Guidelines for Performing a Comprehensive Transesophageal Echocardiographic Examination: Recommendations from the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists

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INTRODUCTION

Transesophageal echocardiography (TEE) is a critically important cardiovascular imaging modality. The proximity of the esophagus to

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Abbreviations

ACHD = Adult congenital heart disease

ASE = American Society of Echocardiography

AUC = Appropriate use criteria

AV = Aortic valve

LA = Left atrial

LAX = Long-axis

LV = Left ventricular

ME = Midesophageal

MV = Mitral valve

PA = Pulmonary artery

PFO = Patent foramen ovale

PV = Pulmonic valve

RV = Right ventricular

RVOT = Right ventricular outflow tract

SAX = Short-axis

SCA = Society of Cardiovascular Anesthesiologists

TEE = Transesophageal echocardiography

TG = Transgastric

3D = Three-dimensional

TTE = Transthoracic echocardiography

TV = Tricuspid valve

2D = Two-dimensional

UE = Upper esophageal

much of the heart and great vessels makes it an excellent ultrasonic window, so that TEE provides additional and more accurate information than transthoracic echocardiography (TTE) for some patients, for several specific diagnoses and for many catheter-based cardiac interventions. Esophageal ultrasound was first reported in 1971 to measure flow in the aortic arch.[1] This was followed in 1976 by its use with M-mode echocardiography[2] and then in 1977 by two-dimensional (2D) imaging using a mechanical scanning transducer.[3] The modern era of TEE really began in 1982, with the introduction of flexible probes with phased-array transducers and manipulable tips,[4] initially as a single, horizontally oriented transducer (monoplane), next as two orthogonally oriented transducers (biplane), and then as adjustable transducers capable of rotating 180° within the tip of the probe (multiplane). More recently, transesophageal echocardiographic probes and systems capable of producing real-time three-dimensional (3D) images have been developed and have achieved wide use.

In 1999, the American Society of Echocardiography (ASE) and the Society of Cardiovascular Anesthesiologists (SCA) published guidelines for performing a comprehensive intraoperative multiplane transesophageal echocardiographic examination[5,6] that defined and named a set of 20 transesophageal echocardiographic views intended to facilitate and provide consistency in training, reporting, archiving, and quality assurance. Although the comprehensive intraoperative views have been widely adopted, they have a number of limitations. They were intended for intraoperative imaging and do not include some views important to other applications of TEE. The 20 views do not address any specific diagnoses and do not include some views needed to adequately examine common cardiac disorders. With significant advancement in technology, TEE has proven utility in a number of clinical arenas,[7-12] including the operating room, intensive care unit, interventional laboratory, and outpatient setting. Thus, TEE has become an essential imaging tool for cardiac surgeons, anesthesiologists, cardiac interventionalists, and clinical cardiologists. The present document is thus intended to be a guide to TEE in the following situations:

1. Diagnostic TEE: TEE performed to address a specific diagnostic question
2. Intraprocedural TEE
   a. Surgical-based procedure
   b. Catheter-based procedure

The writing group acknowledges that individual patient characteristics, anatomic variations, pathologic features, or time constraints imposed on performing TEE may limit the ability to perform all aspects of the examination described in this document. Although the beginner should seek a balance between a fastidiously complete, comprehensive examination and expedience, an experienced echocardiographer can complete the examination described here in a reasonable time period. The writing group also recognizes that there may be other entirely acceptable approaches and views of a transesophageal echocardiographic examination, provided they obtain similar information in a safe manner. In addition, although this document presents a suggested protocol of image acquisition, the order and number of views may differ for various indications. For some indications, additional special views are recommended, and these are described in the "Specific Structural Imaging" section of this document. The document is not intended to review specific indications for TEE or to cover extensively abnormalities seen with this modality.

The present guideline is divided into the following sections:

1. General guidelines
   a. Training and competence
   b. Indications for TEE
   c. Sedation and anesthesia
   d. Probe insertion and manipulation
2. Comprehensive transesophageal echocardiographic imaging examination
   a. Comprehensive 2D imaging examination
3. Specific structural imaging with TEE
   a. Mitral valve (MV) imaging
   b. Aortic valve (AV) and aorta imaging
   c. Pulmonic valve (PV) imaging
   d. Tricuspid valve (TV) imaging
   e. Assessment of ventricular size and function
   f. Left atrium and pulmonary veins
   g. Right atrium and venous connections
   h. Adult congenital heart disease (ACHD): transesophageal echocardiographic imaging algorithm

GENERAL GUIDELINES

Training and Certification

There are several published guidelines addressing training and maintenance of competence for physicians performing TEE that are summarized in Table 1.[13-16] TTE is a prerequisite to TEE for cardiology-based training but not anesthesiology-based training. Demonstration of competence in TEE is usually accomplished by successful completion of a training program and passing an examination. The National Board of Echocardiography, founded in 1998 in collaboration with the ASE and SCA, offers an examination and certification in TEE through three pathways: general diagnostic echocardiography, advanced perioperative TEE, and basic perioperative TEE. The European Society of Echocardiography together with the European Association of Cardiac Anaesthesiologists offers certification in TEE through a multiple-choice examination and the submission of a log book of studies performed that are graded by external examiners. Maintenance of competence in TEE is addressed in the American College of Cardiology clinical competence statement on echocardiography[17] and the ASE and SCA continuous quality improvement recommendations and guidelines in perioperative echocardiography[18] and is also summarized in Table 1.

Table 1 Published recommendations for training in TTE and TEE

	Basic		Advanced		Director	
Guidel ine	Total Exams	TEE Exams	Total Exams	TEE Exams	Total Exams	TEE Exams
ASE and the SCA guidelines for training in perioperative echocardiography (2002 and 2006)						
Number of studies	150*	50 performed	300*	150 performed	450*	300
Duration of Training (months)	NS		NS		NS	
Total CME hours	20		50		NS	
MOC: CME hours	15 within 3 yrs		15 within 3 yrs		15 within 3 yrs	
MOC: Number of TEEs/yr	50 interpreted 25 performed		50 interpreted 25 performed		50 interpreted 25 performed	
The American College of Cardiology/American Heart Association guidelines for training in TTE and TEE (2003) and COCATS 3 (2008)						
Number of studies	150 interpreted 75 performed	NA	300 interpreted 150 performed	25 insertions 50 (± 50) performed	750 interpreted 300 performed	NS
Duration of Training (months)	3		6		12	
Total CME hours	NS		NS		NS	
MOC: CME hours	5		5		>5	
MOC: Number of TEEs/yr	NA		25-50		NS	
Canadian Anesthesiologists' Society and the Canadian Society of Echocardiography (2006)						
Number of studies	150*	100 performed	300*	200 performed	450*	300
Duration of Training (months)	3		6		9	
Total CME hours	50 within 2 yrs		50 within 2 yrs		75 within 2 yrs	
MOC: CME hours	50 within 4 yrs		50 within 4 yrs		75 within 4 yrs	
MOC: Number of TEEs/yr	50		50		50 (75†)	
European Society of Echocardiography (2010)						
Number of studies	250† /150‡	75† /125§	NS		NS	
MOC: CME hours	30 within 5 yrs		30 within 5 yrs		30 within 5 yrs	
MOC: Number of TEEs/yr	50		50		50	

CME, Continuing medical education; *MOC*, maintenance of certification; *NA*, not applicable; *NS*, not specified.
*Includes complete echocardiographic examinations (TTE or TEE) interpreted and reported by trainee under supervision of a physician at the advanced or director level.
†Number of cases personally performed and reported over 24 months.
‡Number of TTE cases personally performed and reported over 24 months if TEE accredited.
§Number of TEE cases personally performed and reported over 24 months if TTE accredited.

The minimum knowledge required for the performance and interpretation of TEE and perioperative echocardiography in adults is addressed in the ACC clinical competence statement on echocardiography[17] and listed in Tables 2 and 3. This document recommends the performance of a comprehensive or complete transesophageal echocardiographic examination whenever possible. The present guideline describes the comprehensive transesophageal echocardiographic examination.

Indications for TEE

TEE has many uses in clinical practice. These uses can be divided into general indications and specific procedural indications (intraoperative and other procedural guidance). This document does not address basic perioperative TEE, which is a noncomprehensive examination for intraoperative monitoring and evaluation of hemodynamic instability covered by recently published guidelines.[19] General indications for TEE are listed in Table 4, but a complete list of explicit indications is not possible given the diversity of diseases and clinical scenarios in which echocardiography is used. Indications for TEE include the evaluation of cardiac and aortic structure and function in situations in which the findings will alter management and the results of TTE are nondiagnostic or TTE is deferred because there is a high probability that results will be nondiagnostic. Situations in which TTE may be nondiagnostic include, but are not limited to, detailed evaluation of the abnormalities in structures that are typically in the far field, such as the aorta and the left atrial (LA) appendage; evaluation of prosthetic heart valves; evaluation of native valve masses; evaluation of paravalvular abscesses (both native and prosthetic valves); and various uses in critically ill patients. Transthoracic echocardiographic image quality may be compromised in patients on ventilators, those with chest wall injuries, obese patients, and those unable to move into the left lateral decubitus position.

Specific procedural indications include the guidance of transcatheter procedures and assessments of cardiac structure and function that will influence cardiac surgery. Although guidance of procedures may require continuous imaging, TEE related to cardiac surgery typically requires an assessment before the institution of cardiopulmonary bypass and then an evaluation after weaning from cardiopulmonary bypass. Recent practice guidelines developed by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists[20] provide basic recommendations on the appropriate use of perioperative TEE, with the intent of improving surgical outcomes with evidence-based use of TEE. These specific procedural indications include the use of TEE in selected cardiac operations (i.e., valvular procedures) and thoracic aortic surgical procedures as well as use in some coronary artery bypass graft surgeries, guiding management of catheter-based intracardiac procedures (including septal defect closure or atrial appendage obliteration, but equivocally during dysrhythmia treatment) when general anesthesia

Table 2 Cognitive and technical skills required for competence in echocardiography

Panel A. Basic Cognitive Skills Required for Competence in Echocardiography	Panel B. Cognitive Skills Required for Competence in Adult TTE
• Knowledge of physical principles of echocardiographic image formation and blood flow velocity measurements.	• Basic knowledge for competence in echocardiography.
• Knowledge of instrument settings required to obtain an optimal image.	• Knowledge of appropriate indications for echocardiography.
• Knowledge of normal cardiac anatomy.	• Knowledge of the differential diagnostic problem in each case and the echocardiographic techniques required to investigate these possibilities.
• Knowledge of pathologic changes in cardiac anatomy due to acquired and congenital heart disease.	• Knowledge of appropriate transducer manipulation.
• Knowledge of fluid dynamics of normal blood flow.	• Knowledge of cardiac auscultation and electrocardiography for correlation with results of the echocardiogram.
• Knowledge of pathological changes in blood flow due to acquired heart disease and congenital heart disease.	• Ability to distinguish an adequate from an inadequate echocardiographic examination.
	• Knowledge of appropriate semi-quantitative and quantitative measurement techniques and ability to distinguish adequate from inadequate quantitation.
	• Ability to communicate results of the examination to the patient, medical record, and other physicians.
	• Knowledge of alternatives to echocardiography.

Panel C. Cognitive Skills Required for Competence in Adult TEE	Panel D. Technical Skills Required for Competence in Adult TEE
• Basic knowledge for echocardiography and TTE.	• Proficiency in using conscious sedation safely and effectively.
• Knowledge of the appropriate indications, contraindications, and risks of TEE.	• Proficiency in performing a complete transthoracic echocardiographic examination, using all echocardiographic modalities relevant to the case.
• Understanding of the differential diagnostic considerations in each clinical case.	• Proficiency in safely passing the TEE transducer into the esophagus and stomach, and in adjusting probe position to obtain the necessary tomographic images and Doppler data.
• Knowledge of infection control measures and electrical safety issues related to the use of TEE.	• Proficiency in operating correctly the ultrasonographic instrument, including all controls affecting the quality of the data displayed.
• Understanding of conscious sedation, including the actions, side effects and risks of sedative drugs, and cardiorespiratory monitoring.	• Proficiency in recognizing abnormalities of cardiac structure and function as detected from the transesophageal and transgastric windows, in distinguishing normal from abnormal findings, and in recognizing artifacts.
• Knowledge of normal cardiovascular anatomy, as visualized tomographically by TEE.	• Proficiency in performing qualitative and quantitative analyses of the echocardiographic data.
• Knowledge of alterations in cardiovascular anatomy that result from acquired and congenital heart diseases and of their appearance on TEE.	• Proficiency in producing a cogent written report of the echocardiographic findings and their clinical implications.
• Understanding of component techniques for transthoracic echocardiography and for TEE, including when to use these methods to investigate specific clinical questions.	
• Ability to distinguish adequate from inadequate echocardiographic data, and to distinguish an adequate from an inadequate TEE examination.	
• Knowledge of other cardiovascular diagnostic methods for correlation with TEE findings.	
• Ability to communicate examination results to the patient, other health care professionals, and medical record.	

Panel A lists the basic cognitive skills required for competence in echocardiography. Panel B lists the cognitive skills required for competence in TTE. Panel C lists the cognitive skills required for competence in TEE. Panel D lists the technical skills required for competence in TEE.
Modified from Quinones *et al.*[17]

is provided and intracardiac ultrasound is not used, noncardiac surgery when patients have known or suspected cardiovascular pathology that may affect outcomes, and in critical care patients when diagnostic information is not obtainable by TTE and this information is expected to alter management.

Appropriate use criteria (AUC) have recently been developed for imaging modalities. The goal of AUC is to categorize the clinical situations in which diagnostic tests and procedures such as TEE are used and to determine if such use is appropriate or not. Although the AUC for TEE in published documents are not all inclusive, they

Table 3 Cognitive and technical skills required for competence in perioperative echocardiography

Panel A. Cognitive Skills Needed to Perform Perioperative Echocardiography at a Basic Level	Panel B. Technical Skills Needed to Perform Perioperative Echocardiography at a Basic Level
• Basic knowledge for echocardiography (Table 1).	• Ability to operate the ultrasound machine, including controls affecting the quality of the displayed data.
• Knowledge of the equipment handling, infection control, and electrical safety recommendations associated with the use of TEE.	• Ability to perform a TEE probe insertion safely in the anesthetized, intubated patient.
• Knowledge of the indications and the absolute and relative contraindications to the use of TEE.	• Ability to perform a basic TEE examination.
• General knowledge of appropriate alternative diagnostic modalities, especially transthoracic, and epicardial echocardiography.	• Ability to recognize major echocardiographic changes associated with myocardial ischemia and infarction.
• Knowledge of the normal cardiovascular anatomy as visualized by TEE.	• Ability to detect qualitative changes in ventricular function and hemodynamic status.
• Knowledge of commonly encountered blood flow velocity profiles as measured by Doppler echocardiography.	• Ability to recognize echocardiographic manifestations of air embolization.
• Detailed knowledge of the echocardiographic presentations of myocardial ischemia and infarction.	• Ability to visualize cardiac valves in multiple views and recognize gross valvular lesions and dysfunction.
• Detailed knowledge of the echocardiographic presentations of normal and abnormal ventricular function.	• Ability to recognize large intracardiac masses and thrombi.
• Detailed knowledge of the physiology and TEE presentation of air embolization.	• Ability to detect large pericardial effusions.
• Knowledge of native valvular anatomy and function, as displayed by TEE.	• Ability to recognize common artifacts and pitfalls in TEE examinations.
• Knowledge of the major TEE manifestations of valve lesions and of the TEE techniques available for assessing lesion severity.	• Ability to communicate the results of a TEE examination to patients and other health care professionals and to summarize these results cogently in the medical record.
• Knowledge of the principal TEE manifestations of cardiac masses, thrombi, and emboli; cardiomyopathies; pericardial effusions and lesions of the great vessels.	

Panel C. Cognitive Skills Needed to Perform Perioperative Echocardiography at the Advanced Level	Panel D. Technical Skills Needed to Perform Perioperative Echocardiography at the Advanced Level
• All the cognitive skills defined for the basic level.	• All the technical skills defined for the basic level.
• Knowledge of the principles and methodology of quantitative echocardiography.	• Ability to perform a complete TEE examination.
• Detailed knowledge of native valvular anatomy and function. Knowledge of prosthetic valvular structure and function. Detailed knowledge of the echocardiographic manifestations of valve lesions and dysfunction.	• Ability to quantify subtle echocardiographic changes associated with myocardial ischemia and infarction.
• Knowledge of the echocardiographic manifestations of CHD.	• Ability to utilize TEE to quantify ventricular function and hemodynamics.
• Detailed knowledge of echocardiographic manifestations of pathologic conditions of the heart and great vessels (such as cardiac aneurysms, hypertrophic cardiomyopathy, endocarditis, intracardiac masses, cardioembolic sources, aortic aneurysms and dissections, pericardial disorders, and post-surgical changes).	• Ability to utilize TEE to evaluate and quantify the function of all cardiac valves including prosthetic valves (e.g., measurement of pressure gradients and valve areas, regurgitant jet area, effective regurgitant orifice area). Ability to assess surgical intervention on cardiac valvular function.
• Detailed knowledge of other cardiovascular diagnostic methods for correlation with TEE findings.	• Ability to utilize TEE to evaluate congenital heart lesions. Ability to assess surgical intervention in CHD.
	• Ability to detect and assess the functional consequences of pathologic conditions of the heart and great vessels (such as cardiac aneurysms, hypertrophic cardiomyopathy, endocarditis, intracardiac masses, cardioembolic sources, aortic aneurysms and dissections, and pericardial disorders). Ability to evaluate surgical intervention in these conditions if applicable.
	• Ability to monitor placement and function of mechanical circulatory assistance devices.

CHD, Coronary heart disease.
Panel A lists the cognitive skills required for competence in perioperative echocardiography at the basic level. Panel B lists the technical skills required for competence in perioperative echocardiography at the basic level. Panel C lists the cognitive skills required for competence in perioperative echocardiography at the advanced level. Panel D lists the technical skills required for competence in perioperative echocardiography at the advanced level. Modified from Quinones *et al.*[17]

Table 4 General indications for TEE

General indication	Specific examples
1. Evaluation of cardiac and aortic structure and function in situations where the findings will alter management and TTE is non-diagnostic or TTE is deferred because there is a high probability that it will be non-diagnostic.	a. Detailed evaluation of the abnormalities in structures that are typically in the far field such as the aorta and the left atrial appendage. b. Evaluation of prosthetic heart valves. c. Evaluation of paravalvular abscesses (both native and prosthetic valves). d. Patients on ventilators. e. Patients with chest wall injuries. f. Patients with body habitus preventing adequate TTE imaging. g. Patients unable to move into left lateral decubitis position.
2. Intraoperative TEE.	a. All open heart (i.e., valvular) and thoracic aortic surgical procedures. b. Use in some coronary artery bypass graft surgeries. c. Noncardiac surgery when patients have known or suspected cardiovascular pathology which may impact outcomes.
3. Guidance of transcatheter procedures	a. Guiding management of catheter-based intracardiac procedures (including septal defect closure or atrial appendage obliteration, and transcatheter valve procedures).
4. Critically ill patients	a. Patients in whom diagnostic information is not obtainable by TTE and this information is expected to alter management.

Table 5 AUC ratings for some scenarios of TEE as initial or supplemental test

Appropriate
- Use of TEE when there is a high likelihood of a nondiagnostic TTE due to patient characteristics or inadequate visualization of relevant structures.
- Re-evaluation of prior TEE finding for interval change (e.g., resolution of thrombus after anticoagulation, resolution of vegetation after antibiotic therapy) when a change in therapy is anticipated.
- Guidance during percutaneous noncoronary cardiac interventions including, but not limited to, closure device placement, radiofrequency ablation, and percutaneous valve procedures.
- Suspected acute aortic pathology including but not limited to dissection/transection.
- Evaluation of valvular structure and function to assess suitability for, and assist in planning of, an intervention.
- To diagnose infective endocarditis with a moderate or high pretest probability (e.g., staph bacteremia, fungemia, prosthetic heart valve, or intracardiac device).
- Evaluation for cardiovascular source of embolus with no identified noncardiac source.
- Atrial fibrillation/flutter: evaluation to facilitate clinical decision making with regard to anticoagulation, cardioversion, and/or radiofrequency ablation.

Uncertain
- Evaluation for cardiovascular source of embolus with a previously identified noncardiac source.

Inappropriate
- Routine use of TEE when a diagnostic TTE is reasonably anticipated to resolve all diagnostic and management concerns.
- Surveillance of prior TEE finding for interval change (e.g., resolution of thrombus after anticoagulation, resolution of vegetation after antibiotic therapy) when no change in therapy is anticipated.
- Routine assessment of pulmonary veins in an asymptomatic patient status post pulmonary vein isolation.
- To diagnose infective endocarditis with a low pretest probability (e.g., transient fever, known alternative source of infection, or negative blood cultures/atypical pathogen for endocarditis).
- Evaluation for cardiovascular source of embolus with a previously identified noncardiac source.
- Atrial fibrillation/flutter: evaluation when a decision has been made to anticoagulate and not to perform cardioversion.

Modified from Douglas *et al.*[21]

identify common scenarios encountered in practice. The most recent version of the AUC for echocardiography[21] evaluated only 15 clinical scenarios for TEE as the test of first choice and did not consider intraoperative indications. The authors of the AUC acknowledged that their list of scenarios was not exhaustive and that some of the scenarios ranked as appropriate for TTE are also appropriate for TEE. A list of AUC rankings is shown in Table 5. Given the many uses of TEE and the potential for overuse or unnecessary use, the AUC approach is a worthwhile methodology when considering indications for TEE. Although the AUC methodology is undergoing modification and the terminology describing appropriateness is changing, the concepts and recommendations for TEE are unchanged.[22] The Intersocietal Accreditation Commission stated, "As part of the ongoing quality improvement program, facilities providing echocardiography imaging must incorporate the measurement of the appropriate criteria published and/or endorsed by professional medical

Table 6 List of absolute and relative contraindications to transesophageal echocardiography

Absolute contraindications	Relative contraindications
• Perforated viscus • Esophageal stricture • Esophageal tumor • Esophageal perforation, laceration • Esophageal diverticulum • Active upper GI bleed	• History of radiation to neck and mediastinum • History of GI surgery • Recent upper GI bleed • Barrett's esophagus • History of dysphagia • Restriction of neck mobility (severe cervical arthritis, atlantoaxial joint disease) • Symptomatic hiatal hernia • Esophageal varices • Coagulopathy, thrombocytopenia • Active esophagitis • Active peptic ulcer disease

GI, Gastrointestinal.
Modified from Hilberath *et al.*[26]

Table 7 List of complications reported with TEE and the incidence of these complications during diagnostic TEE and intraoperative TEE[7,24-31]

Complication	Diagnostic TEE	Intraoperative TEE
Overall complication rate	0.18-2.8% (refs 24,25)	0.2% (ref 7)
Mortality	<0.01-0.02% (refs 24,25,27)	0% (ref 7)
Major morbidity	0.2% (ref 27)	0-1.2% (refs 7,28,29)
Major bleeding	<0.01% (ref 24)	0.03-0.8% (refs 7,28)
Esophageal perforation	<0.01 (ref 24)	0-0.3% (refs 7,28,29)
Heart failure	0.05% (ref 28)	
Arrhythmia	0.06-0.3% (refs 7,28,30)	
Tracheal intubation	0.02% (ref 30)	
Endotracheal tube malposition		0.03% (ref 7)
Laryngospasm	0.14% (ref 27)	
Bronchospasm	0.06-0.07% (refs 24,30)	
Dysphagia	1.8 % (ref 31)	
Minor pharyngeal bleeding	0.01-0.2% (refs 24,25,27)	0.01% (ref 7)
Severe odynophagia		0.1% (ref 7)
Hoarseness	12% (ref 31)	
Lip injury	13% (ref 31)	
Dental injury	0.1% (ref 31)	0.03% (ref 7)

ref, Reference.

organization(s)….Documentation of measurement of AUC will be mandatory requirements for accreditation."[23]

Understanding of, and adherence to, the indications and contraindications for TEE is just one aspect of ensuring that a high level of quality is followed. The safety of TEE has been documented in multiple studies,[7,24,25] and risks of TEE-related complications have recently been reviewed.[26] Table 6 lists the relative and absolute contraindications to TEE. Patients with relative contraindications to TEE should be evaluated on a case-by-case basis to determine if the benefits of the procedure performed with appropriate precautions (such as not advancing probe past the midesophagus, limiting probe manipulation, etc) exceed the potential risks of complication. Whenever there is a question as to whether gastrointestinal symptoms or pathology present poses a risk for TEE, it is strongly recommended that clearance for the procedure from a gastroenterologist be obtained. Some processes and systemic illnesses may affect esophageal tissue, resulting in increased risk for perforation during TEE. These include radiation, scleroderma of the esophagus, and achalasia. Before considering TEE, the severity of such processes must be evaluated to determine if they present an absolute or relative contraindication to introduction of the transesophageal echocardiographic probe. Complications of TEE vary as a function of the setting (intraoperative vs ambulatory)[26] and the size of the probe used. A partial list of the incidence of such complications as reported in the literature is presented in Table 7.[7,24,25,27-31]

Review of all aspects of quality operations in a TEE laboratory is beyond the scope of this document. Specific quality guidelines have been developed for the laboratory structure (physical laboratory, equipment, physician training and certification), the imaging process (patient selection, image acquisition, image interpretation, results communication), and quality assessment.[32]

Management of Patient Sedation

TEE is a semi-invasive procedure with well-defined criteria for training of personnel.[15] There are three groups of patients to consider when discussing management of sedation for an individual requiring TEE: (1) awake patients (either ambulatory or inpatient), (2)

Table 8 American Society of Anesthesiologists Physical Status Classification

American Society of Anesthesiologists Physical Status Classification	
Class I	A normal healthy patient
Class II	A patient with mild systemic disease
Class III	A patient with severe systemic disease
Class IV	A patient with severe systemic disease that is a constant threat to life
Class V	A moribund patient who is not expected to survive without operation
Class VI	A declared brain-dead patient whose organs are being removed for donor purposes
E	If the surgery is an emergency, the physical status classification is followed by "E"

Modified from the American Society of Anesthesiology, Relative Value Guide 2012, page xii, Code 99140.

