closure. Depending on the type of surgery and pathology seen in these views, other views might be clinically indicated. However, for the purpose of this study, only these views at the times indicated were evaluated in this study. ME = midesophageal; AV = aortic valve; SAX = short axis; LAX = long axis; CFD = color flow Doppler; TV = tricuspid valve; RV = right ventricle; TG = transgastric; PV = pulmonic valve.

Ten interpretation forms were not completed because of communication errors and were excluded from the analysis. The remaining 43 studies were analyzed. There was disagreement between the experts in 8% of the possible determinations. Of these, a consensus was reached in 86%. A third expert (NBS) ultimately confirmed 86.7% of these consensus interpretations. In all, 3% of the possible determinations were excluded from further analysis. The intraoperative on-line interpretation of the faculty was correct 79% of the time when compared with the final "expert" evaluation. If omitted diagnoses (blanks on the evaluation sheets) are excluded, correct interpretations were made 94% of the time.

Discussion

Although the revised standard examination that we developed to meet the basic requirements published by the ASA/SCA task force was marginally more complicated than our previous standard examination, our faculty did a far better job completing this revised examination than they had done with the simpler examination. Our study design does not allow us to identify the exact reason for this result, but we hypothesize that two factors were most germane. First, the faculty members were aware of the importance given to nationally endorsed guidelines and wanted to demonstrate that they could meet them. Second, the study provided the faculty members with confidential feedback on their TEE performance and that of their colleagues. Clearly, natural instincts for self-improvement and peer performance played a role in our results, but so did the specific feedback on individual studies. Often, the confidential reports identified which cross-sections were missed and why some recorded cross-sections were deemed inadequate. Thus, our study had motivational and educational effects. Regardless of the ultimate mechanism, our study of our ability to meet the guidelines resulted in a near doubling of our overall acquisition rate of required cross-sections.



Interpretation Form for Initial Basic TEE Examination

Patient Information **Date of Surgery** ________________

Anesthesia Attending ________________________________

Left Atrium ○ Normal **Enlargement** ○ None ○ Trivial or Mild ○ Moderate or Severe
Comments

Right Atrium ○ Normal **Enlargement** ○ None ○ Trivial or Mild ○ Moderate or Severe
Comments

Right Ventricle ○ Normal **Enlargement** ○ None ○ Trivial or Mild ○ Moderate or Severe
Additonal Dx's ○ Hypertrophy
Systolic Dysfunction ○ None ○ Trivial or Mild ○ Moderate or Severe
Comments

Left Ventricle ○ Normal **Enlargement** ○ None ○ Trivial or Mild ○ Moderate or Severe
Additonal Dx's ○ Hypertrophy
Fractional Area Change Systolic Function ○ > 35% Normal to Mild Dysfunction ○ 20 - 35% Moderate Dysfunction ○ < 20% Severe Dysfunction
Comments
SWM Analysis (0-5)* I S L A

Miscellaneous Findings ☐ Mobile Ascending Aortic Atheroma
☐ Large Intracardiac Mass/Thrombus
☐ Large Pericardial Effusion (≥ LVEDA)

Miscellaneous Comments

Aortic Valve ○ Normal **Insufficiency** ○ None ○ Trivial or Mild ○ Moderate or Severe
Stenosis ○ None ○ Trivial or Mild ○ Moderate or Severe
Comments

Mitral Valve ○ Normal **Insufficiency** ○ None ○ Trivial or Mild ○ Moderate or Severe
Stenosis ○ None ○ Trivial or Mild ○ Moderate or Severe
Comments

Pulmonic Valve ○ Normal **Insufficiency** ○ None ○ Trivial or Mild ○ Moderate or Severe
Stenosis ○ None ○ Trivial or Mild ○ Moderate or Severe
Comments

Tricuspid Valve ○ Normal **Insufficiency** ○ None ○ Trivial or Mild ○ Moderate or Severe
Stenosis ○ None ○ Trivial or Mild ○ Moderate or Severe
Comments

Figure 4. Example of the form used to document interpretation of the initial transesophageal echocardiography (TEE) examination. Please see Figure 5 for reference information used to render the interpretations. SWM = segmental wall motion; LVEDA = left ventricular end-diastolic area.