Table 9 Modified Aldrete Score

Criteria	Ability	Score
Activity	Able to move voluntarily or on command	
	4 extremities	2
	2 extremities	1
	0 extremities	0
Respiration	Able to breathe and cough freely	2
	Dyspnea; shallow or limited breathing	1
	Apneic	0
Circulation	BP ± 20 mmHg presedation level	2
	BP ± 20-50 mmHg of presedation level	1
	BP ± 50 mmHg presedation level	0
Consciousness	Fully Awake	2
	Arousable on calling	1
	Not responding	0
Oxygen Saturation	Able to maintain > 92% on room air	2
	Needs oxygen to maintain saturation > 90%	1
	Oxygen < 90% even with supplemental oxygen	0

ventilated patients in the intensive care unit, and (3) anesthetized patients in the operating room. This section focuses on patients undergoing procedures in the echocardiography laboratory with conscious (moderate) sedation. In all three cohorts, preprocedural assessment and planning are necessary to ensure safe conduct of the procedure. Practice guidelines for sedation and analgesia by nonanesthesiologists[6,33] provide the definition of moderate sedation as purposeful response to verbal or tactile stimulation with spontaneous ventilation without need for airway support (i.e., jaw thrust). The Intersocietal Accreditation Commission guidelines address the requirements for laboratory certification in adult TEE.[23] Organizations accrediting hospitals and facilities recognize certain performance standards related to sedation policies, lab personnel, and equipment.

After confirmation of an appropriate indication and receipt of an order for the examination, a patient can be scheduled for the procedure. The vast majority of transesophageal echocardiographic procedures are performed while the patient is sedated, typically using the moderate sedation standard. Patients undergoing procedures with sedation should abstain from food and beverages (other than clear liquids) for a minimum of 6 hours before the planned procedure and restrain from all intake for 3 hours before the procedure.[34] Patients with delayed gastric emptying and other aspiration risks may need a longer period of fasting or preprocedural administration of agents such as metoclopramide to minimize the risk for residual gastric contents and aspiration. Patients can be instructed to take their medications on schedule with a small sip of water as indicated. Intravenous access is required for transesophageal echocardiographic procedures and the left arm is recommended to facilitate contrast injections when evaluating the presence of intracardiac shunts. This recommendation is based on the high incidence (up to 4.3% of the population referred for cardiac evaluation) of persistent left superior vena cava.[35,36] The right arm may otherwise be preferred when the patient is placed in the left lateral decubitus position. A 20-gauge catheter is typically acceptable for these procedures.

Physicians must screen patients for medical problems that contraindicate or increase the risk of conscious sedation. Use of the American Society of Anesthesiologists physical status classification is recommended as part of the preprocedural screening (Table 8).

Consideration should be given to the use of telemetry in addition to the standard monitors in patients with American Society of Anesthesiologists status 3 or higher, because they are higher risk for cardiac and pulmonary complications. Allergies should be reviewed, as well as current or recent use of medications and alcohol or recreational drugs that will affect sedation technique. The procedure room must be large enough to allow needed personnel as noted, a stretcher for the patient, monitors, and echocardiographic equipment. The room must be equipped with an oxygen source and suction devices. Airway equipment (endotracheal tubes and laryngoscopes) in case of respiratory failure and emergency medications for Advanced Cardiovascular Life Support protocol should be easily accessible. In addition, methylene blue, flumazenil, and naloxone should be readily available if appropriate.

In addition to assessment of global health status, the practitioner will also perform an airway examination to ensure that the patient is not in a high-risk category for sedation because of risk for airway compromise. Although it is imperfect, anesthesiologists use the Mallampati airway classification system[21] to evaluate patients before the administration of any anesthetic, including conscious sedation. In most cases, a grade I airway will be easy to mask-ventilate and intubate. A grade IV airway will be difficult to ventilate and/or intubate. In addition to this assessment, the clinician should ensure adequate neck range of motion and adequate oral opening. In obese patients and those with decreased neck mobility, if the distance from the lower jaw to the hyoid bone is less than three fingerbreadths, this is associated with difficulty mask-ventilating and/or intubating the patient.

Before the administration of sedation, a modified Aldrete score (Table 9) should be calculated.[37] Conscious sedation is typically defined as a score of 9 or 10, with a score of <9 defining oversedation. Patients must return to their baseline before discharge from the echocardiography laboratory recovery area. Even short-acting medications will not be metabolized for a few hours, and ambulatory patients should not drive but rather bring individuals who can see them safely home. Facilities must have conscious sedation policies, and all medical and technical staff members must be familiar with these policies and adhere to the requirements, including ongoing medical education related to conscious sedation to ensure optimum patient care. There must be adequate personnel to ensure patient monitoring and administration of sedation in addition to assisting the physician with the ultrasound equipment as needed. At many facilities, a registered nurse is required to administer sedation and monitor the patient.

Monitoring during conscious sedation requires, at a minimum, the assessment of heart rate, noninvasive blood pressure monitoring, respiratory rate, and oxygen saturation. Significant changes in blood pressure or heart rate should be avoided, particularly in cases performed for hemodynamic abnormalities that may be altered by these changes (i.e., valvular stenosis or regurgitation). Capnography is strongly recommended for conscious sedation and patients at risk for respiratory complications. It is mandated for deep sedation and anesthesia.

During the procedure, the vital signs, oxygen saturation, and medical stability of the patient should be periodically evaluated and recorded. Vital signs should be monitored continuously until they have returned to the patient's baseline, oxygen saturation is at baseline without supplemental oxygen, and the patient is fully awake. Discharge instructions specific to the procedure and necessary follow-up are required. Ensure that the patient knows which individual to contact in case of complications or concerns.

Sedation and Anesthesia

The following section is a review of current practices for sedation and anesthesia during the performance of a comprehensive transesophageal echocardiographic evaluation. It should be understood that organizations accrediting hospitals and facilities recognize certain performance standards related to sedation policies, lab personnel, and equipment and that each facility will have its own policies. The following should serve as a guideline and cannot replace these established policies.

Awake patients usually have the oropharynx anesthetized with topical administration of a local anesthetic before administration of sedation. Benzocaine, Cetacaine, or viscous lidocaine is most commonly used. Although an accepted practice, studies of topical anesthesia efficacy in the endoscopy population have been mixed.[38] A randomized, double-blind, placebo-controlled trial of isolated topical pharyngeal anesthesia (without intravenous sedation) for endoscopy showed reduced discomfort of intubation compared with placebo, only in younger patients and first-time examinees.[39] Multiple prospective studies of patient preference[40] and procedural tolerance[41] favor the use of topical anesthesia. Topical anesthesia may be achieved with a variety of different agents, either by spray, gargle, painting, or lozenge. Smith *et al.*[42] suggested that although either method was probably equally effective, administration by spray was preferred by patients over gargle techniques. Advantages and disadvantages for both methods exist. Administration by spray allows direct application to the posterior pharyngeal wall. The spray application may be inadvertently inhaled, however, causing uncontrolled coughing or anesthesia of the larynx, which can increase the risk for aspiration. Gel application reduces absorption of anesthetic but may not adequately anesthetize the entire oropharynx; direct application of gel has also been used. The physician-patient interaction and efficacy of verbal sedation should not be underestimated.

The risk for methemoglobinemia with excess use of benzocaine is rare (0.07%–0.12%) and possibly related to a number of clinical factors, including age, dose of medication, enzyme deficiencies, malnutrition, mucosal erosion, hospitalization, sepsis, and anemia.[43,44] Signs and symptoms of methemoglobinemia (methemoglobin level > 1.5%) include dyspnea, nausea, tachycardia, cyanosis, and a drop in oxygen saturation by pulse oximetry. Arterial blood with elevated methemoglobin levels has a characteristic chocolate-brown color compared with normal bright red oxygen-containing arterial blood. Treatment of this acquired disease is imperative because with severe methemoglobinemia (methemoglobin level > 55%), patients develop lethargy, stupor, and deteriorating consciousness. Higher levels (methemoglobin level > 70%) may result in dysrhythmias, circulatory failure, neurologic depression, and death.[45]

Methemoglobinemia can be treated with supplemental oxygen and methylene blue 1% solution (10 mg/mL) 1 to 2 mg/kg administered intravenously slowly over 5 min followed by intravenous flush with normal saline.[45] Note that methylene blue is associated with serotonin syndrome in patients taking selective serotonin reuptake inhibitors and should be avoided in these patients. Adequate topical anesthesia to the tongue, palate, tonsilar pillars, and posterior pharynx will facilitate probe passage and minimize the amount of intravenous sedation needed. Fully anesthetized patients do not require topical local anesthetic. Ventilated patients in the intensive care unit may benefit from topical agents, as this will diminish or eliminate the need for additional sedative agents. Some patients will tolerate TEE with no sedation if topical anesthesia is adequate.

The most commonly used sedative agents are benzodiazepines, because of their anxiolytic properties, with midazolam being the best choice for most transesophageal echocardiographic procedures. Midazolam has a quick onset (1–2 min) and short duration of action (typically 15–30 min), and it provides better amnesia than other benzodiazepines. Diazepam and lorazepam can also be used but are longer acting and will likely lead to longer recovery and time to discharge. Benzodiazepines should be avoided in pregnancy, in particular in the first trimester, because of known risk for birth defects in the fetus. Dosing of all agents is based on patient history and overall health status. Elderly individuals are at risk for delirium and confusion, and benzodiazepines should be used sparingly in this group. Small starting doses of midazolam for frail or elderly individuals not on chronic benzodiazepine therapy should be used, with small incremental addition until appropriate level of anxiolysis and sedation are achieved. Benzodiazepines can be avoided altogether via the use of topical anesthetic, low-dose analgesics, and reassurance from the care team, in concert with an expeditious examination. Most facilities have dosage maximums regardless of sedation level above which consultation with an anesthesia care provider is indicated.

Opioids are frequently used as adjuncts to the procedure to offset the discomfort of probe insertion and manipulation. Opioids and benzodiazepines are synergistic, and caution is warranted when administering both simultaneously. Fentanyl and meperidine are the most commonly used sedation agents, though the use of meperidine has decreased over time because of increased incidence of respiratory depression and contraindications in patients with renal failure because of the accumulation of active metabolites. Opioids in general present a risk for respiratory depression, nausea, and vomiting. In frail or elderly individuals, the starting dose should be decreased by half. Patients on chronic benzodiazepines or opioids should be instructed to take their normal doses before the procedure and should be expected to have tolerance that will necessitate higher starting and overall dosing to achieve the same end point.

Propofol is an intravenous sedative hypnotic that is not typically used by nonanesthesiologists because of the high risk for apnea associated with dose titration and the need for airway management. Many states have laws preventing the administration of propofol by nonanesthesiologists except in ventilated patients. The advantage of propofol for sedation during TEE and endoscopic procedures despite its higher expense is that it provides rapid sedation and recovery with fewer lingering sedation-related side effects and no increase in cardiopulmonary complications compared with the benzodiazepine-narcotic combination.[46] Its use in the echocardiography lab requires scheduling coordination with anesthesiology services. The cost-effectiveness and efficacy of this approach compared with traditional sedative agents have not been studied.

Intravenous reversal agents are available for benzodiazepines (flumazenil) and opioids (naloxone). There is no reversal agent available for propofol other than drug metabolism. The starting dose of flumazenil is 0.2 mg, with additional doses of 0.2 mg every minute until reversal has been achieved. There is a risk for withdrawal seizures in patients who are on chronic therapy. Flumazenil's duration of action is 10 to 15 min, so the patient should be monitored for ≥30 min after use of this agent to ensure that resedation does not occur. Naloxone dosing for apnea due to narcotics is 0.4 mg. A partial dose can be given to patients for whom partial opioid reversal is preferred. The starting dose is 0.1 mg, with an additional dose every minute until the respiratory rate is >12 breaths/min and the patient has returned to spontaneous respirations and appropriate level of consciousness.

Probe Insertion Techniques

After adequate application of topical anesthetic, a bite block should be placed in the patient's mouth before the administration of conscious sedation. The patient is typically placed in the left lateral decubitus position, and the echocardiographer stands facing the patient on the left-hand side of the stretcher. Before probe insertion, the echocardiographer should check the probe for any obvious damage, ensure proper probe function, and confirm that the probe is in the unlocked position. The transesophageal echocardiographic probe is inserted to the back of the pharynx, which may require slight anteflexion of the probe. The patient is asked to swallow and the probe is advanced in a neutral position down the esophagus as the patient swallows. Ensure that the probe is in a neutral position during this maneuver and midline in the pharynx to avoid placing the probe in the piriform fossa. With a bite block in place, it is safe to insert one or two fingers into the mouth and guide the probe toward the midline and depress the tongue if it is blocking passage. A small percentage of patients will not tolerate probe placement under moderate sedation. If deep sedation is required, or hemodynamic instability is anticipated, or there is a history of difficulties with achieving adequate sedation during prior procedures, it would be prudent to ask for support from anesthesia as well as consider performing the examination in a setting with more intensive monitoring (such as a postanesthetic recovery room or a critical care unit).

Patients requiring TEE as part of a surgical procedure are typically fully anesthetized and intubated. Patients in the intensive care unit on a ventilator will have varying degrees of sedatives, and additional agents may be necessary to facilitate passage of the probe; topical anesthetics may be appropriate in these patients. Placement of the TEE probe in an intubated patient requires different maneuvers than in an awake patient, and care must be taken to prevent dislodgement of the endotracheal tube. A respiratory therapist or other professional capable of managing and monitoring the ventilator may be required. Excessive head movement can dislodge an endotracheal tube, and consideration should be given for placing the probe in the same manner as is done in the operating room, although the patient can then be turned left decubitus to facilitate the examination. A bite block is recommended even for patients under anesthesia, because neuromuscular blockers may not always be used during the procedure.

In the operating room, the patient remains supine for surgery. The transesophageal probe is typically placed from the head of the bed with slight anteflexion of the probe. The bite block should not be placed in the mouth before placement of the probe, because this maneuver will displace the tongue posteriorly and obstruct probe passage. Lifting the mandible anteriorly and caudally usually opens the mouth and displaces the tongue anteriorly to allow smooth probe placement. A laryngoscope can be used to facilitate probe placement into the esophagus, or the fingers can guide the probe into the posterior fossa in anesthetized patients. Ensure the patient is deeply anesthetized or chemically paralyzed before inserting fingers into the oropharynx, as the bite block is not present.

At the conclusion of a transesophageal echocardiographic examination of an ambulatory patient, vital signs should return to within 10% of their baseline values before discharge to home or return to the ward. The modified Aldrete score is used to assess return to baseline mental status after sedation. Patients should have "nothing by mouth" for ≥1 hour until all local anesthetic and sedation has metabolized, to decrease the risk for aspiration. Patients should be counseled to call their physicians for odynophagia or dysphagia that lasts >1 day because of the low but real risk for soft tissue or esophageal injury from TEE.

Instrument Controls

Physicians performing TEE are expected to be familiar with both ultrasound system controls and the optimization of ultrasound image quality. When examining the heart with TEE, the transducer is first moved into the desired location in the esophagus or the stomach. Image acquisition is accomplished by watching the image develop as the probe is manipulated, rather than by relying on the depth markers on the probe or the transducer angle icon. Although the

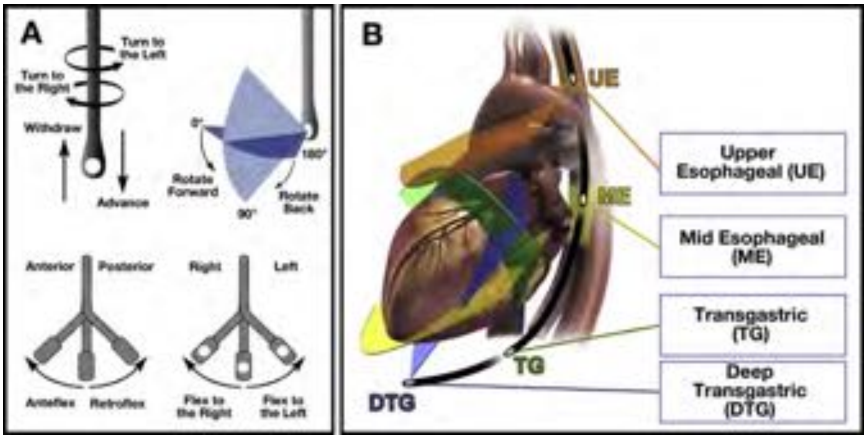


Figure 1 Terminology used to describe manipulation of the transesophageal echocardiographic probe during image acquisition. **(A)** Terminology used for the manipulation of the transesophageal echocardiographic probe. **(B)** Four standard transducer positions within the esophagus and stomach and the associated imaging planes.

most common transducer location and transducer angle are provided in this document for each cross-sectional image, final adjustment of the image is based on the anatomic structures that are displayed. It is recognized that there is individual variation in the anatomic relationship of the esophagus to the heart; in some patients, the esophagus is adjacent to the lateral portion of the atrioventricular groove, whereas in others it is directly posterior to the left atrium. This relationship is taken into consideration when developing each of the desired cross-sectional views. When possible, each structure is examined in multiple imaging planes and from more than one transducer position. Standard multiplane transesophageal echocardiographic equipment produces a 2D or tomographic imaging plane. Manipulating the probe and/or the transducer is required to move the imaging plane through the entire cardiac volume for a comprehensive examination. With the recent introduction of 3D fully sampled matrix-array transesophageal transducers, simultaneous multiplane imaging as well as real-time 3D images can be acquired and displayed.

Instrument Manipulation

The following terminology is used to describe the four ways the probe and the transducer can be manipulated during image acquisition (Figure 1). It is assumed that the patient is supine in the standard anatomic position, and the imaging plane is directed anteriorly from the esophagus through the heart. With reference to the heart, *superior* means toward the head, *inferior* toward the feet, *posterior* toward the spine, and *anterior* toward the sternum. The terms *right* and *left* denote the patient's right and left sides, except when the text refers to the image display. First, the probe tip can be pushed distally to a certain depth into the esophagus or the stomach. This is called advancing the transducer, and pulling the tip in the opposite direction more proximally is called withdrawing. Second, the probe can be manually turned to the right and left sides of the patient. Rotating the anterior aspect of the probe clockwise within the esophagus toward the patient's right is called turning to the right, and rotating counterclockwise is called turning to the left. Third, the probe tip can be flexed in four different directions, typically using the two control wheels located on the probe handle. The large control is for motion in the anterior-posterior axis and the, smaller control is for motion in the right-left axis. Flexing the tip of the probe anteriorly with the large control wheel is called anteflexing, and flexing it posteriorly is called retroflexing. With the probe facing anteriorly, flexing the tip of the probe to the patient's right with the smaller control wheel is called flexing to the right, and flexing it to the patient's left is called flexing to the left; this terminology is maintained even when the probe is rotated (and thus not facing anteriorly). Flexion to the right or left must be distinguished from turning the probe to the right or left. When the probe is turned to the right, it is clockwise rotated, and when turned to the left, it is counterclockwise rotated. When advancing or withdrawing the probe, there should not be excessive flexion in any direction; this will minimize pressure on the esophageal wall and reduce the incidence of esophageal trauma. Finally, the imaging plane of the transducer can be electronically rotated axially from 0° through 180° by means of buttons located on the probe handle. This is called rotating forward, and rotating in the opposite direction toward 0° is called rotating backward.

The conventions of image display (Figure 2) have been described in prior guidelines.[5] Images are displayed with the transducer location at the top of the images, with the near field (vertex) close to the transducer and the far field at the bottom. At a transducer angle of 0° (the horizontal or transverse plane), with the imaging plane directed anteriorly from the esophagus through the heart, the patient's right side appears in the left of the image display (Figure 2A). Rotating the transducer angle forward to 90° (vertical or longitudinal plane) moves the left side of the display inferiorly toward the spine (Figure 2B). The angle of rotation thus occurs in a "counterclockwise" manner, as depicted in an icon typically depicted on the screen. Rotating the transducer angle to 180° places the patient's left side to the left of the display, the mirror image of 0° (Figure 2C).

Simultaneous multiplane imaging is unique to the matrix-array transducer and permits the use of a dual screen to simultaneously display two real-time 2D images. The first (primary) image is the reference view, with the second view typically being orthogonal (rotated 90°) to the primary view. This second view, however, can be modified by the imager as any plane from 0° to 180° from the primary view.

The 90° orthogonal image is oriented as if forward rotated from the primary view. Thus, once the primary imaging plane reaches 90°, the orthogonal multiplane image may appear "reversed" compared with standard single-plane imaging. Figure 3 shows the simultaneous multiple plane imaging of the standard primary left ventricular (LV) views and the associated secondary views. Because of differences in rotation during simultaneous multiple plane imaging compared with single-plane imaging, careful attention must be paid to the secondary image orientation for accurate anatomic display.

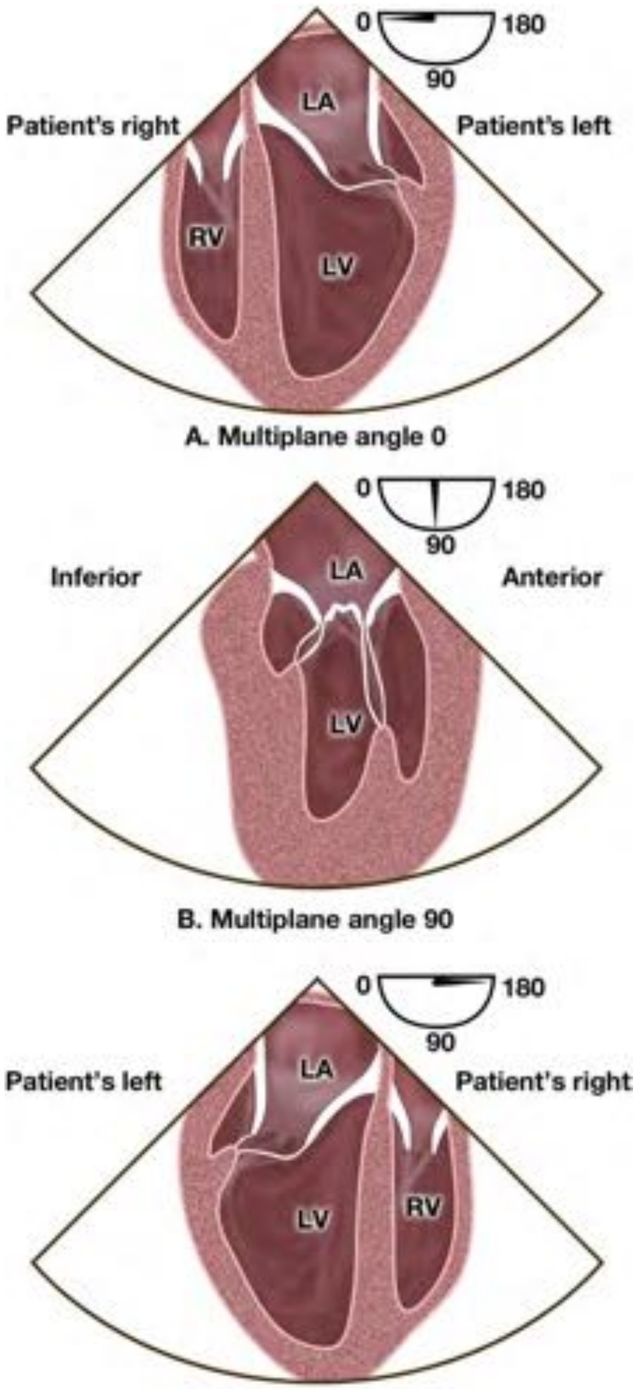


Figure 2 Conventions of 2D transesophageal echocardiographic image display. The transducer location and the near field (vertex) of the image sector are at the top of the display screen and far field at the bottom. **(A)** Image orientation at transducer angle 0°. **(B)** Image orientation at transducer angle 90°. **(C)** Image orientation at transducer angle 180°. *LA*, Left atrium; *LV*, left ventricle; *RV*, right ventricle. Modified from Shanewise *et al*.[6]

COMPREHENSIVE IMAGING EXAMINATION

Prior guidelines developed by the ASE and SCA have described the technical skills for acquiring 20 views in the performance of a comprehensive intraoperative multiplane TEE examination.[5] With the development of technology and expansion of indications for TEE, the views necessary to perform a comprehensive examination have expanded. A comprehensive examination can still be performed using three primary positions within the gastrointestinal tract (Figure 3B): midesophageal (ME), transgastric (TG), and upper esophageal (UE) levels. An additional eight views have been added to the prior comprehensive transesophageal echocardiographic images to include multiple LAX and SAX views of all four valves, all four cardiac chambers, and the great vessels (Table 10). Using 3D technology that allows simultaneous multiplane imaging, further efficiencies in acquisition are possible.

The comprehensive imaging examination described below is presented in a suggested order. The clinical indication for TEE should be the primary determinant of which views are obtained first as well as the level of detail that is obtained from each view. It is important to realize that additional images, beyond the described 28 views, may be necessary to comprehensively image specific structures. In addition, the degree of rotation of the transducer provided below is approximate, and additional manipulation such as right or left flexion, anteflexion or retroflexion, and turning of the probe may be required in individual patients to achieve optimal visualization. The "Specific Structural Imaging" section that follows this section addresses some of these additional views. In the following discussion, the regions or scallops of the MV leaflets are indicated as in Figure 4 according to Carpentier *et al.*'s[47] classification.

1. ME Five-Chamber View (Video 1 [All videos available at www.onlinejase.com])

After initially passing the probe into the esophagus, it is slowly advanced until the AV and LV outflow tract come into view at a probe depth of about 30 cm. Slight transducer angle manipulation (10° rotation) will allow image optimization of the AV and LV outflow tract. In this plane, the left atrium, right atrium, LV, right ventricle, MV, and TV will also be imaged, hence the name "ME five-chamber view." This view allows visualization of the A^2-A^1 and P^1-P^2 scallops (from left to right on the imaging plane) of the MV and two of the three AV cusps. Color flow Doppler can be applied to aid in identifying aortic, mitral, and tricuspid regurgitation. Because this view may not image the true apex of the ventricles, assessment of global and regional ventricular systolic function may be limited.

2. ME Four-Chamber View (Video 2)

From the ME five-chamber view, the probe is advanced slowly to a depth of about 30 to 35 cm until the MV is clearly seen. The image depth is then adjusted to ensure viewing of the LV apex. Note that this view is deeper than the ME five-chamber view, and the AV and LV outflow tract will not be visualized. Furthermore, the transducer angle may need to be rotated to approximately 10° to 20° to eliminate the AV or LV outflow tract from the image display and to maximize the tricuspid annular dimension. To better align the MV and LV apex, slight probe retroflexion may be necessary. Structures seen include the left atrium, right atrium, interatrial septum, LV, right ventricle, interventricular septum, MV (A_3A_2 and P_2P_1 scallops), and TV. The TV septal leaflet adjacent to the interventricular septum is to the right of the sector display, and the TV posterior leaflet is adjacent to the right ventricular (RV) free wall, to the left of the display. The orthogonal view obtained during simultaneous biplane imaging is the ME two-chamber view (Figure 3). The ME four-chamber view is one of the

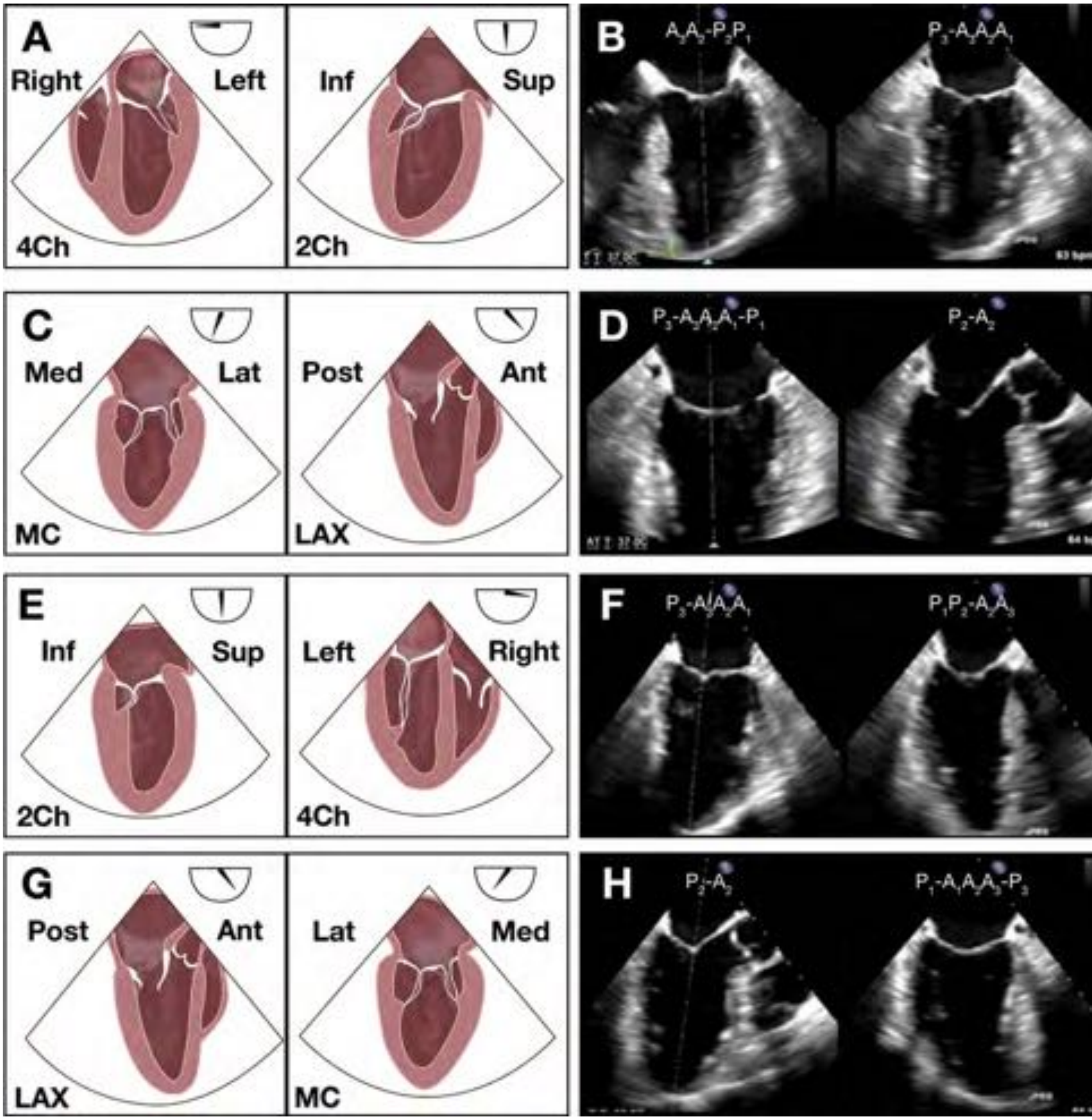


Figure 3 Simultaneous multiplane transesophageal echocardiographic image display. Simultaneous multiplane imaging permits the use of a dual screen to simultaneously display two real-time 2D images. In these examples, the primary image (on the *left* in each panel) is the reference view, with the second view (on the *right* in each panel) orthogonal (rotated 90°) to the primary view, but any angle can be used for the secondary view. The typical 90° orthogonal second image is oriented as if the rotation has occurred in a clockwise manner and, for some views, appears "left-right reversed" compared with single-plane imaging. **(A,B)** The primary view is the ME four-chamber (4Ch) view. **(C,D)** The primary view is the ME mitral commissural (MC) view. **(E,F)** The primary view is the ME two-chamber (2Ch) view. **(G,H)** The primary view is the ME LAX view. *Ant*, Anterior; *Inf*, inferior; *Post*, posterior; *Sup*, superior.

most comprehensive views available for evaluating cardiac anatomy and function. Turning the probe to the left (counterclockwise) allows imaging of primarily the left heart structures. Turning the probe to the right (clockwise) allows imaging of primarily right heart structures. Diagnostic information obtained from this view include MV and TV function and assessment of regional LV (inferoseptal and anterolateral walls) and RV (lateral wall) function. Color flow Doppler can be applied to aid in identifying mitral and tricuspid regurgitation, and in some patients, aortic regurgitation. After slight probe advancement, the coronary sinus is imaged in the long-axis (LAX) view immediately above the attachment of the TV septal leaflet to the interventricular septum (see Right Atrium and Venous Connections section).

3. ME Mitral Commissural View (Video 3)

From the ME four-chamber view, rotating the transducer angle to between 50° and 70° will generate the ME mitral commissural view. The MV scallops on the image display (from left to right) are

Table 10 Comprehensive transesophageal echocardiographic examination. The table lists the suggested 28 views included in a comprehensive transesophageal echocardiographic examination. Each view is shown as a 3D image, the corresponding imaging plane, and a 2D image. The acquisition protocol and the structures imaged in each view are listed in the subsequent columns

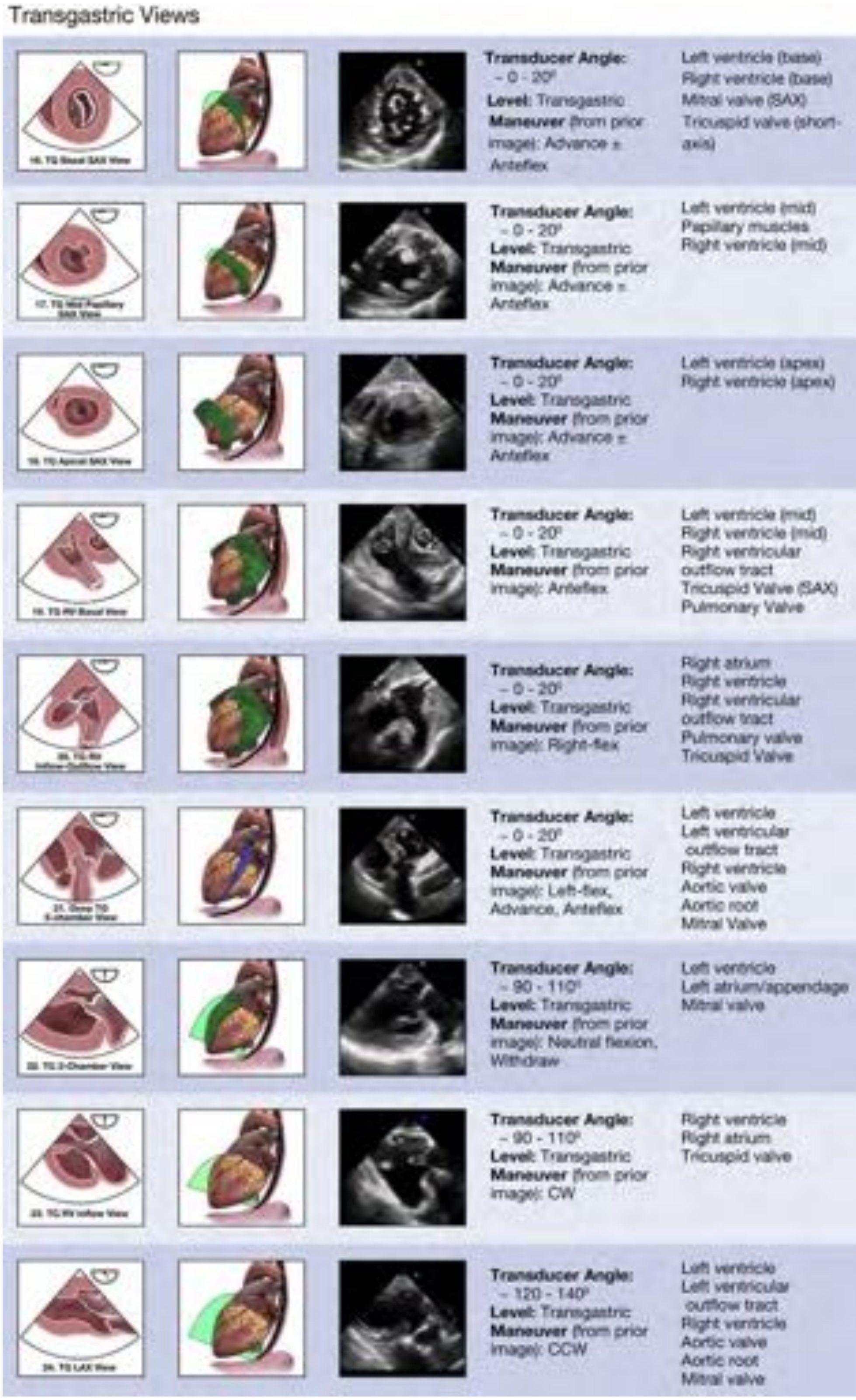
Imaging Plane	3D Model	2D TEE Image	Acquisition Protocol	Structures Imaged
Midesophageal Views				
			**Transducer Angle:** ~ 0 - 10° **Level:** Mid-esophageal **Maneuver** (from prior image): NA	Aortic valve LVOT Left atrium/Right atrium Left ventricle/Right ventricle/IVS Mitral valve (A_2A_1-P_1) Tricuspid valve
			**Transducer Angle:** ~ 0 - 10° **Level:** Mid-esophageal **Maneuver** (from prior image): Advance ± Retroflex	Left atrium/Right atrium IAS Left ventricle/Right ventricle/IVS Mitral valve (A_2A_1-P_1P_2) Tricuspid valve
			**Transducer Angle:** ~ 50 - 70° **Level:** Mid-esophageal **Maneuver** (from prior image): NA	Left atrium Coronary Sinus Left ventricle Mitral Valve (P_3- $A_3A_2A_1$ - P_1) Papillary muscles Chordae tendinae
			**Transducer Angle:** ~ 80 - 100° **Level:** Mid-esophageal **Maneuver** (from prior image): NA	Left atrium Coronary sinus Left atrial appendage Left ventricle Mitral valve (P_3-$A_3A_2A_1$)
			**Transducer Angle:** ~ 120 - 140° **Level:** Mid-esophageal **Maneuver** (from prior image): NA	Left atrium Left ventricle LVOT RVOT Mitral valve (P_2- A_2) Aortic valve Proximal ascending aorta
			**Transducer Angle:** ~ 120 - 140° **Level:** Mid-esophageal **Maneuver** (from prior image): Withdrawl ± anteflex	Left atrium LVOT RVOT Mitral valve (A_2- P_2) Aortic valve Proximal ascending aorta
			**Transducer Angle:** ~ 90 - 110° **Level:** Upper-Esophageal **Maneuver** (from prior image): Withdrawl	Mid-ascending aorta Right pulmonary artery
			**Transducer Angle:** ~ 0 - 30° **Level:** Upper-Esophageal **Maneuver** (from prior image): CW	Mid-ascending aorta (SAX) Main/bifurcation pulmonary artery Superior vena cava

Table 10 Continued

	**Transducer Angle:** ~ 0 - 30° **Level:** Upper-esophageal **Maneuver** (from prior image): CW, Advance	Mid-ascending aorta Superior vena cava Right pulmonary veins
	**Transducer Angle:** ~ 25 - 45° **Level:** Mid-esophageal **Maneuver** (from prior image): CCW, Advance, Anteflex	Aortic valve Right atrium Left atrium Superior IAS RVOT Pulmonary Valve
	**Transducer Angle:** ~ 50 - 70° **Level:** Mid-esophageal **Maneuver** (from prior image): CW, Advance	Aortic valve Right atrium Left atrium Superior IAS Tricuspid Valve RVOT Pulmonary Valve
	**Transducer Angle:** ~ 50 - 70° **Level:** Mid-esophageal **Maneuver** (from prior image): CW	Right atrium Left atrium Mid-IAS Tricuspid Valve Superior vena cava Inferior vena cava/coronary sinus
	**Transducer Angle:** ~90 - 110° Level: Mid-esophageal **Maneuver** (from prior image): CW	Left atrium Right atrium/appendage IAS Superior vena cava Inferior vena cava
	**Transducer Angle:** ~ 90 - 110° **Level:** Upper-esophageal **Maneuver** (from prior image): Withdraw, CW for the right veins, CCW for the left veins	Pulmonary vein (upper and lower) Pulmonary artery
	**Transducer Angle:** ~90 - 110° **Level:** Mid-esophageal **Maneuver** (from prior image): Advance	Left atrial appendage Left upper pulmonary vein

P_3-A_2-P_1, although frequently, adjacent A_3 and A_1 segments can also be imaged (P_3-$A_3A_2A_1$-P_1). From this neutral probe orientation, turning the probe leftward (counterclockwise) may allow imaging of the length of the posterior leaflet ($P_3P_2P_1$). Turning the probe rightward (clockwise from the neutral position) may allow imaging of the length of the anterior leaflet ($A_3A_2A_1$).[48] Extreme turning of the probe to the right and left enables visualization of parts of the MV annulus (or sewing ring of prosthetic valves). In addition, the anterolateral and posteromedial papillary muscles with their corresponding chordae are prominent structures in the ME commissural view. Diagnostic information obtained from this view includes regional LV function (anterior/anterolateral and inferior/inferolateral walls) and MV function. The orthogonal view obtained during simultaneous biplane imaging is the ME LAX view (Figure 3). Color flow Doppler can be applied to aid in identifying commissural mitral regurgitation jets.

Table 10 Continued



Transgastric Views

16. TG Basal SAX View	**Transducer Angle:** ~ 0 - 20° **Level:** Transgastric **Maneuver** (from prior image): Advance ± Anteflex	Left ventricle (base) Right ventricle (base) Mitral valve (SAX) Tricuspid valve (short-axis)
17. TG Mid Papillary SAX View	**Transducer Angle:** ~ 0 - 20° **Level:** Transgastric **Maneuver** (from prior image): Advance ± Anteflex	Left ventricle (mid) Papillary muscles Right ventricle (mid)
18. TG Apical SAX View	**Transducer Angle:** ~ 0 - 20° **Level:** Transgastric **Maneuver** (from prior image): Advance ± Anteflex	Left ventricle (apex) Right ventricle (apex)
19. TG RV Basal View	**Transducer Angle:** ~ 0 - 20° **Level:** Transgastric **Maneuver** (from prior image): Anteflex	Left ventricle (mid) Right ventricle (mid) Right ventricular outflow tract Tricuspid Valve (SAX) Pulmonary Valve
20. TG-RV Inflow-Outflow View	**Transducer Angle:** ~ 0 - 20° **Level:** Transgastric **Maneuver** (from prior image): Right-flex	Right atrium Right ventricle Right ventricular outflow tract Pulmonary valve Tricuspid Valve
21. Deep TG 5-chamber View	**Transducer Angle:** ~ 0 - 20° **Level:** Transgastric **Maneuver** (from prior image): Left-flex, Advance, Anteflex	Left ventricle Left ventricular outflow tract Right ventricle Aortic valve Aortic root Mitral Valve
22. TG 2-Chamber View	**Transducer Angle:** ~ 90 - 110° **Level:** Transgastric **Maneuver** (from prior image): Neutral flexion, Withdraw	Left ventricle Left atrium/appendage Mitral valve
23. TG RV Inflow View	**Transducer Angle:** ~ 90 - 110° **Level:** Transgastric **Maneuver** (from prior image): CW	Right ventricle Right atrium Tricuspid valve
24. TG LAX View	**Transducer Angle:** ~ 120 - 140° **Level:** Transgastric **Maneuver** (from prior image): CCW	Left ventricle Left ventricular outflow tract Right ventricle Aortic valve Aortic root Mitral valve

Table 10 Continued

Aortic Views

	**Transducer Angle:** ~ 0 - 10° **Level:** Transgastric to Mid-esophageal **Maneuver** (from prior image): Neutral flexion	Descending aorta Left thorax Hemiazygous and Azygous veins Intercostal arteries
	**Transducer Angle:** ~ 90 - 100° **Level:** Transgastric to Mid-esophageal **Maneuver** (from prior image): Neutral flexion	Descending aorta Left thorax
	**Transducer Angle:** ~ 0 - 10° **Level:** Upper Esophageal **Maneuver** (from prior image): Withdrawl	Aortic arch Innominate vein Mediastinal tissue
	**Transducer Angle:** ~ 70 - 90° **Level:** Transgastric to Mid-esophageal **Maneuver** (from prior image): NA	Aortic arch Innominate vein Pulmonary artery Pulmonary valve Mediastinal tissue

A, Anterior; *IAS*, interatrial septum; *IVS*, interventricular septum; *LAA*, left atrial appendage; *LUPV*, left upper pulmonary vein; *LVOT*, left ventricular outflow tract; *NA*, not applicable; *P*, posterior; *RVOT*, right ventricular outflow tract.