Despite the marked improvement in our faculty's performance, not all required cross-sections were recorded or interpreted correctly. We believe there are two major reasons why a very experienced faculty could not always achieve all the basic requirements in this study. First, some cross-sections are not attainable in some patients no matter how skilled the operator. For instance, the left ventricular midesophageal short-axis cross-section is unattainable in 5%–10% of patients (9,11,15), probably because of anatomic variations in the relative positions of the heart, distal esophagus, and stomach. In addition, other responsibilities of the anesthesiologist may have preempted the acquisition of some cross-sections and/or proper interpretations. The finding that our faculty missed recording more cross-sections during the postbypass and chest closure periods than they did during the prebypass period suggests that "multitasking" responsibilities played a significant role in our results. Thus, although we used an examination that included only the minimal number of cross-sections required to meet the basic requirements of the guidelines, and although we studied very experienced and motivated faculty, the best they could achieve was an overall acquisition rate of 81% and a diagnostic accuracy rate of 79%. These rates should serve as more realistic

Reference Information for Basic Interpretation Form

Left Atrium/Right Atrium	Right Ventricle	Left Ventricle
ME 4 Chamber	ME 4 Chamber or ME Mid Sax	ME Mid Sax
Diameter (at end ventricular systole)	Size (at end diastole)	Ant-Posterior Diameter (at end diastole)
Ant-Posterior or Med-Lateral Diameter	Normal: ≈2/3 of LV Size	Normal: 43 ± 7 mm
Normal: 38 ± 6 mm	Trivial & Mild: 2/3 - LV Size	Trivial & Mild: 50 - 57 mm
Trivial & Mild: 44 - 50 mm	Moderate & Severe: > LV Size	Moderate & Severe: > 57 mm
Moderate & Severe: > 50 mm	Hypertrophy: > 9 mm at end diastole	Hypertrophy: > 11 mm at end diastole
	Assume Normal LV Size	

Aortic Valve

Aortic Insufficiency

Color Flow Doppler	Trivial	Mild	Moderate	Severe	View-Axis	Technique
Jet Height to LVOT Height Ratio (%)	1 - 24	25-46	47-64	≥ 65	AV-Long	CFD

Findings Associated with Moderate & Severe AI

Abnormal Valve Structure	Dilated Aortic Root	Fluttering of IVS and Anterior MV Leaflet
Premature AV Opening	Premature MV Closure	Reverse Doming of Anterior MV Leaflet
LV Overload/Dilation	Non-coapting Valve Cusps	Pre-systolic Mitral Regurgitation

Aortic Stenosis

General Criteria	Mild	Moderate	Severe	View-Axis	Technique
Aortic Valve Area (cm^2) (Normal 2-4)	1.2-2.5	0.75-1.2	< 0.75	ME AV-SAX	Planimetry

Findings Associated with Moderate & Severe AS

Calcium Deposition LV Hypertrophy LV Systolic Dysfunction Post-stenotic Dilation

Mitral Valve

Mitral Insufficiency

Color Flow Doppler	Trivial	Mild	Moderate	Severe	View-Axis	Technique
Width of Vena Contracta (mm)	< 2	< 4	4 - 5	> 5	4C	CFD

Findings Associated with Moderate & Severe MR

Failure of coaptation	Left Atrial Enlargement	Eccentric Jet
Increase in Left Atrial size in systole	Left Ventricular Enlargement	Jet enters pulmonary veins or LAA
Interatrial Septum bulges to right	Large PISA	Jet circles atrium

Mitral Stenosis

Findings Associated with Moderate & Severe MS

Abnormal Valve Structure	Calcium Deposition	Restricted Motion	Doming of MV Leaflets
Left Atrial Enlargement	Small LV Size	Decreased AV Motion	

Pulmonic Valve

Pulmonic Insufficiency (Color flow Doppler guidelines similar to aortic insufficiency (No validation.))