4. ME Two-Chamber View (Video 4)

From the ME mitral commissural view, rotating the transducer angle to between 80° and 100° will generate the ME two-chamber view. Structures seen include the left atrium, LA appendage, LV, and MV (P_3-$A_3A_2A_1$). Diagnostic information obtained from this view includes regional LV function (anterior and inferior walls) and MV function. Color flow Doppler is applied over the MV to aid in the identification of valvular pathology (regurgitation and/or stenosis). The coronary sinus is seen in a short-axis (SAX) orientation, immediately above the basal inferior LV segment. The orthogonal view obtained during simultaneous biplane imaging is the ME four-chamber view (Figures 3 and 4), but the left heart is now to the left of the display (mirror image of the 0° view). Turning to the right (clockwise) at this transducer angle will result in the ME bicaval view (see view #13 below). Turning to the left (counterclockwise) at this transducer angle will result in the ME LA appendage view (see view #15 below).

5. ME LAX View (Video 5)

From the ME two-chamber view, the transducer angle is rotated to approximately 120° to 140° to image the ME LAX view, which is the same orientation as a transthoracic LAX or three-chamber view. Structures seen include the left atrium, LV, LV outflow tract, AV, proximal ascending aorta, coronary sinus, and MV (P_2-A_2). Diagnostic information obtained from this view includes regional LV function (inferolateral and anterior septal walls) and MV and AV function. The membranous interventricular septum as well as the RV wall that subtends the RV outflow tract (RVOT) can also be imaged. The orthogonal view obtained during simultaneous biplane imaging is the ME mitral commissural view (Figures 3 and 4), but the anterior/anterolateral LV wall is now to the left of the display (mirror image of the 60° view). Color flow Doppler can be applied to identify aortic regurgitation.

6. ME AV LAX View (Video 6)

From the ME LAX view, slight withdrawal of the probe while maintaining a transducer angle of 120° to 140° results in the ME AV LAX view. Fine tuning by turning the probe to the right (clockwise) may be needed. Reducing the depth of field allows concentrated imaging of the LV outflow tract, AV, and proximal aorta, including the sinuses of Valsalva, sinotubular junction, and a variable amount of the tubular ascending aorta. This view is useful in evaluating the AV function and obtaining the dimensions of the annulus and sinotubular junction. The anterior (far-field) AV cusp is the right coronary cusp; not infrequently, the right coronary ostium is imaged from this view. The posterior (near field) cusp can be the noncoronary cusp or the

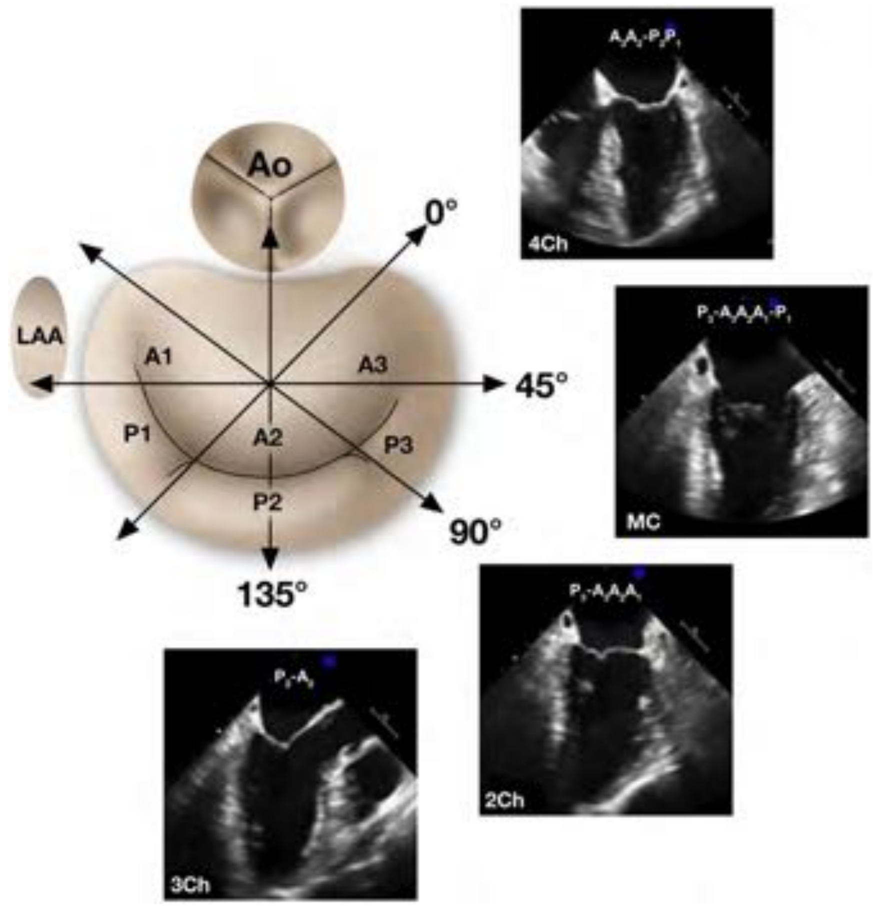


Figure 4 Schematic of the MV with leaflet scallops (or segments) labeled. Corresponding images from different standard imaging views are labeled with the respective scallops and segments. Although this labeling scheme is applicable in the majority of cases, the exact regions of the MV leaflets image vary on the basis of the relation of the heart to the esophagus as well as transesophageal echocardiographic probe position within the esophagus. *Ao*, Aorta; *LAA*, LA appendage; *MC*, mitral commissural; 2Ch, two-chamber; 3Ch, three-chamber; 4Ch, four-chamber.

left coronary cusp, depending on the window; when perfectly centered on the aorta, however, the plane of imaging may be at the commissure between these two cusps. The orthogonal view obtained during simultaneous biplane imaging is the ME AV SAX view (see view #10 below), but the left heart is now to the left of the display (mirror image of the 0° view). Color flow Doppler can be applied to identifying aortic regurgitation as well as flow within the right coronary ostium.

7. ME Ascending Aorta LAX View (Video 7)

From the ME AV LAX view, withdrawal of the probe, typically with backward rotation to approximately 90° to 110°, results in the ME ascending aorta LAX view. This view allows evaluation of the proximal ascending aorta. The right pulmonary artery (PA) lies posterior to the ascending aorta in this view. Although aortic flow is typically perpendicular to the insonation beam from this view, color flow Doppler may still be useful in some pathologies. By centering the image plane on the SAX image of the right PA (in the near field), turning the probe to the left (counterclockwise) with possible retroflexion results in LAX imaging of the main PA and the PV. This view aligns the insonation beam with PA flow and optimizes the imaging plane for pulsed-wave, continuous-wave, and color Doppler of the RVOT, PV, or main PA. The orthogonal view of the ME AV LAX obtained during simultaneous biplane imaging is the ME ascending aorta SAX view (see view #8 below), but the left heart is now to the left of the display (mirror image of the 0° view).

8. ME Ascending Aorta SAX View (Video 8)

From the ME AV and ascending aorta view, backward transducer rotation to approximately 0° to 30° results in the ME ascending aorta SAX view. In addition to the ascending aorta in SAX and the superior vena cava in SAX, the main PA and right lobar PA can be seen. From this neutral probe orientation, turning the probe to the left (counterclockwise) allows imaging of the PA bifurcation. Turning the probe to the right from the neutral position allows imaging of a greater extent of the right lobar PA. The left lobar PA is difficult to image because of the left main stem bronchus. The PV can also be imaged from this plane in some patients. The orthogonal view obtained during simultaneous biplane imaging is the 90° view of the right pulmonary artery (ME ascending aorta LAX, view #7). Pulsed-wave, continuous-wave, and color Doppler of the PA may be useful. Careful insertion of the probe should allow imaging of the proximal left coronary artery, as well as the bifurcation to the left anterior descending and circumflex coronary arteries.

9. ME Right Pulmonary Vein View (Video 9)

From the ME ascending aorta SAX view (and typically at 0°), advancing the probe and turning to the right (clockwise) will result in the ME right pulmonary vein view. The inflow of the inferior pulmonary vein is typically perpendicular to the insonation beam, but superior pulmonary vein inflow is typically parallel to the beam, and Doppler from this view can be performed. In addition to the right pulmonary veins, the superior vena cava (SAX view) and ascending aorta (SAX view) are also imaged. The right pulmonary veins can also be imaged from the 90° to 110° view by first obtaining a ME bicaval view (view #13 below) and turning the probe to the right (clockwise). This orthogonal image is the ME right pulmonary vein view (view #14) described below. Note that the left pulmonary veins may be imaged by turning the probe to the left (counterclockwise) just beyond the left atrial appendage.

10. ME AV SAX View (Video 10)

From the ME right pulmonary vein view, reposition the probe (turning to the left, counterclockwise) to center the aorta in the display (as in the ME ascending aorta SAX view), and advance and rotate the transducer angle to between 25° and 45° to obtain the ME AV SAX view. Slight anteflexion may be required. For a trileaflet valve, the left coronary cusp will be posterior (in the near field) and to the right on the display, the noncoronary cusp will be adjacent to the interatrial septum, and the right coronary cusp will be anterior (in the far field) and adjacent to the RVOT. AV morphology and function can be evaluated from this view. In addition, with a subtle degree of withdrawal, the left coronary artery (arising from the left coronary cusp) and the right coronary artery (arising from the right coronary cusp) can be imaged. In addition to the AV, a portion of the superior LA, interatrial septum, and right atrium are imaged. This superior portion of the interatrial septum is important because not infrequently, shunting from a patent foramen ovale (PFO) may be imaged. In addition, the RVOT and PV may be seen in the far field. Color flow Doppler (and when appropriate pulsed-wave and continuous-wave Doppler) should be used to assess all imaged structures. The orthogonal view obtained during simultaneous biplane imaging is the ME AV LAX view (view #6).

11. ME RV Inflow-Outflow View (Video 11)

From the ME AV SAX view, slight advancement of the probe and rotating the transducer angle to 50° to 70° until the RVOT and PV appear in the display results in the ME RV inflow-outflow view. Structures seen in the view include the left atrium, right atrium, interatrial septum, TV, RV (on the left of the display), RVOT (on the right of the display), PV, and proximal (main) PA. From this view, one can evaluate RV size and function (with RVOT diameter), TV morphology and function, and PV morphology and function. Color flow Doppler as well as spectral Doppler of both valves should be performed.

12. ME Modified Bicaval TV View (Video 12)

From the ME RV inflow-outflow view, maintaining a transducer angle of 50° to 70°, the probe is turned to the right (clockwise) until primarily the TV is centered in the view, resulting in the ME modified bicaval TV view. The left atrium, right atrium, interatrial septum, inferior vena cava, and TV are well imaged. Occasionally, the right atrial appendage as well as the superior vena cava will be seen. Because of the radially short septal TV leaflet, many tricuspid regurgitant jets are eccentric and directed toward the interatrial septum; from this view, the septal TV leaflet is imaged en face, and jets directed toward the interatrial septum may be parallel to the insonation beam. The orthogonal view (at ∼120°-140°) results in a LAX view of the TV which similarly may image an eccentric medial regurgitant jet parallel to the insonation beam. Color flow Doppler and spectral Doppler (particularly continuous-wave Doppler) should be performed in these views.

13. ME Bicaval View (Video 13)

From the ME modified bicaval TV view, the transducer angle is rotated forward to 90° to 110°, and the probe is turned to the right (clockwise) to obtain the ME bicaval view. Imaged in this view are the left atrium, right atrium, inferior vena cava, superior vena cava, right atrial appendage, and interatrial septum. Motion of the interatrial septum should be observed, because atrial septal aneurysms may be associated with interatrial shunts. From this view, interatrial septum morphology and function should be assessed. In addition, inferior vena cava and superior vena cava inflow are well imaged. The orthogonal view obtained during simultaneous biplane imaging is an ME four-chamber view focused on the interatrial septum. Further turning to the right (clockwise) with slight withdrawal of the probe allows imaging of the right pulmonary veins (orthogonal to view #9 above).

14. ME Right and Left Pulmonary Vein View (Video 14)

At a transducer angle of 90° to 110°, imaging of either the right or left pulmonary veins can be performed. From the ME bicaval view, turning the probe further to the right (clockwise) will result in imaging of the right pulmonary veins with the superior vein to the right of the display. Turning the probe to the left (counterclockwise) takes the imaging through the entire heart (past the left atrium) to the ME left pulmonary vein view. The left superior vein is to the right of the display, and typically inflow is parallel to the insonation beam, allowing accurate spectral Doppler assessment.

15. ME LA Appendage View (Video 15)

From the ME left pulmonary vein view (at a transducer angle of 90° to 110°), turning the probe to right (clockwise) with possible advancement and/or anteflexion of the probe will open the LA appendage for the ME LA appendage view. Often, the left superior pulmonary vein is also imaged. Given the complex and highly variable anatomy of the LA appendage, a complete assessment of morphology typically requires imaging the LA appendage in multiple views. Backward rotating from 90° to 0° while imaging the LA appendage and/or simultaneous multiplane imaging should be performed. Color flow Doppler and pulsed-wave Doppler may be useful, particularly for assessment of emptying velocities.

16. TG Basal SAX View (Video 16)

From the ME views and at a transducer angle of 0° to 20°, the probe is straightened and advanced into the stomach, frequently imaging the coronary sinus inflow as well as the inferior vena cava and hepatic vein before reaching the TG level. The probe is then anteflexed to obtain the TG basal SAX view. This view demonstrates the typical SAX view or "fish mouth" appearance of the MV in the TG imaging plane with the anterior leaflet on the left of the display and the posterior leaflet on the right. The medial commissure is in the near field, with the lateral commissure in the far field. An assessment of MV morphology and function as well as LV size and function can be performed from this view. The orthogonal view obtained during simultaneous biplane imaging is a two-chamber view of the base of the LV (view #22). Color flow Doppler of the MV in this view may help characterize regurgitant orifice morphology.

17. TG Midpapillary SAX View (Video 17)

While maintaining contact with the gastric wall, the anteflexed probe for the TG basal SAX view can be relaxed to a more neutral position, or the probe may be advanced further into the stomach to obtain the TG midpapillary SAX view. Proper positioning may require multiple probe manipulations using varying probe depths and degrees of anteflexion. The transducer angle should typically remain at 0° to 20°. The TG midpapillary SAX view provides significant diagnostic information and can be extremely helpful in assessing LV size and volume status and global and regional function. This is the primary TG view for intraoperative monitoring of LV size and function because myocardium supplied by the left anterior descending, circumflex, and right coronary arteries can be seen simultaneously. Turning the probe to the right from this view will typically image the mid-RV in SAX.

18. TG Apical SAX View (Video 18)

From the TG midpapillary SAX view (0°-20°), the probe is advanced while maintaining contact with the gastric wall, to obtain the TG apical SAX view. The RV apex is imaged from this view by turning to the right (clockwise). This view allows evaluation of the apical segments of the left and right ventricles.

19. TG RV Basal View (Video 19)

Returning to the TG basal SAX view (anteflexed, at a transducer angle of approximately 0° to 20°) by turning the probe toward the patient's right (clockwise), the TG basal RV view can be seen. The TV is imaged in the SAX view while the RVOT is imaged in the LAX view. The orthogonal view obtained during simultaneous biplane imaging of the TV is with the TG RV inflow view (view #23, described below). The orthogonal view obtained during simultaneous biplane imaging of the RVOT is with the TG RV inflow-outflow view (mirror image of view #20, described below). Color flow Doppler of the TV in this view may help characterize regurgitant orifice morphology.

20. TG RV Inflow-Outflow View (Video 20)

From the TG basal RV view (transducer angle of 0° to 20°), maximal right flexion results in the TG RV inflow-outflow view. In this view, typically the anterior and posterior leaflets of the TV are imaged, as well as the left and right cusps of the PV. Advancing the probe may be necessary to align RVOT flow with the insonation beam. The mirror image of this view can be also be obtained from a neutral probe position (no flexion), with the probe turned to the right (clockwise) so that the right ventricle is in view, and then forward rotating to 90° to 120°.

21. Deep TG Five-Chamber View (Video 21)

From the TG RV inflow-outflow view (transducer angle of 0° to 20°), advancing the probe to the deep TG level, with anteflexion and often with left flexion, results in the deep TG five-chamber view. Because of parallel Doppler beam alignment with the LV outflow tract, AV, and proximal aortic root, color and spectral Doppler interrogation of the LV outflow tract and AV is possible. The MV is also imaged, and complete Doppler interrogation of this valve may also be attempted.

22. TG Two-Chamber View (Video 22)

The probe is returned to the TG midpapillary SAX view, and the transducer angle is rotated to approximately 90° to 110° to obtain the TG two-chamber view. The anterior and inferior walls of the left ventricle are imaged in addition to the papillary muscles, chordae, and MV. Although the left atrium and LA appendage are often seen, far-field imaging may not allow accurate assessment of LA appendage pathology.

23. TG RV Inflow View (Video 23)

From the TG two-chamber view (transducer angle of 90° to 110°), turning to the right (clockwise) will result in the TG RV inflow (or RV two-chamber) view. The anterior and inferior walls of the right ventricle are imaged in addition to the papillary muscles, chordae, and TV. The proximal RVOT is also frequently seen and slight advancement of the probe may allow imaging and Doppler interrogation of the PV.

24. TG LAX View (Video 24)

From the TG RV inflow view, turning to the left (counterclockwise) to return to the TG two-chamber view, then rotating the transducer angle to 120° to 140° will result in the TG LAX view. Sometimes, turning the probe slightly to the right is necessary to bring the LV outflow tract and AV into view. Portions of the inferolateral wall and anterior septum are imaged, as well as the LV outflow tract, AV, and proximal aorta. With parallel Doppler beam alignment of the LV outflow tract, AV, and proximal aortic root, spectral and color Doppler interrogation of the LV outflow tract and AV is possible.

25 and 26. Descending Aorta SAX (Video 25) and Descending Aorta LAX Views (Video 26)

Imaging of the descending aorta with TEE is easily performed, because the aorta is immediately adjacent to the stomach and esophagus. From the TG LAX view, the transducer angle is returned to 0° to 10° and the probe turned to the left (counterclockwise). Although one can begin imaging the descending aorta below the diaphragm (typically beginning at the celiac artery), abdominal gas and variable aortic position may prevent adequate imaging, and withdrawing the probe to just above the diaphragm allows imaging of the descending thoracic aorta. The SAX view of the aorta is obtained at a transducer angle of 0° to 10° (Video 25), while the LAX view is obtained at a transducer angle of approximately 90° to 100° (Video 26). Image depth should be decreased to enlarge the size of the aorta and the focus set to be in the near field. Finally, gain should be adjusted in the near field to optimize imaging. While keeping the aorta in the center of the image, the probe can be advanced or withdrawn to image the entire descending aorta. Because there are no internal anatomic landmarks in the descending aorta, describing the location of pathology is difficult. One approach to this problem is to identify the location in terms of distance from the incisors. The descending thoracic aorta is located posterior and to the left of the esophagus and when imaging this structure the transesophageal echocardiographic probe faces the left thoracic cavity. Thus, intercostal arteries are typically seen arising from the aorta toward the right side of the screen. When imaging the descending thoracic aorta, the hemiazygous vein (which drains the left posterior thorax) may be seen in the far field of imaging. In the mid to upper thorax, this vein joins the azygous vein (which drains the right posterior thorax). This venous structure is typically parallel to the aorta and aortic arch, eventually draining into the superior vena cava. Because their

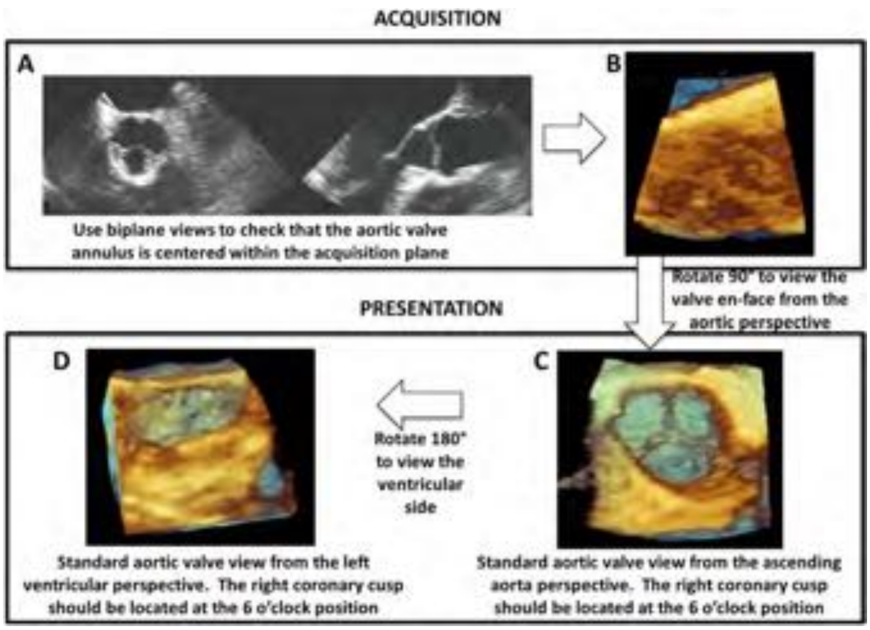


Figure 5 Three-dimensional transesophageal echocardiographic imaging acquisition steps for the AV.

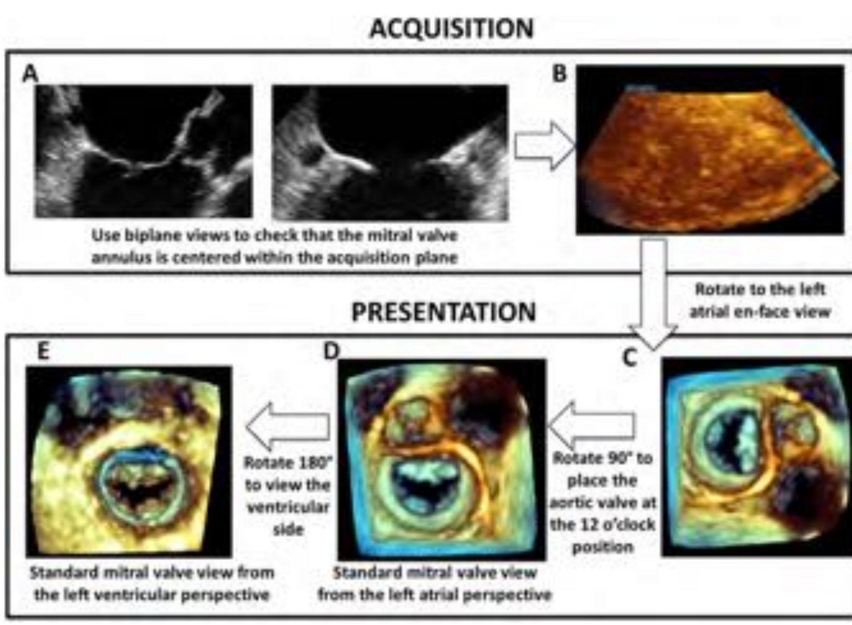


Figure 6 Three-dimensional transesophageal echocardiographic imaging acquisition steps for the MV.

walls are contiguous, the two structures could be mistaken for a dissection flap within the aorta; color flow Doppler or pulsed Doppler easily distinguishes venous from arterial flow within each lumen.

27. UE Aortic Arch to LAX View (Video 27)

While evaluating the descending aorta SAX view (transducer angle 0° to 10°) and withdrawing the probe, the aorta will eventually become elongated, and the left subclavian artery may be imaged, indicating the beginning of the distal aortic arch. At this location, the aorta is positioned anterior to the esophagus, and thus the UE aortic arch LAX view is best imaged by then turning to the right (clockwise) so the probe faces anterior. This allows imaging of the mid aortic arch. In addition to the aorta, the left innominate vein is frequently imaged with venous flow by color flow Doppler. Because the left main stem bronchus typically crosses between the esophagus and the aorta, a portion of the proximal aortic arch and distal ascending aorta may not be visualized.