Findings Associated with Moderate & Severe PI

Right Atrial Enlargement Right Ventricular Enlargement Dilated Pulmonary Root

Tricuspid Valve

Tricuspid Insufficiency (Color flow Doppler guidelines similar to mitral regurgitation (No validation.))

Findings Associated with Moderate & Severe TR

Right Atrial Enlargement	Jet circles atrium	Large PISA
Right Ventricular Enlargement	Eccentric Jet	Interatrial Septum bulges to left
Increase in Right Atrial size in systole	Failure of coaptation	Inc. RV ejection

Segmental Wall Motion Analysis

Score	Description	Radial Shortening (Center to Endocardium)	Wall Thickening (Endocardium to Epicardium)
0	Not Evaluated/Interpretable	NA	NA
1	Normal	> 30 %	+++
2	Mild Hypokinesis	10 - 30 %	++
3	Severe Hypokinesis	< 10 %	+
4	Akinesis	No Radial Shortening	None
5	Dyskinesis	Radial Enlargement	Myocardial Thinning

Figure 5. This reference information form was available during all transesophageal echocardiography examinations, and contained the same guidelines used by the experts in making the definitive interpretations of all recordings. Reference values were taken from published texts and articles (9,19–25). ME = midesophageal; LV = left ventricular; LVOT = left ventricular outflow tract; AV = aortic valve; MV = mitral valve; IVS = interventricular septum; SAX = short axis; CFD = color flow Doppler; MR = mitral regurgitation; PISA = proximal isovelocity surface area; LAA = left atrial appendage; MS = mitral stenosis; PI = pulmonary insufficiency; RV = right ventricle; TR = tricuspid regurgitation; Inc. = increased; NA = not applicable.

benchmarks for us and for other practitioners than arbitrarily assumed rates.

The general applicability of our results is limited by the nature of our practice and our unblinded study design. The faculty members were assisted in the clinical care of the patients in our study by a second-year anesthesia resident. Thus, another physician was available to monitor the patient while the faculty performed TEE. Moreover, some of the surgical assistance was from residents, thereby allowing more time to perform TEE. Neither of these "teaching" factors would be present in nonacademic settings. However, the impact of the teaching factors on our results is probably limited, because any benefit the trainees provided may be offset by the additional responsibilities they created for the faculty. For instance, the second-year anesthesia residents present during this study were just beginning their training in cardiac anesthesia and typically required very close supervision and instruction throughout the anesthetic.

Another major limitation is our unblinded study design. Specifically, the faculty members were aware of the principal preoperative cardiac diagnosis in all of the patients studied. Thus, their diagnostic accuracy rate may have been better than it would have been if they been blinded. However, this limitation has little importance, because our goal was to test our faculty in a clinical setting where detailed preoperative cardiac assessment is a standard of care, and because many of the diagnoses on TEE were not available or different than those documented in the preoperative assessment. For instance, detailed documentation of segmental ventricular function is usually unavailable in our patients. Thus, our rates of image acquisition and