28. UE Aortic Arch SAX View (Video 28)

From the UE aortic arch LAX view, the transducer angle is rotated toward 70° to 90° to obtain the UE aortic arch SAX view. The main PA and PV can frequently be seen in LAX in the far field but may require adjustment of imaging depth, probe frequency, and focal zone. Because of parallel Doppler beam alignment of the PV and main PA, spectral and color Doppler interrogation of the PV may be performed. Because of the curvature of the aorta, between the LAX and SAX view of the aortic arch, the right brachiocephalic and left common carotid arteries may be seen arising from the aorta, typically in the near field and to the right of the screen.

TRANSESOPHAGEAL 3D EXAMINATION PROTOCOL

A comprehensive 3D TEE examination using the matrix transducer usually starts with "real-time" or "live" acquisition using single-beat mode. However, to obtain acquisitions with high temporal and spatial resolution, electrocardiographically gated 3D transesophageal acquisitions should be used, especially when the patient's rhythm and respirations allow high-quality images to be obtained. When moving from a narrow-angle to a wide-angle pyramid of acquisition, there is a reduction in temporal resolution. Multiple-beat mode combined with a wide-angle acquisition will improve image quality and permits a wider sector of acquisition. Table 8 describes the recommended views to obtain 3D images of cardiac structures with TEE, described in more detail in the ASE 3D echocardiography guidelines.[49] Figures 5 and 6 demonstrate how to display 3D Transesophageal echocardiographic images of the AV and MV from the original 2D TEE views. Specific structural imaging using 3D TEE is included in the "Specific Structural Imaging" section of this document.

SPECIFIC STRUCTURAL IMAGING

General Considerations

The following section describes the anatomy and imaging or Doppler of specific structures. It is important to remember that the comprehensive imaging views discussed previously are not intended to represent all the imaging planes that can be obtained when imaging specific structures, particularly in the setting of significant individual anatomic variability. From standard imaging planes, small adjustments in position of the probe or transducer angle may be integral in the complete structural evaluation.

The complete Doppler examination for any valve or structural abnormality should include 2D structural and color flow Doppler imaging in SAX and multiple LAX views, spectral Doppler of the antegrade and retrograde flow through the valve or defect, and 3D structural and color Doppler imaging from various perspectives. During color Doppler recordings, special attention must be paid to instrument settings. In particular, the Nyquist level should be set to 50 to 60 cm/sec for assessment of high-velocity jets to standardize the resulting size of the aliased flow pattern from valve regurgitation of a given severity. Color gain should be set to limit the amount of color speckle in the far field. Sector angle and color depth should be minimized as may be feasible, to maximize frame rate. Magnified views are also useful to define regional flow, while allowing a higher frame rate.

MV

Imaging the MV is an important role for TEE. The MV and left atrium are in the far field for every transthoracic echocardiographic imaging plane, but because the esophagus is directly posterior to the LA, TEE is the ideal real-time imaging modality for the MV. As a result, TEE is more sensitive for detecting and quantifying MV abnormalities, particularly in the setting of anatomy that might cause acoustic shadowing from TTE, such as severe annular calcification or prosthetic valve material. A precise understanding of the mechanism of mitral regurgitation[50] and the 3D valve morphology is important in planning mitral repair[9,48,51-53] to optimize outcomes.[54] Some aspects of mitral regurgitation, particularly functional mitral regurgitation from apical tethering, can best be understood by 3D measurements.[56,56]

Anatomy. An extensive review of MV anatomy can be found in numerous reviews,[57-60] but it is important for echocardiographers to understand the basic anatomy of this complex structure. The MV complex is composed of the annulus, the leaflets (anterior and posterior), chordae tendineae, and papillary muscles. Unlike the TV, the MV is in direct continuity with the AV complex.

The mitral annulus has received increased attention in recent years as interventionalists and surgeons have focused on this important part of mitral anatomy for MV repair. In addition, accurate assessment of annular dimensions or area is an important part of quantitative Doppler assessment of regurgitant volume. The native mitral annulus is D shaped, with the straight border composed of the mitral-aortic intervalvular fibrosa. The shape of the mitral annulus is also nonplanar, and its area changes during the cardiac cycle. Expansion of fibrous tissue on either end of this region creates fibrous trigones medially and laterally. Traditional 2D imaging of the mitral annulus is performed using a "view-based" approach (four-chamber and two-chamber windows), and the ASE guidelines advocate using a single four-chamber view to measure the annular diameter in mid-diastole (one frame after maximum leaflet opening) and then calculating the mitral annular area using the formula for a circle,[61] but this is an oversimplification of this complex structure.[61-64] Correct anatomic imaging planes of the LAX and commissural views have been proposed for more accurate measurement of the mitral annular diameters using an elliptical formula to estimate the annular area.[64-66] Importantly, when measuring the annular diameter in the LAX view, the hinge point of the mitral leaflet (seen along the apical or inferior border of the mitral-aortic curtain) must be identified. These orthogonal images can easily be obtained using simultaneous multiplane imaging or reconstruction of 3D transesophageal echocardiographic volumes; annular measurements using this technology correlate well with in vitro[67] and in vivo[68] models. Direct planimetry of the annular area by 3D imaging for quantifying mitral stroke volume may be more accurate but has not been validated.

The anterior (or aortic) leaflet is rounded and occupies a third of the circumference of the annulus (Figure 7). The posterior (or mural) leaflet occupies the other two thirds of the circumference and tends to be narrower in radial length. The relative areas of each leaflet are roughly equal, and the line of coaptation approximates an arc, with each end of this arc referred to as a commissure. The anterolateral and posteromedial commissures do not extend to the annulus, and although sometimes there may be distinct commissural leaflets, more often, this region is less well defined. The posterior leaflet is often indented, creating three frequently unequal scallops, with the middle scallop quite variable in size but typically the largest. Carpentier *et al.*'s[47] nomenclature describes the most lateral segment as P_1 which lies adjacent to the anterolateral commissure. P_2 is central and can significantly vary in size, and most medial and posterior is P_3. The anterior leaflet is curtain like, and distinct scallops cannot be identified, but similar labels (A_1, A_2 and A_3) are applied to the lateral, middle, and medial regions of the anterior leaflet. The anterolateral papillary muscle subtends the lateral commissure of the MV and gives off chordae to the lateral half of both

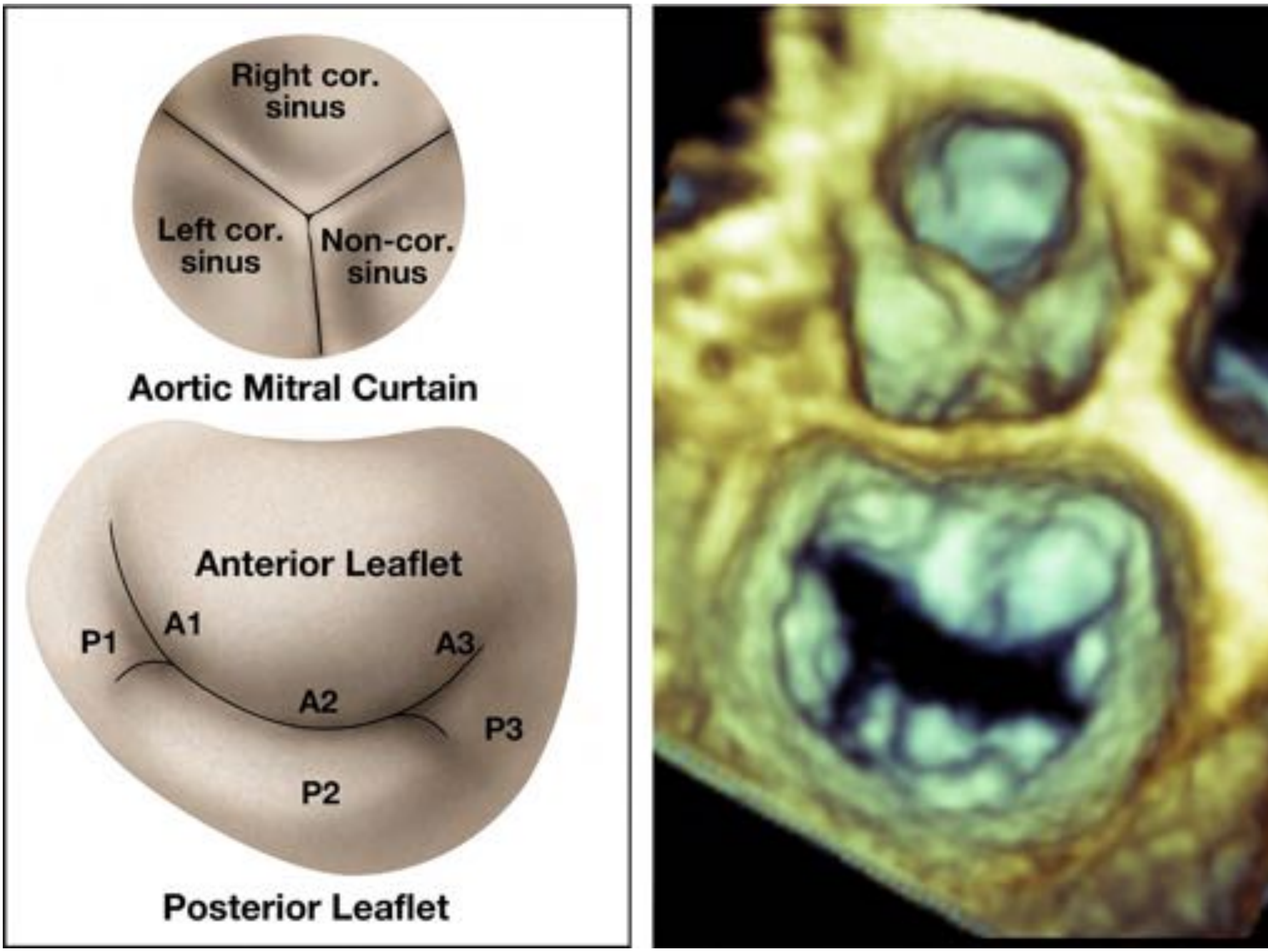


Figure 7 **(A)** Schematic diagram and **(B)** en face view of the MV from LA or surgeon's perspective depicting typical anatomic relationships. In this view, the AV is in the 12 o'clock position. The anterior leaflet is large, nonindented, triangularly shaped, and comprises two thirds of the valve surface area. The anterior segments ($A_1A_2A_3$) corresponding to the posterior scallops ($P_1P_2P_3$) are labeled accordingly. The anterior and posterior leaflets are conjoined laterally and medially to form the anterolateral and posteromedial commissures. The aortic mitral curtain (or mitral-aortic intervalvular fibrosa) separates the anterior leaflet from the AV. *cor.*, Coronary.

the anterior and posterior leaflets. The posteromedial papillary muscle subtends the medial commissure of the MV and gives off chordae to the medial half of both the anterior and posterior leaflets. Each chord from the papillary muscles divides several times before their attachment to the mitral leaflets; first-order (primary) chordae attach to the leaflet free edge, and second-order (secondary) chordae attach to the body of the leaflets (or rough zone). Third-order (tertiary) chordae attach directly from the ventricular wall or trabeculations to the base of the posterior leaflet or the annulus of the LV free wall; direct myocardial chordal attachments to the anterior leaflet are not normally seen.

MV 2D Imaging and Doppler. The MV should be visualized for imaging and color Doppler in LAX views (showing the left ventricle and left atrium) with at least four different imaging views: ME four-chamber view, ME mitral commissural view, ME two-chamber view, and ME LAX view. From these four views, all the scallops of both leaflets can be imaged (Figure 4). Multiple TG views may also be used for both imaging and Doppler interrogation. In general, the imaging protocol should be adapted to the individual patient's heart using rotational angles that optimize recording important structural and flow information. Panning to or rotating to additional images is often necessary to record specific jets or structural abnormalities that may be present. Color Doppler imaging planes should be selected on the basis of the maximum instantaneous size of the aliased portion of the mitral regurgitant jet, if present.

Numerous methods of quantitation of mitral stenosis and regurgitation have been previously described in the ASE guidelines,[69,70] and newer techniques including 3D imaging have been recently reviewed[71] and continue to be developed.[72]

MV 3D TEE and Doppler. Evaluation of the mitral apparatus using 3D TEE is most useful for (1) defining the extent and location of pathology, (2) determining the mechanism and severity of valvular dysfunction, and, when appropriate, (3) communicating the results of the echocardiographic examination to the interventional cardiologist or

Table 11 Summary of 3D transesophageal echocardiographic acquisition views

Protocol For Three-Dimensional Transesophageal Echocardiography Image Acquisition		
Left Ventricle	1. Obtain a view of the left ventricle from the 0°, 60°, or 120° mid-esophageal positions 2. Use the biplane mode to check that the left ventricle is centered in a second view 90° to the original. 3. Acquire using wide-angle, multi-beat mode	
Right Ventricle	1. Obtain a view of the right ventricle from the 0° mid-esophageal position with the right ventricle tilted so that it is in the center of the image 2. Acquire using wide-angle, multi-beat mode	
Interatrial Septum	1. 0° with the probe rotated to the inter-atrial septum 2. Acquire using narrow-angle, single-beat or wide-angle, multi-beat modes	
Aortic Valve	1. Obtain a view of the aortic valve from either the 60° mid-esophageal, short-axis view or the 120° mid-esophageal, long-axis view 2. Acquire using either the narrow-angle, single-beat or the wide-angle, multi-beat modes	
Mitral Valve	1. Obtain a view of the mitral valve from the 0°, 60°, 90° or 120° mid-esophageal views 2. Use the biplane mode to check that the mitral valve annulus is centered with the acquisition plane in a second view 90° to the original. 3. Acquire using narrow-angle, single-beat mode	
Pulmonic Valve	1. Obtain a view of the pulmonic valve from either the 90° high-esophageal view or the 120° mid-esophageal, 3-chamber view rotated to center the pulmonic valve 2. Acquire using narrow-angle, single-beat mode	
Tricuspid Valve	1. Obtain a view of the tricuspid valve from either the 0° to 30° mid-esophageal, 4-chamber view tilted so that the valve is centered in the imaging plane or the 40° transgastric view with anteflexion 2. Acquire using a narrow-angle, single-beat mode	

cardiac surgeon when an intervention is required. Acquisition is typically from an ME view (Table 11).

Narrow-Angle 3D Mode. "Real-time" 3D echocardiography using the single-beat mode on the matrix-array transducer permits display of a 30° × 60° (narrow-angle) pyramidal volume, which is usually sufficient to visualize the entire mitral apparatus when the ME mitral commissural view is the primary view (in the 60° or lateral plane of the pyramid). Typically, this mode allows an initial rapid 3D assessment of the mitral apparatus. The availability of multiple-beat mode with narrow-angle acquisition allows detailed examination of the MV with high temporal and spatial resolution but with the potential pitfall of stitching artifacts.

Cropping of the MV should not completely exclude adjacent structures, because they provide landmarks for orienting and displaying the MV. The MV should be oriented with the AV at the top of the screen in the 12 o'clock position regardless if viewed from the LA or the LV perspective (Figure 6).

Wide-Angle 3D Mode. The focused wide sector (zoom view) permits a focused, wide-sector view of the MV apparatus from the annulus to the papillary muscle tips. It allows visualization of the mitral apparatus from the annulus to the papillary muscle tips. It must be noted that enlarging the region of interest excessively will result in a further detrimental decrease of temporal resolution. However, this can be ameliorated by the use of multiple-beat mode, which optimizes spatial resolution, permitting detailed diagnosis of complex pathologies. In contrast, the wide-angle acquisition mode has the largest acquisition sector possible, which is ideal for imaging the entire mitral apparatus together with the LV. This mode also has optimal spatial resolution, which permits detailed diagnosis of complex pathologies. As well, it has high temporal resolution (>30 Hz), which is desirable when diagnosing mechanisms of abnormal mitral leaflet motion. The gated full volume can also be rotated to orient the mitral apparatus in unique en face views from the LA and LV perspectives.

3D Color Flow Doppler. Color flow Doppler should be added to the multiple-beat acquisition in patients with mitral regurgitation and/or stenosis. Similar to the technique for acquiring noncolor Doppler multiple-beat imaging, obtaining a 3D color flow Doppler data set initially requires the identification of a region of interest in orthogonal 2D imaging planes. The size of the region of interest should be limited to the mitral apparatus and color flow Doppler jet to optimize frame rate. Newer software may allow high frame rates with lower line density, which would permit a larger sector to be displayed. Finally, the largest number of individual gated component sub-volumes (4-6 beats) should always be attempted when electrocardiographic gating and reasonable acquisition times can be achieved. Additional color 3D data sets allowing cut planes to be oriented perpendicularly and parallel to the regurgitant or antegrade flow orifice may be of value for understanding morphologic and hemodynamic importance of those structures.

AV and Aorta

When evaluating the AV complex, the strength of TEE frequently rests on the morphologic assessment rather than the functional assessment of the native AV. Evaluation of the hemodynamic performance of the AV may be best accomplished using TTE because of the ability to interrogate flow across the AV from multiple transducer angles, which is more limited by TEE.

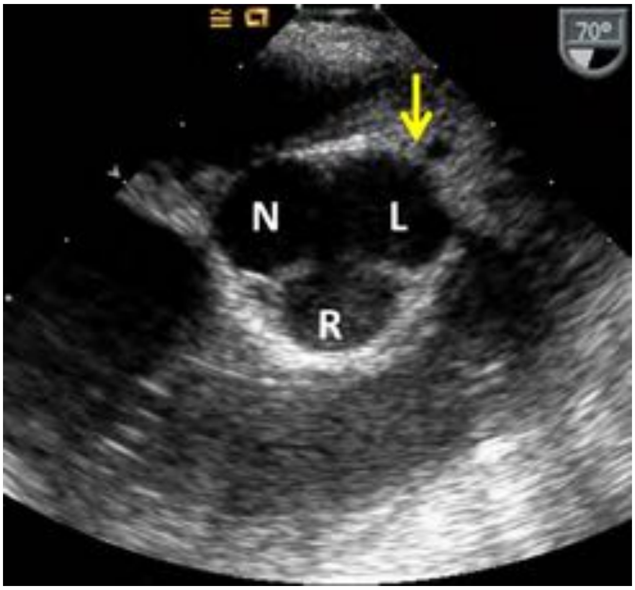


Figure 8 Midesophageal short-axis view of the aortic valve. The aortic cusps are identified by the corresponding presence or absence of the coronary arteries arising from the corresponding sinuses of Valsalva: left coronary (L), right coronary (R), and noncoronary cusps. The ostium of the left main coronary artery is seen in this view (*arrow*).

Accurate assessment of the AV depends on the understanding of the entire AV complex, which is composed of the AV, aortic root, and LV outflow tract. Because obstruction to LV outflow may occur not only at the level of the AV but also below or above the AV, it is important to carefully evaluate these regions. Two-dimensional echocardiography remains the gold standard for morphologic assessment of the AV. However, 3D TEE may significantly improve assessment of the valve as well as outflow tract and annular morphology. Three-dimensional TEE closely approximates aortic annular area measurements obtained by computed tomography.[73] Assessment of the aortic root is also an important component of the assessment of AV morphology and function, because aortic root dilatation may be associated with abnormalities of the AV.

Anatomy. The AV is a semilunar valve typically with three cusps located close to the center of the heart. The aortic cusps are identified by the presence or absence of the coronary arteries arising from the corresponding sinuses of Valsalva (left coronary, right coronary, and noncoronary cusps). These three semilunar cusps form part of the sinuses of Valsalva and the fibrous interleaflet triangles. Each semilunar cusp is attached to the aortic wall in a curved manner, with the basal attachment located in the left ventricle below the anatomic ventriculoaortic junction and the distal attachment at the sinotubular junction.[74] The sinuses of Valsalva and the sinotubular junction are integral parts of the valvular mechanism, such that any significant dilatation of these structures will result in AV incompetence. Overall, when tracking the curved path of the aortic leaflet insertion points, the 3D spatial configuration of the AV resembles a crown.[75]

The aortic root is not a specific structure per se but includes the AV annulus, cusps, sinuses of Valsalva, coronary artery ostia, sinotubular junction, and proximal ascending aorta. The LV outflow tract is the outflow portion of the LV just proximal to the AV. The coronary ostia originate from their respective sinuses, but the exact location within the sinuses can vary.

AV and LV Outflow Tract 2D Imaging and Doppler. Imaging of AV and LV outflow tract morphology is best undertaken from an ME transducer position, as described in the section "Comprehensive Imaging Examination." Both LAX and SAX views of the AV and surrounding structures are possible from this location. When specifically imaging the AV, it is best to crop or magnify the image to focus in on the AV. To maximize image resolution, imaging should ideally be performed using the highest imaging frequency possible, and because the AV is in the near field, imaging at higher frequencies is generally feasible. On occasion, however, if there is exuberant calcification, imaging at a lower frequency may be best.

From the ME AV SAX view (view #10), AV cusp number, the length of the free edges of the AV cusps, and the area of the AV orifice can be measured. Simultaneous imaging of all three cusps of the AV is possible (Figure 8). The cusp adjacent to the atrial septum is the noncoronary cusp, the most anterior cusp is the right coronary cusp, and the other is the left coronary. Color flow Doppler is applied in this cross-section to detect aortic regurgitation and estimate the size and location of the regurgitant orifice. The probe is withdrawn or anteflexed slightly to move the imaging plane superiorly through the sinuses of Valsalva to bring the right and left coronary ostia and then the sinotubular junction into view. The probe is then advanced to move the imaging plane through and then proximal to the AV annulus to produce a SAX view of the LV outflow tract.

The ME AV LAX view (view #6) allows imaging of the basal portion of the ventricular septum, LV outflow tract, as well as AV, annulus, and aortic sinuses. It is particularly important to appreciate the presence of basal septal hypertrophy, because this may accompany aortic stenosis or hypertrophic cardiomyopathy. Measurement of the LV outflow tract should be performed in early to midsystole, distal to a sigmoid septum if present and typically within 5 mm of the annulus. These measurements correlate well with transthoracic echocardiographic measurements.[76,77] In the absence of significant aortic stenosis (and proximal flow convergence), the diameter measurement used in calculating stroke volume is the annulus at the hinge point of the cusps.[61] However, in the setting of aortic stenosis and proximal flow convergence, the LV outflow tract diameter should be taken at the same level of the LV outflow tract as the pulsed Doppler sample volume,[70] which is typically within 5 mm apical to the annulus. A complete discussion of echocardiographic quantification of aortic stenosis is covered in prior guidelines.[70]

From the ME AV LAX view, the AV can also be assessed. The cusp of the AV that appears anteriorly or toward the bottom of the display is always the right coronary cusp, but the cusp that appears posteriorly in this cross-section may be the left or the noncoronary cusp, depending on the exact location of the imaging plane as it passes through the valve. This view is the best cross-section for assessing the size of the aortic root. The diameter of the LV outflow tract as well as AV annulus is measured during systole, particularly for transcatheter AV replacement.[12] The annulus is identified as the points of attachment of the AV cusps (or hinge point) and is normally between 1.8 and 2.5 cm. In the setting of acoustic shadowing secondary to AV and annular calcification, imaging from multiple windows obtained by withdrawing or advancing the probe may be required.

Doppler imaging from an ME AV LAX can assess flow through the LV outflow tract, AV, and proximal ascending aorta. Color flow Doppler assessment of the LV outflow tract is often valuable in determining the site of LV outflow tract obstruction. Because flow is perpendicular to the Doppler beam, peak velocities across the LV outflow tract or AV are not typically obtained from ME views unless jets are markedly eccentric and/or the Doppler beam can be aligned by withdrawing or advancing the probe. Other Doppler measurements, however, can be performed, including regurgitant jet vena contracta, the jet area/LV outflow tract area ratio in SAX, as well as the radius of the aliasing velocity for proximal isovelocity surface area method of regurgitant quantification. Quantitation of aortic regurgitation is discussed in detail in prior ASE guidelines.[69]

The primary purpose of the two TG views of the AV (the deep TG five-chamber view and the TG LAX view [view #27]) is to align the Doppler beam parallel to transaortic flow, which is required for accurate assessment of transaortic flow and peak velocities. They also provide images of the ventricular aspect of the AV in some patients, although far-field imaging may limit a detailed assessment. The exact position of the probe and transducer is more difficult to determine and control deep in the stomach, but with manipulating the probe in the various axes, both views in most patients can be obtained. In both TG views, the AV is located in the far field at the bottom of the display, with the LV outflow directed away from the transducer. Transducer angle rotation from this cross-section can achieve images of the aortic arch and great vessels in the far field in some patients. Blood flow velocity in the LV outflow tract is measured by positioning the pulsed-wave Doppler sample volume in the center of the LV outflow tract just proximal to the AV. This spectral Doppler is used with the LV outflow tract or annular diameter, to calculate LV stroke volume.[61,62] Peak flow velocity through the AV is measured by directing the continuous-wave Doppler beam through the LV outflow tract and across the valve cusps or across other high-velocity or turbulent jets seen by color Doppler. Given the limited imaging windows, peak transaortic velocities may still be underestimated compared with TTE. Assessment of valvular stenosis is fully covered by prior guidelines.[70] The assessment of aortic regurgitant jets may be performed from these views, but far-field imaging of color jets has multiple limitations.[12,69,78]

Aortic Root and Proximal Ascending Aorta 2D Imaging and Doppler. The ME AV LAX view and ME ascending aorta LAX view (views #6 and #7) are most useful for imaging and measurement of the aortic root and proximal ascending aorta. Although the ME AV LAX view is best obtained at an angle of 120° to 140°, the ME ascending aorta LAX view is better appreciated at the lower imaging angles, around 90° to 110°, because this portion of the aorta is positioned to the right of the aortic root. The ME ascending aorta SAX view can be obtained with orthogonal views from corresponding LAX views; simultaneous multiplane imaging using 3D echocardiography may be useful.

Measurements of the aortic root are usually made at (1) the AV annulus (hinge point of aortic leaflets), (2) the maximal diameter in the sinuses of Valsalva, and (3) the sinotubular junction (transition between the sinuses of Valsalva and the tubular portion of the ascending aorta). There is some controversy about measurement technique for the aorta. Some experts favor inner edge–to–inner edge techniques to match those used by other methods of imaging the aorta, such as magnetic resonance imaging and computed tomography. According to ASE guidelines,[79] normative data for adults were generated using diastolic leading edge to leading edge. Normative data for the pediatric population, on the other hand,[80] were generated using a systolic inner edge–to–inner edge technique. Recent 2010 American College of Cardiology Foundation and American Heart Association thoracic aorta guidelines[81] review the use of echocardiography as well as other imaging modalities for the assessment of the thoracic aorta. Views used for measurement should be those that show the

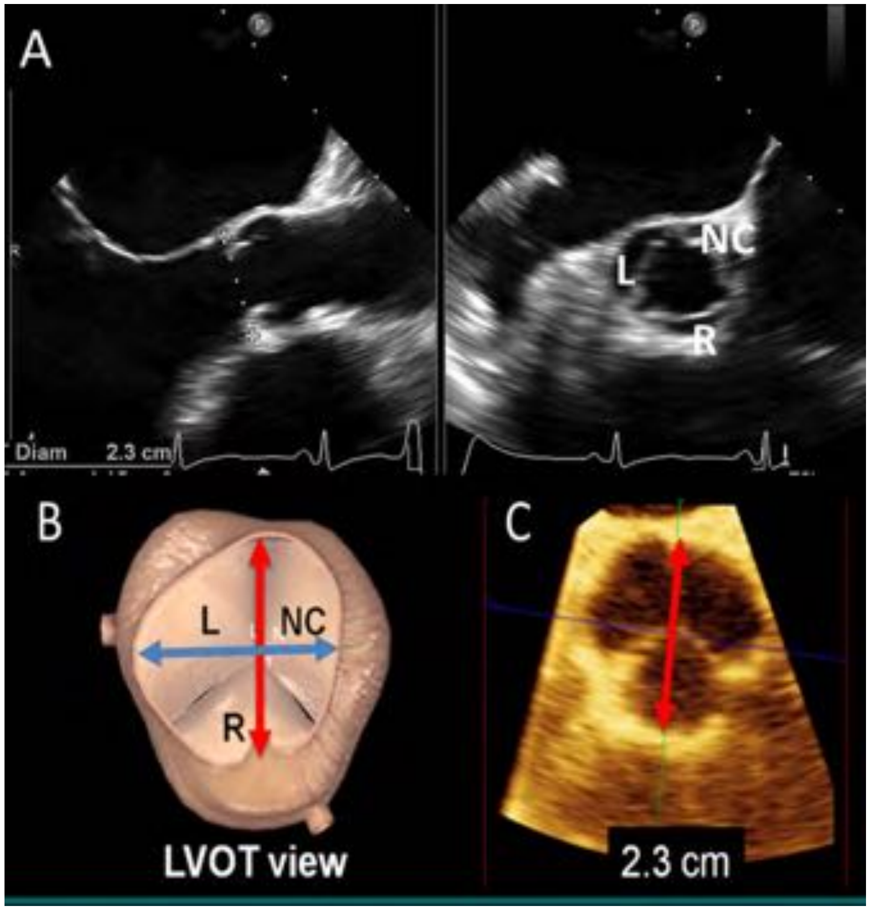


Figure 9 Two-dimensional echocardiographic planar measurements may incorrectly estimate true aortic annulus size if the LAX view does not bisect the maximum diameter of the aortic root. **(A)** The simultaneous multiplane imaging of a well-aligned LAX view which bisects the left noncoronary commissure posteriorly, and the right coronary cusp anteriorly. **(B)** A schematic showing the optimal sagittal dimension measurement plane (*red arrow*) which aligns with the left noncoronary commissure and the right coronary cusp. The sagittal plane annular measurement on 3D echocardiography **(C)** is 2.3 cm. Note; however, that the largest dimension is the coronal plane (*blue arrow*). *LVOT*, Left ventricular outflow; *L*, left; *R*, right; *NC*, noncoronary.

largest diameter of the aortic root when measured perpendicular to the long axis of the vessel in that view. Two-dimensional aortic diameter measurements are preferable to M-mode measurements, as cyclic motion of the heart and resultant changes in M-mode cursor location relative to the maximum diameter of the sinuses of Valsalva result in systematic underestimation (by 2 mm) of aortic diameter by M-mode in comparison with the 2D aortic diameter.[82] The aortic annular diameter may be measured in diastole between the hinge points of the AV leaflets (inner edge to inner edge) in the LAX views that reveal the largest aortic annular diameter (see above), but for the purposes of valve sizing before transcatheter or surgical valve replacement, the measurement should be performed in systole.[12,83] Color flow Doppler may be important in the setting of abnormalities such as aortic dissection or intramural hematomas.

Thoracic Aorta 2D Imaging and Doppler. The entire descending thoracic aorta and upper abdominal aorta are examined by rotating the transesophageal probe to the left, imaging posterior and to the left chest (the descending aorta is positioned to the left of the spine). The probe is advanced until the image is lost as the aorta descends beyond the diaphragm and then gradually withdrawn within the esophagus to obtain the descending aorta SAX and LAX images (views #25 and #26); simultaneous multiplane imaging may again be useful. To optimize image quality, the size of the aorta on the display is increased by reducing the depth, the focus is moved to the near field, and the transducer frequency is increased. As the probe is withdrawn from the diaphragm to the thoracic aortic arch, the origin of the left subclavian artery is appreciated. The distal ascending aorta and aortic arch are less well appreciated because the air filled trachea is interposed between the esophagus and these segments.[84] The transducer angle is rotated forward from 0° (SAX views) to between 90° and 110° to yield circular, oblique, and eventually the descending aortic LAX view in which the walls of the descending aorta appear as two parallel lines (LAX view). Irregularities of the aortic wall and presence of atheroma, atheroma thickness, as well presence of mobile atherosclerotic elements should be noted.

Color Doppler evaluation of the thoracic aorta is appropriate to evaluate for abnormal flow, particularly in the setting of ulcerated atheroma or a dissection flap. Pulsed-wave Doppler for assessment of diastolic flow reversal in the descending thoracic aorta can be reliably performed and should be used as supportive evidence for severe aortic regurgitation, particularly in the setting of poor LV outflow tract imaging.

Because of the changing relationship between the esophagus and the descending thoracic aorta and lack of internal anatomic landmarks, it is difficult to designate anterior and posterior or right-to-left orientations of the descending thoracic aorta on transesophageal

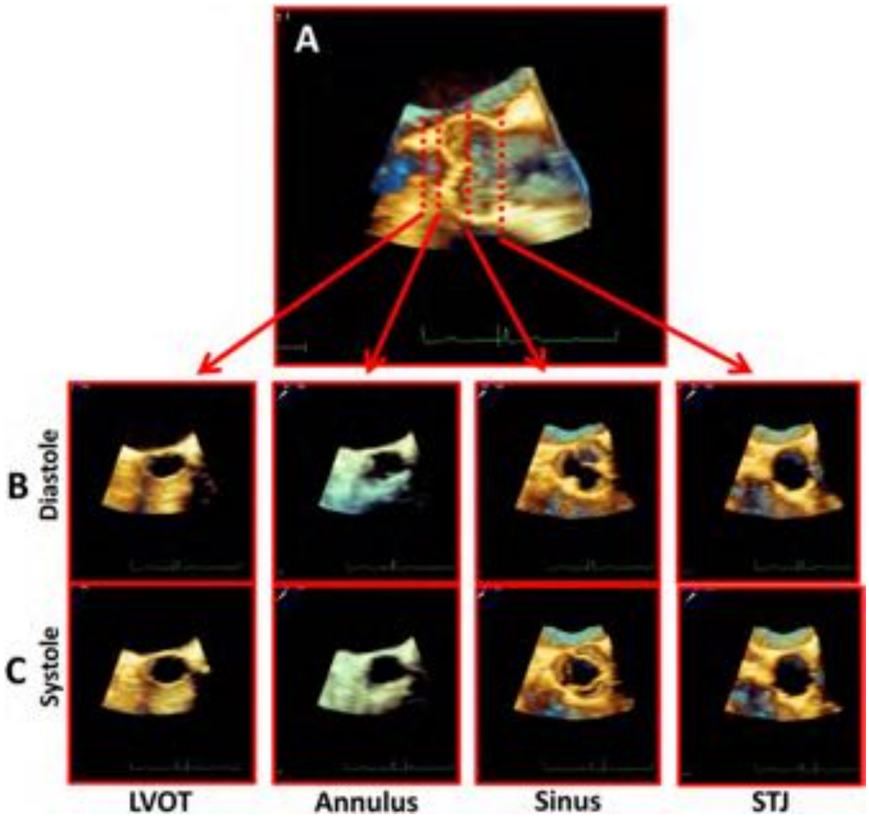


Figure 10 Three-dimensional imaging of the aorta. **(A)** A real-time 3D volume cropping the aorta in long-axis. Corresponding short-axis cuts are shown in **B** (diastolic frames) and **C** (systolic frames). The anatomy changes from one level to the next; oval in the left ventricular outflow tract (LVOT) and circular at the sino-tubular junction (STJ). In addition the LVOT and annulus in particular, also change in shape with the cardiac cycle, becoming larger and more circular in systole.

echocardiographic images. One approach to anatomically localize abnormalities within the descending thoracic aorta is to describe the location of the defect as a distance from the origin of the left subclavian artery and its location on the vessel wall relative to the position of the esophagus (e.g., the wall opposite the esophagus). Another approach is to record the depth of the lesion from the incisors. The presence of an adjacent structure, such as the LA or the base of the LV, may also designate a level within the descending aorta.

The aortic arch is imaged from the UE aortic arch LAX view (view #27) and UE aortic arch SAX view (view #28). In some individuals, withdrawing the transducer farther from the UE aortic arch LAX view can image the proximal left subclavian artery and left carotid artery. The right brachiocephalic artery is more difficult to image because of the interposition of the air-filled trachea. As the transducer is withdrawn, it can be turned to the left (counterclockwise) to follow the left subclavian artery distally. The left internal jugular vein lies anterior to and to the left of the common carotid artery and sometimes is seen. In the UE aortic arch SAX view, the origin of the great vessels often is identified at the superior aspect of the arch to the right of the display. The visualization rate of the arch vessels by TEE is lowest for the right brachiocephalic artery and highest for the left subclavian artery. The left brachiocephalic vein is also often seen anterior to the arch in views of the aortic arch. Forward rotating from the LAX view of the aortic arch (at 0°) to the SAX view (at 90°) may allow imaging of the main PA in the far field (typically between 70° and 90°).

AV and Aorta 3D TEE. Three-dimensional TEE from ME views provides important morphologic characterization of the AV and LV outflow tract. Intercommissural distance and free leaflet edge lengths, which can be measured by 3D echocardiography, are used to choose the tube graft size in valve-sparing root operations[85] (Figure 9). Because the LV outflow tract is often not circular but oval in shape, sagittal plane (LAX) measurements derived from 2D images may underestimate the true LV outflow tract dimensions (Figure 10). Three-dimensional TEE will typically yield larger LV outflow tract areas and calculated AV dimensions and areas.[86] Indeed, planimetry of the AV and LV outflow tract area using 3D echocardiography has been demonstrated to be more reproducible.[87,88] With accurate measurement of the LV outflow tract, geometric assumptions used in the continuity equation are avoided, resulting in more precise estimations of AV areas using 3D echocardiography over traditional 2D methods.

Three-dimensional echocardiography has become an important component of the evaluation of the aortic annulus and aorta for transcatheter procedures.[89] Studies suggest that 3D TEE can accurately measure the area or perimeter of aortic annulus[90-93] and can also be used to measure the distance between the annulus and leaflet tips to the coronary ostia[89] in the setting of severe, calcific aortic stenosis. For transcatheter valve procedures, this annular measurement is performed in midsystole.[94]

Narrow-Angle 3D Mode. With TEE, a 2D image of the AV at either the ME AV SAX view or the ME AV LAX view should be obtained (Table 11). After the 2D image is optimized, narrow-angle acquisition mode can be used to optimize the 3D image and to examine AV and root anatomy. After acquisition, when displayed en face, the AV should be oriented with the right coronary cusp located at the bottom of the sector regardless of whether the aortic or the LV outflow tract perspective is presented (Figure 5).

Wide-Angle 3D Mode. Once a wide-angle acquisition 3D data set of the aortic root is obtained, the cropping plane can be aligned parallel to the AV orifice, as identified from the LAX view. This results in a SAX 3D image of the AV orifice, which can be used for planimetry. As well, the cutting plane can be moved to the LV outflow tract, the sinus of Valsalva, or the sinotubular junction to obtain these respective cross-sectional areas. Last, the cropping planes can be placed perpendicular as well as parallel to the aortic annulus to assess supravalvular and subvalvular anatomy for serial stenoses.

3D Color Flow Doppler. Color Doppler 3D TEE should also be performed to detect the appearance of flow in both systole and diastole. Additional color 3D data sets allowing cut planes to be oriented perpendicular and parallel to the regurgitant or antegrade flow orifice may be of value for understanding the morphologic and hemodynamic importance of abnormal flow.

PV

Anatomy. The PV, similar to the AV, is a semilunar valve with three cusps. Unlike the AV, the PV cusps are thinner, and there is no fibrous continuity with the muscular septum or the right atrioventricular (tricuspid) valve.[95] The three PV cusps are named by their relative position to the AV. Thus, the right and left cusps, corresponding to the right and left cusps of the AV. The third cusp is named the anterior or "opposite" cusp given its position opposite the AV.[49] The plane of the PV is oblique to the plane of the AV. Awareness of this spatial relationship is useful when the operator is attempting to define the optimal imaging window for the PV. Because the PV is an anterior and thus far-field structure for TEE, views are more challenging to obtain, either because of interference from other structures (bronchus) or from patient intolerance of the high esophageal or TG transducer position. Therefore, these additional views may be of particular clinical utility in the critical care unit or operating room where patients are receiving heavy sedation or general anesthesia.[96,97]

PV 2D and Doppler Imaging. The PV can be imaged from several windows, not all of which can be consistently obtained or necessary in every study. Similar to other valves, 2D, color Doppler, spectral Doppler, and 3D imaging modalities are useful.

During the comprehensive imaging examination, the first view of the PV can be obtained by turning the probe to the left (counterclockwise) from the ME ascending aorta LAX view (view #7) as well as the ME ascending aortic SAX view (view #8). Imaging the PV from these ME views typically requires slight withdrawal of the probe into a higher esophageal position. From the ME ascending aorta LAX turning left (counterclockwise) yields a LAX view of the main PA with the PV in the far field. Maintaining the position of the main PA in the center of the imaging sector, rotating backward (toward 0°) allows visualization of the main PA and PA bifurcation. Because the Doppler beam will be parallel to transvalvular flow, pulsed-wave and continuous-wave Doppler as well as color flow Doppler can be performed from either of these views. In addition, turning to the right (clockwise) allows imaging of the right lobar PA (in the LAX view) and the main pulmonary artery bifurcation, as well as the superior vena cava (in the SAX view).

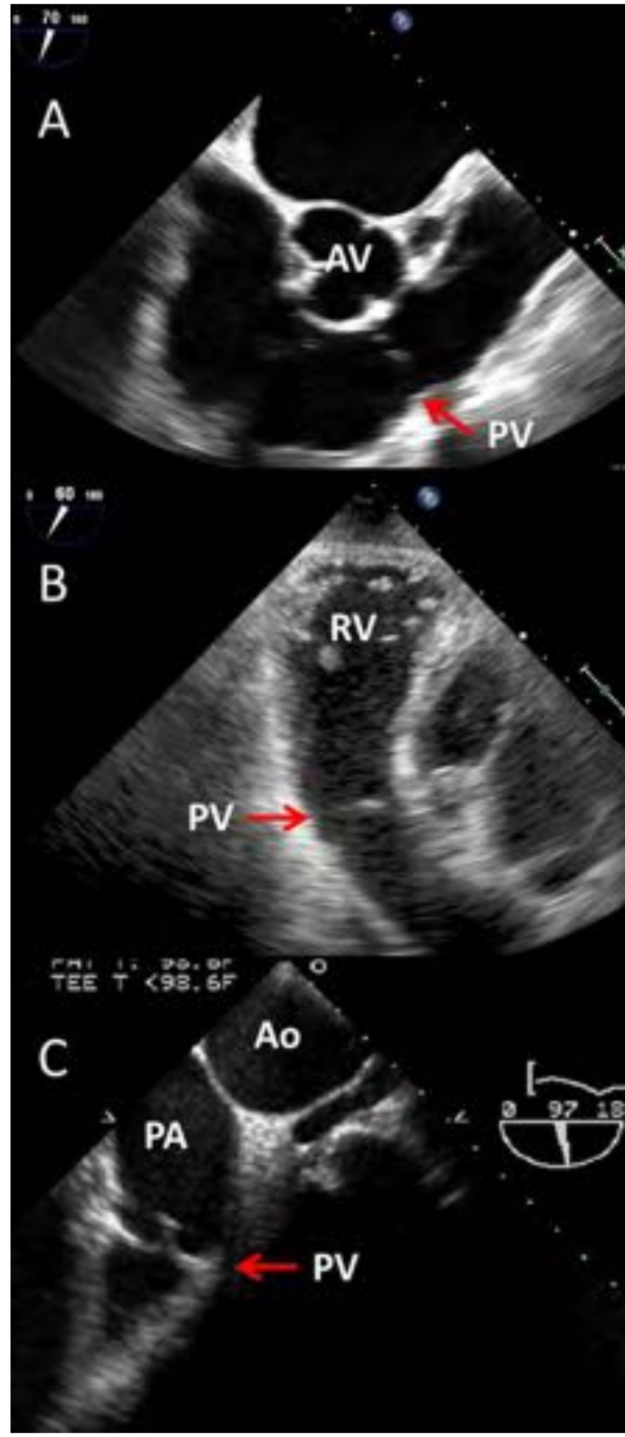


Figure 11 PV imaging from the ME RV inflow-outflow view (**A**, *red arrow*), TG basal RV view (**B**, *red arrow*), and UE aortic arch SAX view (**C**, *red arrow*). *AV*, Aortic valve.

The ME RV inflow-outflow view (view #11) allows visualization of two of the leaflets (typically the left or right and anterior) and is a useful screen for leaflet mobility, thickness, and regurgitation with 2D and color Doppler imaging. This view is frequently limited by acoustic noise from the AV or aortic prosthesis, which is immediately posterior to the PV. Advancing the probe and placing the RVOT perpendicular to the insonation beam enhances imaging for measurement of RVOT diameter (Figure 11A).

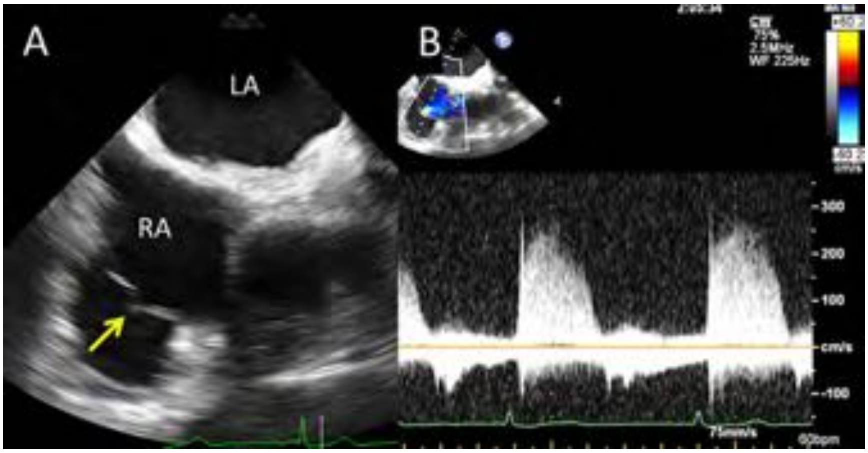


Figure 12 The ME modified bicaval TV view **(A)** images the coaptation point of the tricuspid leaflets (*yellow arrow*), and regurgitant jets directed toward the interatrial septum may be optimally aligned for continuous-wave Doppler of the jet **(B)**. *LA*, Left atrium; *RA*, right atrium.

TG views of the PV (Figure 11B) are primarily used to align transpulmonic flow with the Doppler beam. The transducer is advanced into the stomach and anteflexed from the TG apical SAX view (view #18) to obtain the TG basal RV view (view #19). Right flexion from this view typically yields the TG RV inflow-outflow view (view #20). A similar mirror-image view can be obtained by rotating the TG basal RV view to 90° to 120°. Color and spectral Doppler should be performed once the Doppler beam is aligned with transpulmonic flow. The UE aortic arch SAX view (level of the aortic arch) will frequently result in a LAX view of the main PA with the PV in the far field (Figure 11C).

PV 3D TEE. When imaging the PV in three dimensions, the transesophageal echocardiographic probe can be positioned at either the UE aortic arch SAX view (view #28) position at 70° to 90° or by obtaining a three-chamber LV–aortic root view at ~120° and then turning the probe to the left (counterclockwise) to bring the PV into view (Table 11). Typically, acquisition is difficult because there is signal dropout from the thin leaflets.