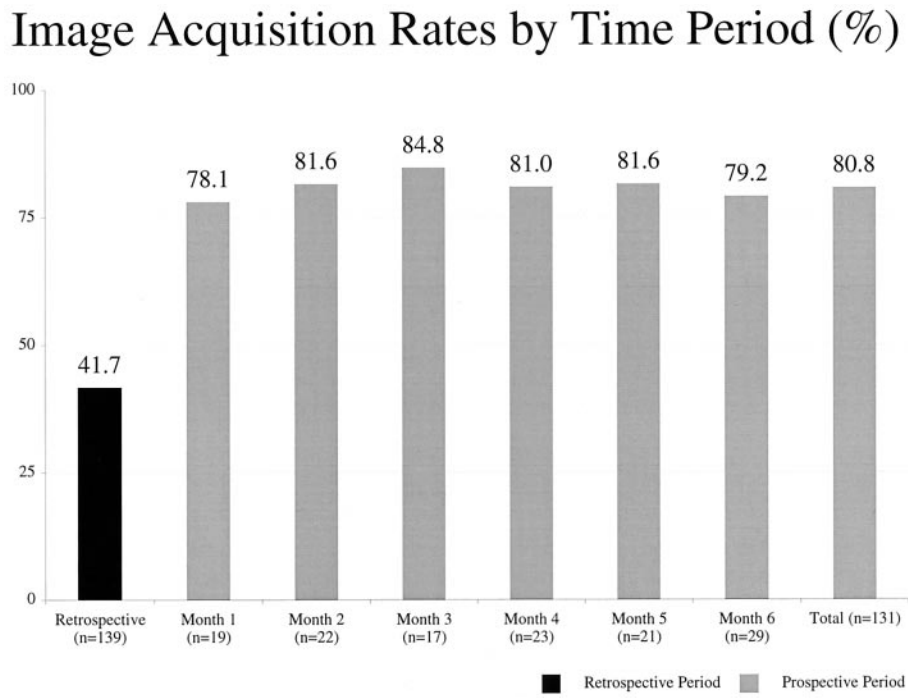


Figure 6. This graph depicts the improvements seen in all eight anesthesiologists in acquisition of the required images in the complete intraoperative examination. Data points were recorded as a percentage of total possible images. Please see Figure 3 for a depiction of the required images in a complete examination.

diagnostic accuracy may be widely applicable to other practices, but this remains to be proven by subsequent studies.

Just as our anesthesiologists were unblinded to preoperative data, so were our surgeons unblinded to the intraoperative TEE results. Thus, we do not know how often the course of surgery and anesthesia may have been correctly or incorrectly altered as a result of information provided or missed by TEE. By using staged blinding of intraoperative TEE results and an expert echocardiographer other than the attending anesthesiologist, Savage et al. (5) demonstrated that intraoperative TEE detected the need for an alteration in surgical or anesthetic management in 33% and 51%, respectively, of high-risk patients undergoing coronary surgery. From our results, we cannot determine whether the performance of our faculty for detection of important findings (those requiring patient management changes) was better or worse than for incidental findings. However, our study tested the faculty members' ability to detect major abnormalities of ventricular and valvular function as outlined in the guidelines for basic TEE. Their diagnostic accuracy for these abnormalities was more than 94% (if recording omissions are excluded), suggesting that if major changes in these vital cardiac functions were to have occurred, our faculty would have diagnosed them. Additional study will be required to determine whether an expert echocardiographer, in addition to the primary anesthesiologist, would significantly benefit adults undergoing cardiac surgery. Recently, this issue has become controversial for children requiring congenital heart surgery (16–18).

The fact that our expert observers were given only the cross-sections recorded by the faculty, and no supplemental TEE information, produced one other limitation of our study: any missing cross-sections with unique diagnostic information would theoretically result in under- or over-estimation of the performance of the faculty. Under-estimation of the faculty members' performance would occur if they had viewed the missing cross-section, failed to record it, but made the correct diagnosis. This correct diagnosis would not be confirmed by the experts because they viewed only the recorded cross-sections. Over-estimation of the faculty members' performance would occur if they failed to view and record the missing cross-section and therefore also missed making the diagnosis. Because the number of missing cross-sections was small during the interpretation part of the study (12%), and the chance that a new diagnosis would be evident in only the missing cross-section(s), we believe our estimates of faculty interpretation rates have not been significantly affected by missing data.

In conclusion, our attempt to assess our compliance with the ASA/SCA guidelines for basic intraoperative TEE resulted in a marked improvement in our intraoperative TEE practice. After institution of our study, the participating faculty anesthesiologists achieved an acquisition rate for required basic cross-sections of 81% and a diagnostic accuracy rate for basic interpretation of 79%.

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