Narrow-Angle 3D Mode. Once the valve is optimally visualized, the PV can be acquired using single-beat, narrow-angle acquisition mode for rapid assessment. The narrow-angle, multiple-beat mode allows visualization of the PV leaflets. The image set can be cropped and rotated to display the valve in an en face view from either the PA or the right ventricle. When displayed in this en face view, the anterior leaflet should be located superiorly in the 12 o'clock position irrespective of perspective.

Wide-Angle 3D Mode. The wide-angle acquisition mode of the PV also permits examination of the main PA and the RVOT. Once the pyramidal volume is captured, cropped and rotated, the en face view of the valve can be displayed. As well, the cropping plane can be used to assess the dimensions of the main PA and the RVOT.[98] Last, the cropping plane can be used to show the RVOT, PV, and main PA in a single image.

3D Color Flow Doppler. In patients with pulmonary regurgitation or stenosis, color flow Doppler should be added to the narrow-angle, multiple-beat acquisition. The size of the region of interest should be limited to the PV and the color flow Doppler jet to optimize frame rate. As mentioned previously, the largest number of individually gated component slabs should always be attempted when electrocardiographic gating and brief acquisition times are possible. Once acquired, the pyramidal volume can first be viewed as originally obtained and then rotated to view the PV from the PA and right ventricle to identify the site of jet origin. Further cropping and the use of the black-and-white suppress can be used to identify effective orifice area, regurgitant orifice area, 3D proximal isovelocity surface areas, and vena contracta.

TV

Interest in the TV has increased in recent years[99-101] with the recognition of the importance of secondary tricuspid regurgitation[102-105] and tricuspid repair[106,107] on outcomes. Severe tricuspid regurgitation is an independent predictor of long-term mortality.[102] Because the prevalence of secondary tricuspid regurgitation with MV disease[99-101] is >30%,[93-95] an assessment of TV anatomy has thus become an important part of the comprehensive transesophageal echocardiographic examination.

Anatomy. The TV is the largest and most apically positioned valve. The TV complex is composed of three leaflets (anterior, posterior, and septal), attached chordae tendineae, three papillary muscles (anterior, posterior, and a third variable papillary muscle), and the fibrous TV annulus.[108] Tricuspid leaflets are significantly different in circumferential (annular) and radial size. The relative circumferential or annular ratio of the anterior to septal to posterior leaflets in normal patients is 1:1:0.75.[101,109] The anterior leaflet is the longest radial leaflet, and the septal leaflet is the shortest. This short septal leaflet is attached to the tricuspid annulus directly above the interventricular septum, with a number of third-order chordae attached directly to the septum. The tricuspid annulus is complex and dynamic. Three-dimensional echocardiography has been integral in our understanding of TV anatomy.[110,111] A normal annulus is triangular with nonplanar high and low points, superiorly displaced in the anterior/posterior portion and inferiorly (apically) displaced in the posteroseptal portion.[100]

TV 2D and Doppler Imaging. Typically the first image of the TV is obtained from the ME four-chamber view (view #2). From this view, the septal and anterior leaflets are typically imaged. Turning the probe to the right (clockwise) to bring the TV annulus to the center of the sector allows imaging of multiple planes of the TV

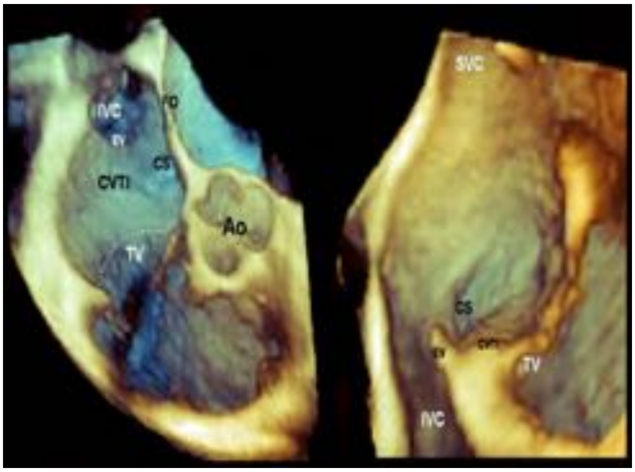


Figure 13 Wide-angle acquisition mode allows visualization of the tricuspid apparatus from the annulus to the papillary muscle tips, as well as the right atrium and associated structures. *Ao*, Aorta; *CS*, coronary sinus; *CVTI*, cavotricuspid isthmus; *EV*, Eustachian valve; *FO*, fossa ovale; *IVC*, inferior vena cava; *SVC*, superior vena cava. Modified from Lang *et al*.[49]

during axial rotation. The TV plane is frequently not coaxial with the transesophageal echocardiographic imaging plane, however, making an assessment of all the leaflets difficult; 3D imaging may be helpful (see below). Because the septal leaflet has the shorter radial length and is most often fixed by the rigid tricuspid annulus, regurgitant jets frequently are directed toward the interatrial septum. The ME inflow-outflow view (view #11) as well as the ME modified bicaval TV view (view #12) thus may be the most useful for color flow Doppler and spectral Doppler, because the septal leaflet is seen en face, and tricuspid regurgitant jets imaged in this plane may be directed toward the interatrial septum and thus well aligned with the insonation beam.

The TG basal RV view (view #19), TG RV inflow-outflow view (view #20), and TG RV inflow view (view #23) are additional TG views that may be useful when imaging the TV. From these views, the posterior leaflet of the TV is typically seen (in the near field). Color Doppler of the valve in the SAX view (TG basal RV view) may give a better assessment of the shape of the vena contracta for complex TR jets (Figure 12). Nonstandard deep TG views may also be performed to obtain the deep TG LAX views of the TV (0°); maximal anteflexion possibly with some right flexion results in the TV annular plane aligning perpendicular to the insonation beam (with TR jet parallel to the insonation beam).

TV 3D TEE. Three-dimensional TEE of the TV allows visualization of all aspects of the TV from a single full-volume data set or a focused examination on a particular TV aspect using a narrower imaging acquisition mode with higher resolution. Acquisition is from a 0° to a 30° view, with the TV centered in the image (Table 11).

Narrow-Angle 3D Mode. Once the TV image is optimized with 2D echocardiography, a narrow-angle single-beat acquisition can be performed. When displaying the TV en face, the septal leaflet should be located in the 6 o'clock position, irrespective of perspective. These en face views may be especially helpful in localizing leaflet disease such as leaflet prolapse, perforation, or vegetation, as well as localizing the origin of regurgitation jets, or performing planimetry of the tricuspid regurgitant orifice area to assess the severity of tricuspid stenosis. In addition to standard views, the cropping plane can be adjusted to visualize a particular section of the TV.

Wide-Angle 3D Mode. Wide-angle acquisition mode allows visualization of the tricuspid apparatus from the annulus to the papillary muscle tips. Enlarging the region of interest excessively will result in a further detrimental decrease of temporal resolution. This can be ameliorated using multiple-beat mode, which increases spatial resolution, permitting detailed diagnosis of complex pathologies (Figure 13) with high temporal resolution (>30 Hz), which is desirable when diagnosing mechanisms of abnormal tricuspid leaflet motion.

3D Color Flow Doppler. Color flow Doppler should be added to the multiple-beat acquisition in patients with tricuspid regurgitation and/or stenosis. Similar to the technique for acquiring noncolor Doppler multiple-beat imaging, obtaining a 3D color flow Doppler data set initially requires the identification of a region of interest in the orthogonal planes. The size of the region of interest should be limited to the tricuspid apparatus and color flow Doppler jet to optimize frame rate. In addition, although a high line density may be desirable, a lower line density will permit a larger sector to be displayed. Finally, the largest number of individually gated component subvolumes (4-6 beats) should always be attempted when electrocardiographic gating and reasonable acquisition times can be achieved.

Assessment of Ventricular Size and Function

Assessment of ventricular function is most commonly performed by TTE. However, there are some situations in which TEE may be used to assess ventricular function.[32,112] Three-dimensional and simultaneous multiplane imaging has enabled the application of a variety of qualitative and quantitative techniques for the assessment of LV and RV function.[113] Higher frequency transesophageal echocardiographic transducers, however, have restrictions such as reduced penetration and increased attenuation, resulting in limited far-field image resolution from ME views and a reliance on TG views for accurate wall motion assessment in large hearts. Hemodynamic alterations (i.e., due to anesthetic agents) may affect ventricular function and should be considered when assessing global function.

Anatomy. The normal LV is composed of an inlet portion containing the MV apparatus, an apical portion with characteristic muscle bundles, and an outlet portion proximal to the AV.[114] The normal LV is shaped like a prolate ellipse, and thus geometric models are used to estimate the ventricular volume using linear measurements. Studies have suggested that measurements from TTE are nearly identical to those from TEE,[98,115,116] but standard imaging planes for measurements have yet to be determined. Studies directly comparing TEE with TTE measurements used the TG mid-LV SAX view (view #17), its orthogonal TG LV two-chamber view (view #22), or the TG LV LAX view (view #24). Diameter measurements should be made perpendicular to the long axis of the left ventricle, so the LAX or two-chamber view is the recommended view for obtaining these measurements. If the SAX view is used, use of simultaneous multiplane imaging helps ensure an on-axis measurement, perpendicular to the long axis of the left ventricle (Figure 14). Normative values for TEE have not been published. The location of measurement differs slightly (closer to the mid left ventricle for TEE and closer to the MV leaflet tips for TTE), and this may account for differences. The use of ME views for linear measurements is feasible but discouraged given lateral gain resolution issues with the endocardial surface,

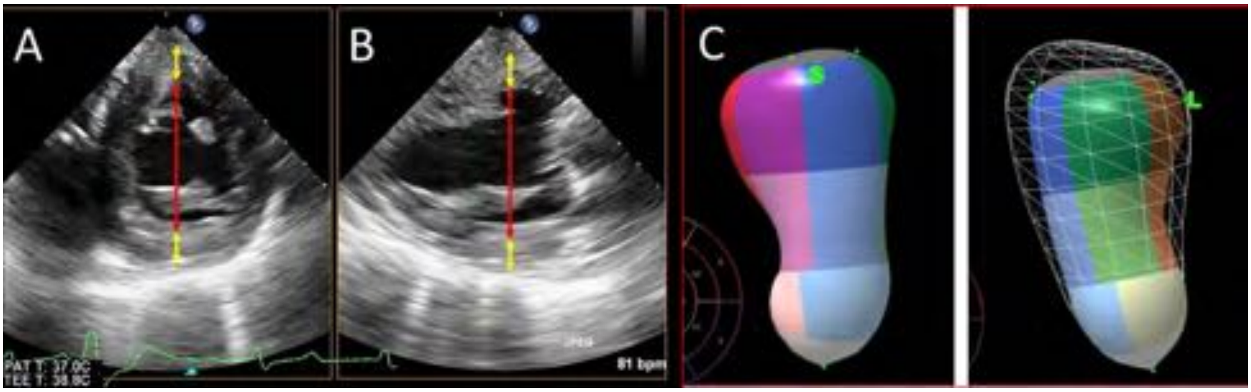


Figure 14 Recommended view for measuring LV wall thickness and internal dimension. Simultaneous multiplane imaging of the *left ventricle* at the level of the tips of the mitral leaflets shows the recommended LV measurements in the TG LV SAX view **(A)** and the orthogonal TG LV two-chamber view **(B)**. LV volume 3D display and semiautomated quantification are performed by creating volumes enclosed by the 3D shell of the LV endocardium derived from border tracings (either manual or automated) **(C)**.

which is parallel to the insonation beam from these views. The ME view can be used for the biplane Simpson's method of disks for the calculation of LV volume and ejection fraction when the entire length of the left ventricle can be imaged without foreshortening however this method has limited validation.

The normal RV is similarly composed of an inlet portion containing the TV apparatus, an apical portion with characteristic muscle bundles, and an outlet portion proximal to the PV. The shape of the RV, however, differs significantly. The three portions do not lie in one plane, and the apical and outflow portions of the ventricle wrap around the LV. The shape of the RV cannot be distilled into a simple geometric shape, and thus volumes cannot be accurately derived from linear measurements.

LV 2D and Doppler Imaging. Assessment of ventricular function can be performed via the gastric and esophageal views. In the TG views, SAX projections can be obtained at the basal, midpapillary, and apical levels (views #16–18).[113] Orthogonal views can be obtained either at the midgastric (view #24) or deep gastric (apical) levels. The ME level (views #1–5) provides views that are analogous to TTE views; the four-chamber (0°–10°), two-chamber (80°–100°), and apical LAX (120°–140°) views[113] as well as the five-chamber (0°-10°) and mitral commissural (50°-70°) views. The sum of these views provides excellent and comprehensive coverage of the LV endocardial motion for all segments, as previously described,[79] allowing assessment of regional wall motion abnormalities, although the apex is frequently poorly visualized because of foreshortening.

Optimizing 2D images helps improve the accuracy and reliability of ventricular function assessment. This includes adjusting the depth to include the entire ventricle, manipulating the anteflexion and retroflexion of the probe tip to avoid foreshortening the ventricle, optimizing gain to best depict the endocardium, and either placing the focal zone midway between the ventricular base and apex or using dual focal zones to better define the apical region. If necessary, use contrast to better delineate the endocardial border. The entire left ventricle cannot always be imaged from ME view, because of variation in its orientation in relation to the esophagus.

LV Global Systolic Function. An initial qualitative analysis is followed by a more detailed quantitative assessment if needed. Qualitative assessment of global function is performed by visually estimating the ejection fraction after reviewing multiple orthogonal views. Although quantitative assessment is possible, the limited imaging planes and lack of normative data for TEE limit the use of standard M-mode, B-mode, and Doppler-based methods used in TTE.

Limitations of TEE in the Assessment of Ventricular Function. The ventricular apex can be foreshortened unless care is taken to avoid this issue. If unnoticed or unaddressed, apical foreshortening can result in underestimation of ventricular volumes. Because Doppler beam alignment can be challenging, particularly of the AV, Doppler-based ventricular function indices may not be as accurate with TEE.

Contrast TEE

In many patients TEE avoids the physical contributors to poor transthoracic echocardiographic images, such as soft tissue and intervening lung. In addition, the close proximity of the probe to the heart permits use of higher transducer frequencies and thereby higher resolution images but at the cost of far field attenuation. Although overall, endocardial definition should be better with TEE, on occasion image quality may be limited. In such cases, contrast agents can improve border definition. Contrast administration also is able to augment Doppler signals. Last, agitated saline contrast via a peripheral venous access is used to rule out atrial shunts.

Evaluation of LV Diastolic Function

Although evaluation of diastolic function is accurately and efficiently performed by TTE, in technically difficult situations or when TEE is being done for other purposes, TEE can be used to evaluate diastolic parameters.[117,118] TEE can be used to obtain mitral inflow velocities, pulmonary vein velocities, and tissue Doppler velocity. Among these, access to all four pulmonary veins and an optimal orientation of the Doppler beam is a particular advantage of TEE. Mitral inflow and annular tissue Doppler velocities are equally well assessed by TTE or TEE, unless the former images are poor quality or transducer positions inaccessible. A recent study of patients undergoing coronary artery bypass graft surgery evaluated a simplified TEE algorithm for assessing diastolic dysfunction, using only the lateral mitral annular e′ velocity (abnormal < 10 cm/s) and transmitral E to e′ ratio (normal ≤ 8). LV diastolic dysfunction using this algorithm was predictive of long-term major adverse cardiac events.[119]

Evaluation of RV Global and Regional Function

Evaluation of the RV is easily performed by TTE, but poor image quality or limited access of the transducer to the chest wall may require TEE. Also, when TEE is being performed for other reasons, it may provide high-resolution and superior quality images of the RV compared with TTE. During the evaluation of a critically ill patient, assessment of RV size and function may offer insights into the presence or physiologic consequences of pathology, such as RV infarction, pulmonary embolus, loculated pericardial effusion, and extracardiac pathology such as masses that may be impinging on the right ventricle. Although RV size on TEE is often assessed visually and considered normal if less than two thirds the diameter of the LV, the guidelines are published with TTE reference values for size and function.[117] RV assessment by TEE is usually performed in the ME four-chamber view or in the TG views. LAX (views #20 and #23) and SAX (views #16-19) views of the right ventricle are available from these projections. To date, there are inadequate data to make specific recommendations for values for RV size and function by TEE.

LV Function 3D TEE

Single-beat and real-time 3D acquisition allow the potential use of 3D imaging in routine clinical practice. At the present time, it is feasible to obtain "full-volume" data sets of the left or right ventricle. Offline analysis of the full 3D volume allows the operator to delineate the endocardial border without making any geometric assumptions. Thus, when the entire ventricle can be imaged in the 3D volume, accurate and reliable measurements of end-diastolic and end-systolic volumes can be made and lend themselves to calculation of volume-based function indices such as stroke volume and ejection fraction (Figure 14C).

Left Atrium and Pulmonary Veins

LA and LA appendage imaging has become an increasingly important role for TEE. The most common reason for TEE is cardiac source of embolus, and the LA appendage is a primary target for this evaluation.[8,120] The sensitivity and specificity of TEE to diagnose thrombus in the LA appendage are 100% and 99%, respectively,[121,122] but because of the complex nature of this structure, small (<2 mm) thrombi can be missed.[123] AUC support the use of TEE for the evaluation of cardiac source of embolus or to facilitate clinical decision making in patients with atrial fibrillation or atrial flutter.[21] Exclusion of the LA appendage has been shown to reduce stroke risk in some patient populations,[125,126] and transcatheter LA appendage closure devices have sparked interest in characterizing the highly variable LA appendage anatomy by TEE.[123,128-130] The LA appendage orifice is typically oval shaped, and the body of the LA appendage is highly variable length and shape (Figures 1–3).[131,132] Because the LA appendage is actively contractile and is trabeculated with pectinate muscles, its size and position vary with the cardiac cycle, making it particularly difficult to image with static imaging planes. Both the shape and function of the LA appendage also vary with a number of factors, including age, hypertension, diabetes, and the duration of atrial fibrillation.[132,133] Autopsy studies have shown that the LA appendage can vary from having one to as many as five lobes.[134]

Anatomy. The left atrium is a boxlike chamber that lies posterior at the base of the heart. On the septal surface, there is a shallow depression that corresponds to the right atrial fossa ovalis. The venous portion of the chamber receives the openings of the four pulmonary veins posteriorly, with the left veins typically more superior than the right veins. The vestibule of the left atrium surrounds the MV.[135] The LA appendage or auricle is a blind-ending structure with the orifice or os typically located superiorly and laterally. The normal diameter of the os ranges from 10 to 24 mm.[131] The ridge between the os of the LA appendage and the left superior pulmonary vein is a triangular fold of serous pericardium and has been variously referred to as the Q-Tip sign the posterolateral ridge, the warfarin ridge, and the ligament (or fold) of Marshall.

The walls of the left atrium are muscular, but thickness may vary. Autopsy studies have shown areas of deficient myocardium resulting in markedly thinned regions (1 ± 0.5 mm) typically occurring along the anterolateral or lateral LA wall within the vestibule leading to the mitral annulus as well as distal to the LA appendage orifice. In addition, small pits and troughs can be seen around the orifice; each of these is thin walled, which may have implications for percutaneous devices.[127] Abnormal increases in thickness may be a result of laminar, mural thrombus or endocarditis. Dystrophic mitral annular calcification may extend onto the wall of the left atrium, also increasing the wall thickness.

LA and Pulmonary Vein 2D TEE and Doppler Imaging. MV imaging planes will necessarily image the left atrium. Because the left atrium is a near-field structure during TEE, the entire structure is difficult to see from a single imaging plane, making quantitative measures of LA volume difficult. LA area or volume by TEE underestimates the area and volume by TTE.[136] The linear measurement of the left atrium that has best correlated with transthoracic echocardiographic anteroposterior (parasternal LAX) measurements is taken from the ME AV LAX view (view #6) or the ME AV SAX view (view #10), measuring from the apex of the sector (i.e., the posterior wall of the left atrium) to the posterior aortic root,[116,136] but normative data are limited. LA width (septolateral) in the ME four-chamber view has the highest correlation with equivalent transthoracic echocardiographic views,[136] but normative data for this measurement are not available.

The orifice of the LA appendage, however, is a lateral cardiac structure and is frequently imaged initially in the 0° four-chamber plane. To image 180° of the LA appendage, however, this orifice should be centered in the imaging plane, typically by turning the probe to the left (counterclockwise) and ante flexing to bring the LA appendage to the center of the imaging plane. Not infrequently, the ligament of Marshall causes a reverberation artifact that can be confused with thrombus. In this situation, a better position for imaging the LA appendage requires a deeper probe position in which the ridge is no longer between the cavity of the LA appendage and the probe. Organized thrombus is defined echocardiographically as a well-circumscribed, highly reflective mass with different texture from the atrial wall and uniform consistency.[27] Spontaneous echocardiographic contrast, on the other hand, will not be well circumscribed or have uniform consistency. Its location may be dynamic with a "smokelike" appearance due to its slow motion.[137] There are some thrombi, however, that do not appear well circumscribed but have spontaneous echocardiographic contrast surrounding an organized portion; in these instances, prolonged observation in a single plane or using simultaneous multiple-plane imaging may be required to differentiate sludge from thrombus.

Doppler of the LA appendage can be performed, particularly in the setting of atrial fibrillation or atrial flutter, to assess the risk for thrombus formation, because flow velocity at the ostium has significant prognostic utility.[138] The pulsed Doppler sample volume is typically placed 1 to

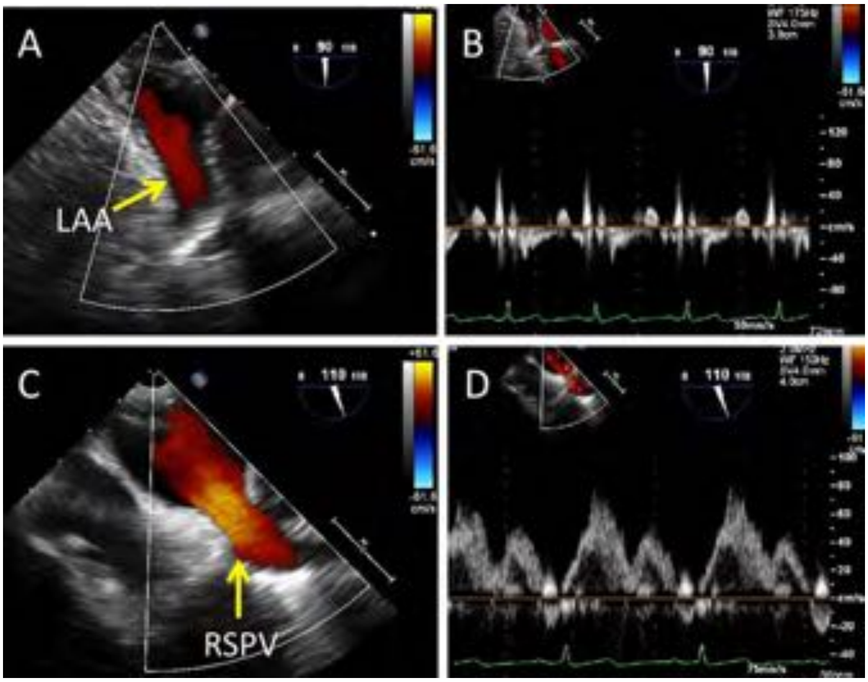


Figure 15 The LA appendage (LAA) **(A)** is imaged from the ME views; given the complex and highly variable anatomy, imaging should be performed from multiple transducer angles. Pulsed Doppler **(B)** can be performed for assessment of contractility and risk for thrombus formation. Both the right and left pulmonary veins should also be imaged. The right pulmonary vein **(C)** may be imaged by turning to the right (clockwise) from the 90° to 110° ME bicaval view. Pulsed Doppler **(D)** or continuous-wave Doppler can be performed for assessment of flow. *RSPV*, Right superior pulmonary vein.

2 cm from the orifice within the chamber (Figures 15A and 15B). LA appendage emptying velocities of <20 cm/sec were associated with spontaneous echocardiographic contrast, thrombus formation, and embolic events. LA appendage emptying velocities >40 cm/sec predict a greater likelihood of sustained normal sinus rhythm after cardioversion from atrial fibrillation.[139]

The left pulmonary veins are imaged from the ME LA appendage and left upper pulmonary vein view (view #16). Right pulmonary veins are imaged from the ME right pulmonary vein view (view #9) at 0° or turning right (clockwise) from the ME bicaval view (view #13) at 90°. Doppler evaluation of the pulmonary vein flow can also be assessed by TEE in select situations (Figures 15C and 15D). Although the presence of pulmonary vein stenosis (either congenital or acquired) is more frequently and accurately diagnosed with computed tomography and magnetic resonance imaging, continuous-wave Doppler of the veins during TEE adds to the assessment of severity.[140,141] Reversal of systolic pulmonary vein flow has a high specificity for severe mitral regurgitation when the mitral regurgitant jet is not directed into the vein imaged.[69]

LA and LA Appendage 3D TEE. Assessment of the LA appendage by 3D echocardiography has been well described.[133,142-144] Using the simultaneous imaging modality may be helpful in excluding thrombus as well as positioning catheters during percutaneous procedures. Real-time 3D TEE is useful to define the variable anatomy of the orifice and the relationship to the pulmonary veins both preprocedurally and intraprocedurally.

Right Atrium and Venous Connections

Understanding right atrial anatomy has become increasingly important for transcatheter interventions as TEE is increasingly used to aid in transseptal punctures and catheter ablation techniques.

Anatomy. The right atrium is the receiving chamber for blood from the superior and inferior vena cavae and the coronary sinus. The right atrial side of the interatrial septum is demarcated by the limbus of the fossa ovalis. This semicircular structure is the edge of the secundum septum. The shallow depression of the thin fossa ovalis (the foramen ovale in the fetus) overlaps this edge. Within weeks of delivery, closure of the foramen ovale eliminates the communication between the left and right atria. However, when this closure is incomplete, a PFO results. Autopsy studies suggest that the incidence of PFO is about 27%, but this is inversely dependent on age.[145] Although there may be a separation of the primum septum flap and the secundum septum limbus resulting in left-to-right flow under resting conditions, the in vivo diagnosis often is made by injecting agitated saline contrast (see below), with or without maneuvers that increase the right atrial pressure (i.e., release of the Valsalva maneuver).

A higher prevalence of shunting has long been associated with atrial septal aneurysms.[146-149] There is no consensus on the definition of an atrial septal aneurysm, which has variously been defined as diameter of the base of the flimsy portion of interatrial septum ≥ 15 mm and excursion of the aneurysmal membrane ≥11 mm in either the left or right atrium, or if the sum of the total excursion is ≥11 mm[147]; a protrusion of the aneurysm >10 mm beyond the plane of the atrial septum into either the right or left atrium[150]; a dilated portion of the interatrial septum protruding ≥15 mm beyond the plane of the interatrial septum or when the atrial septum shows phasic excursions during the cardiorespiratory cycle ≥15 mm with the base of the aneurysm ≥15 mm[151]; and a thin localized outpouching of the middle portion

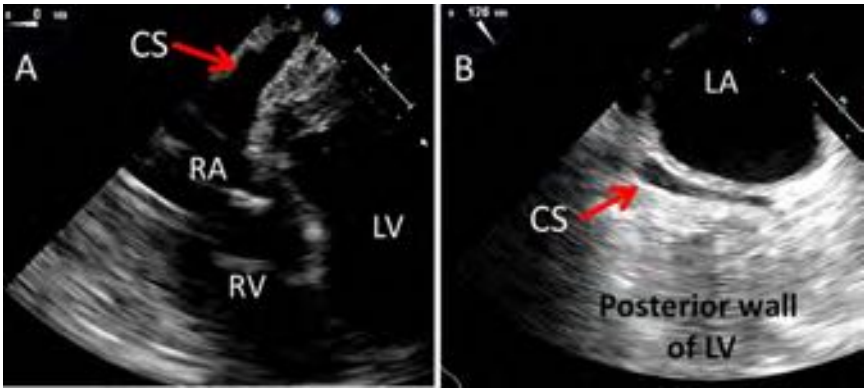


Figure 16 Multiple views of the coronary sinus (CS) can be obtained. Deep esophageal views should allow imaging of the CS, which is an inferior and posterior structure **(A)**. ME views, however, can also be used to image the CS; at 90° to 130° with a counterclockwise turn from a ME two-chamber view, the posterior region of the left atrium (LA) can be imaged **(B)**. *LV*, Left ventricle; *RA*, right atrium; *RV*, right ventricle.

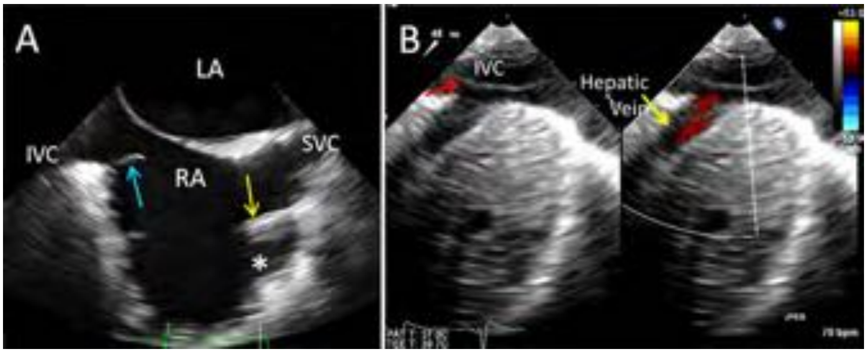


Figure 17 From the bicaval view **(A)**, the inferior vena cava (IVC), Eustachian valve (*blue arrow*), crista terminalis (*green arrow*), right atrial appendage (*asterisk*), and superior vena cava (SVC) are seen. Further insertion **(B)** (with simultaneous color Doppler imaging) may allow imaging of the IVC within the liver as well as imaging of the hepatic vein (*yellow arrow*). A femoral vein catheter is seen in the IVC (*red arrow*). *LA*, Left atrium; *RA*, right atrium.

of the atrial septum, but not the entire septum, protruding >6 mm outside the plane of the atrial septum.[148]

Eustachian Valve and Chiari Network.–The Eustachian valve is a fibrous or fibromuscular flap of tissue that guards the entrance of the inferior vena cava. It is typically concave and directed superiorly, extending between the fossa ovalis and the ostium of the coronary sinus along the Eustachian ridge. In utero, this structure directed blood flow from the inferior vena cava across the foramen ovale. In the setting of a PFO, a prominent Eustachian valve may perform the same function. In 1% to 4% of the population, a reticulated network or fibers or thin membrane called a Chiari network may be seen. The Chiari network is a remnant of the right sinus venosus valve.[152] Although thought to be benign, studies have shown a much higher prevalence of atrial septal aneurysms as well as PFO.[153,154] The PFOs associated with this congenital anomaly are more likely to exhibit pronounced right-to-left shunting.

Crista Terminalis.–The crista terminalis is a C-shaped structure that separates the smooth-walled venous inflow of the right atrium from the pectinated right atrial appendage. This structure can vary considerably in thickness and depth.

Coronary Sinus.–The coronary sinus opens into the right atrium between the inferior vena cava and the TV. In the majority of patients, the orifice is guarded by the valve of the coronary sinus (or valve of Thebesius), and this valve can be variable in size.

Inferior Vena Cava.–This venous structure runs in the retroperitoneal space, to the right of the vertebral body, and enters directly into the right atrium from the abdominal cavity. The hepatic vein is the last tributary to the inferior vena cava. Both venous structures may be important to image or Doppler for hemodynamic assessment of right atrial pressures, severity of tricuspid regurgitation and abnormal RV filling patterns.

Superior Vena Cava.–This venous structure resides in the anterior right superior mediastinum and is the confluence of the right and left brachiocephalic (or innominate) veins. Imaging and Doppler of the superior vena cava may also be important for hemodynamic assessment of right atrial pressures, but because it courses through the thoracic cavity, flow and pressures may be influenced by intrathoracic pressures.

Right Atrium and Venous Connections 2D TEE and Doppler Imaging. Imaging of the TV will result in imaging of the majority of the right atrium, but focused imaging of the interatrial septum is required to assess intracardiac shunts. In addition, focused imaging of the coronary sinus is important intraoperatively when coronary sinus cannulation is required. The ME four-chamber view (view

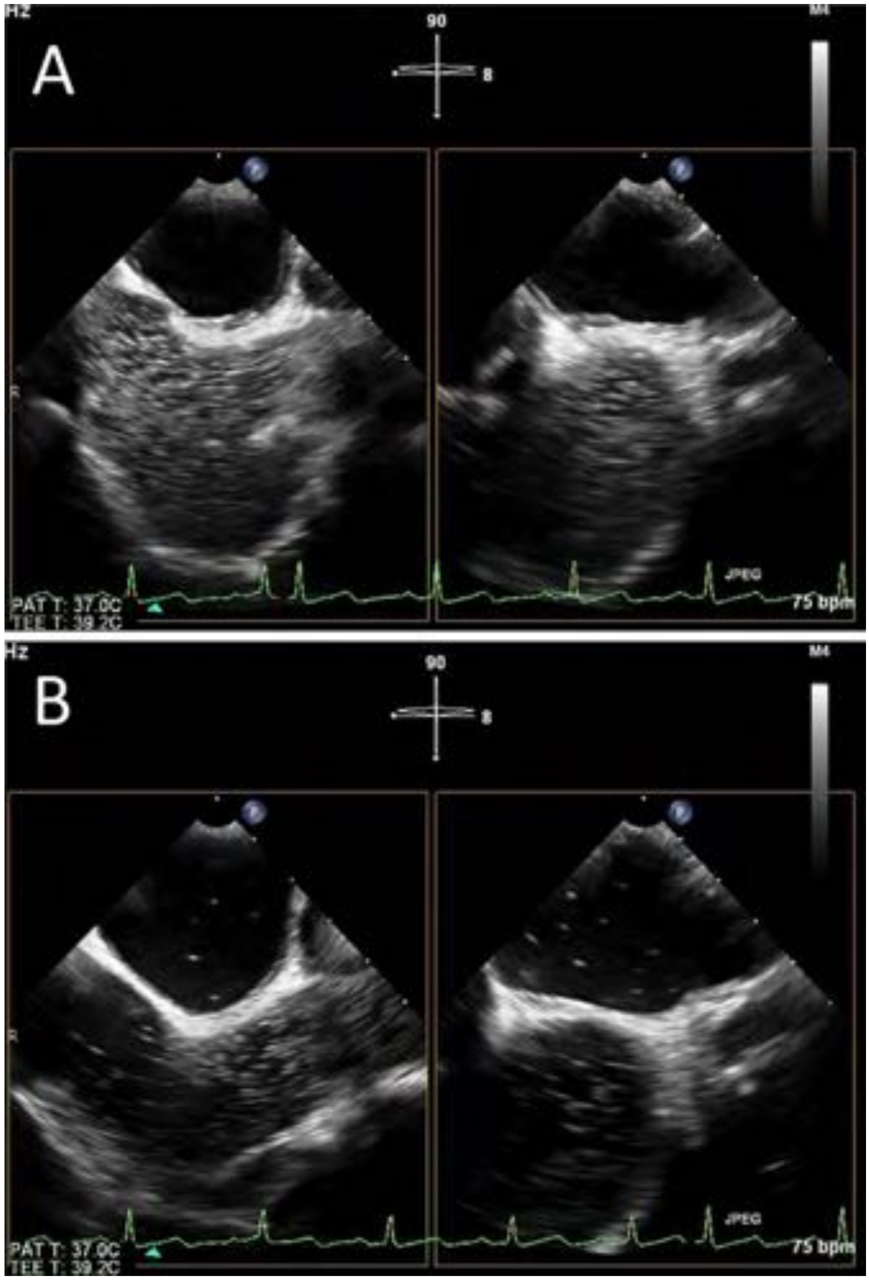


Figure 18 Saline contrast study: After opacification of the right heart **(A)**, the appearance of more than three saline bubbles in the left heart **(B)** is most consistent with a PFO. Both the rate of shunt detection and the clinical interpretation of the shunts found have varied considerably.

#2) images the midanterior interatrial septum and the primum portion of the interatrial septum. Deeper esophageal views (at 0°) allow imaging of the coronary sinus, which is an inferior and posterior structure (Figure 16A). The coronary sinus can be also be imaged in the SAX view in the ME two-chamber view (view #4) at 90°, but turning the probe to the left (counterclockwise) from this view will frequently allow LAX imaging of the coronary sinus (Figure 16B). Occasionally, the coronary sinus can be imaged from the ME bicaval view (view #13) with slight advancement and clockwise turning of the probe.

The ME bicaval view (view #13) is also obtained at 90° with a clockwise turning of the probe to focus on right heart structures. In this view, the superior vena cava, inferior vena cava, crista terminalis, and right atrial appendage are well defined (Figure 17A). From this view, the fossa ovalis is well imaged as well as the "flap" of a PFO.[154] Withdrawing the probe will allow more complete imaging of the superior vena cava and the caval-septal wall. The right superior pulmonary vein is adjacent to the superior vena cava, and clockwise turning will allow imaging of this structure as well as the right inferior pulmonary vein. Anomalous right pulmonary venous return into the superior vena cava is typically imaged from these views.

Inserting the probe to a deeper bicaval view (still at 90°) is helpful to assess the inferior vena cava, Eustachian valve, and the inferior caval-septal wall. Further insertion may allow imaging of the inferior vena cava within the liver as well as imaging of the hepatic veins (Figures 17B and 17C).

The use of 3D imaging of the right atrium has been well described.[49,155] Although the guidelines suggest imaging orientations for individual structures, often reorientation is required for improving an understanding of adjacent structures, particularly when communicating with interventionalists (Figure 13).

Interatrial Shunt Determination. Detection of an intracardiac shunt is a common indication for both TTE[156] and TEE.[157] A full evaluation of the interatrial septum should include extensive 2D and color Doppler evaluation of the entire septum. Defects may occur anywhere in the septum. Compared with TEE, TTE performed with multiple (at least five) saline injections and provocative maneuvers has also been shown to be an accurate test for right-to-left intracardiac shunt detection (sensitivity, 99%; specificity, 85%). TEE improves the diagnostic accuracy of shunt detection; false-positive results on TTE were due to intrapulmonary shunts, and false-negative results were due to inadequate right atrial opacification. The use of color Doppler alone with TTE reduces the sensitivity for shunt detection to 22% (specificity, 96%).[156] Thus, although PFO can be documented with color flow Doppler, the absence of flow across the foramen ovale should not be used to exclude PFO. Normally, because of their large size (>5 μm), intravenously injected saline bubbles are trapped in the lungs and do not appear in the left heart unless there is an intracardiac or intrapulmonary shunt. The appearance of more than three saline bubbles in the left heart soon after opacification of the right heart (within three beats) is most consistent with the PFO (Figure 18).[158] The timing of appearance of bubbles in the left atrium will depend on the pressure difference between the right and left atria. Some authors have advocated quantifying the relative size of the PFO by the number of microbubbles appearing in the left atrium: three to 10 microbubbles were defined as a small shunt, 11 to 30 microbubbles as a moderate shunt, and >30 microbubbles as a large shunt,[159] but others have suggested that a PFO is present if more than one contrast bubble appears in the LA and a large shunt if >10 bubbles can be demonstrated in the left atrium.[160] The sensitivity of detection of a right-to-left shunt through a PFO may vary depending on the site of injection and right atrial pressure; femoral vein injections have the highest sensitivity, particularly in the setting of a prominent Eustachian valve.[161] Intrapulmonary shunting occurs when there are arteriovenous communications that bypass the capillaries. After intravenous injection, saline bubbles typically appear in the left heart after a delay (more than three to eight cardiac cycles). There is significant overlap, however, in the timing of bubble presentation with a PFO compared with intrapulmonary shunt. The larger the intrapulmonary shunt, the earlier the bubbles may appear in the left heart. Thus, timing of bubble appearance in the left heart is not a reliable indicator of shunt location and is significantly influenced by the size and intensity of shunt flow.

Provocative maneuvers to increase both filling and pressure within the right atrium have been shown to increase the sensitivity of this test. Coughing or releasing a sustained Valsalva maneuver is most effective, but abdominal compression has been used in the setting of conscious sedation during TEE.[157] Failure of the interatrial septum to move toward the left atrium even when the right atrium is well opacified with agitated saline should be considered an indeterminate bubble study. Repeat attempts at the end of the examination when the patient may be awakening and capable of performing a cough or a Valsalva maneuver can be considered.

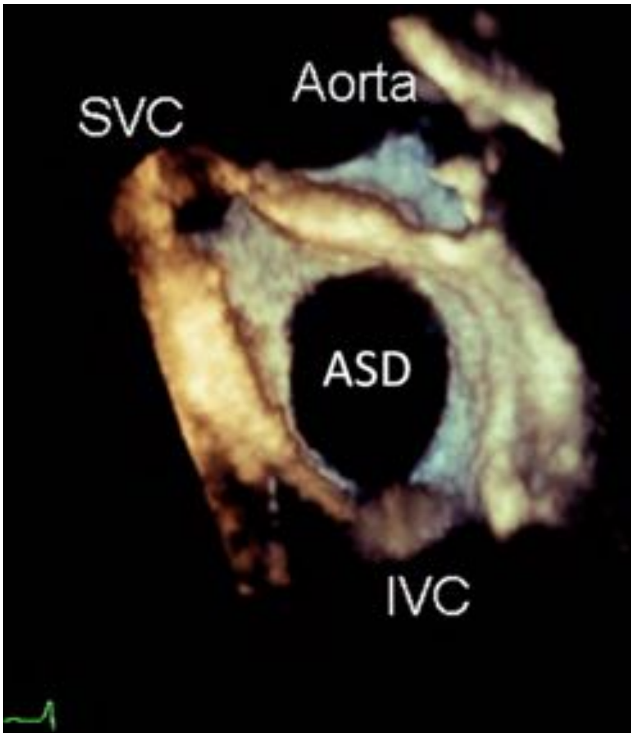


Figure 19 Three-dimensional assessment of atrial septal defect (ASD) size and location. *IVC*, Inferior vena cava; *SVC*, superior vena cava.

ACHD: Transesophageal Echocardiographic Imaging Algorithm

In adults with known or suspected ACHD, TEE is performed for diagnosis, indications, guidance of cardiac intervention, and to assess the results of interventions. Because of the limited flexibility in imaging and Doppler windows, TEE in ACHD is most useful in clinical circumstances in which comprehensive TTE was not definitive or could not be performed. TTE should be the initial test for evaluating suspected or known ACHD. TEE should be performed and interpreted by physicians with experience and/or training in ACHD to maximize the clinical utility of results obtained.

Equally important is the process of care of patients with ACHD undergoing TEE. Younger patients with ACHD and/or those with extensive cardiac interventions may have higher sedation requirements than those with acquired heart disease. If high sedation requirement is anticipated or there is a history of difficulty achieving adequate sedation during prior procedures, it would be prudent to ask for support from anesthesia and perform TEE in a setting with more intensive monitoring (such as a postanesthetic recovery room or critical care unit). The importance of achieving satisfactory sedation cannot be overstated in the ACHD population, as evaluation of primary and associated congenital abnormalities will often prolong the study.

The diagnostic utility of TEE is most apparent in circumstances in which the results of TTE are nondiagnostic or equivocal and the site of suspected pathology is better visualized by TEE than by TTE, including interatrial shunts, pulmonary venous drainage, aortic dissection, abscesses or vegetations, intracardiac thrombus, intracardiac baffles, and prosthetic valves. Although 3D TEE is now available and has been shown to be feasible,[162] the evidence for superior diagnostic utility of TEE was compiled from studies examining the

Table 12 Recommended TEE imaging views in selected ACHD diagnostic scenarios

	Primary lesion and corresponding views	Common associated lesions and corresponding views
ASD	• Location, size, number, morphology, and suitability for device closure (rim, distance from pulmonary veins): ME four-chamber (view 2), ME AV SAX (view 10), and ME bicaval (view 13). • May require slight counterclockwise rotation on ME bicaval view to optimally visualize sinus venosus defects	• Partial anomalous pulmonary venous drainage (right upper and/or right middle, with sinus venosus): ME right pulmonary vein (view 9 and orthogonal view 14) • Inlet ventricular septal defect (primum ASD): ME four-chamber (view 2) • Cleft mitral valve: TG basal SAX (view 16) • Subaortic obstruction (AV septal defects): ME three-chamber (view 5), deep TG five-chamber (view 21), and TG LAX (view 24)
Ventricular septal defect	• Location, size, number: ME 5-chamber (view 1), ME four-chamber (view 2), ME three-chamber (view 5), ME AV SAX (view 10), TG basal SAX (view 16), TG mid papillary (view 17), TG apical SAX (view 18), deep TG five-chamber view (view 21)	• AV prolapse (supracristal defects): ME three-chamber (view 5) and ME AV SAX (view 10) • Double chamber RV: ME AV SAX (view 10) and ME RV inflow-outflow (view 11)
Left heart obstruction: aortic stenosis	• Site of obstruction: subvalvular vs valvular vs supravalvular (discrete vs dynamic): ME AV LAX (view 6), deep TG five-chamber view (view 21)and TG LAX (view 24)	• Ascending aortopathy: ME AV LAX (view 6), ME ascending aorta LAX (view 7), ME ascending aorta SAX (view 8), UE aortic arch LAX (view 27)
Right heart: Ebstein Anomaly	• Morphology of leaflets, and suitability for repair (mobility of anterior leaflet, chordal attachments to right ventricular outflow tract, number of regurgitant jets): ME four-chamber (view 2), ME RV inflow-outflow (view 11), TG RV inflow-outflow (view 20)	• Interatrial shunt (see above) • Noncompaction of left ventricle: ME four-chamber (view 2) and ME two-chambers (view 4), TG two-chamber (view 22)
Atrial switch procedures (Mustard and Senning)	• Pulmonary venous baffle: ME four-chamber (view 2) • SVC and IVC limbs of systemic venous baffle: ME modified bicaval TV (view 12), and ME bicaval (view 13)	• Subaortic ventricular dysfunction and systemic atrioventricular (morphologic TV) regurgitation: ME five-chamber, ME four-chamber, ME commissural, ME two-chamber and ME three-chamber (views 1-5) • Subpulmonic ventricular obstruction: ME AV LAX (view 6), ME AV SAX (view 10), ME RV inflow-outflow (view 11), TG RV basal (view 19), TG RV inflow-outflow (view 20)
Fontan connections	• Atriopulmonary connection: ME ascending aortic SAX (view 8) • Lateral tunnel connection: ME modified bicaval TV and TG bicaval (views 12 and 13) • Pulmonary artery flow: withdrawal probe from ME ascending aortic SAX (view 8 and counterclockwise or left turn of view 7), UE aortic arch SAX view (view 28)	• Right pulmonary vein compression by dilated right atrium of atriopulmonary connection; ME right pulmonary veins (view 9 and orthogonal view 14) • Right atrial clot in atriopulmonary connection: ME four-chamber (view 2), ME modified bicaval TV and TG bicaval (views 12 and 13) • Lateral tunnel patency, clot, and fenestration: ME four-chamber (view 2)
Subpulmonic ventricle to PA conduit	• Morphology, conduit stenosis, and regurgitationt: ME RV inflow-outflow (view 11)	

ASD, Atrial septal defect; *IVC*, inferior vena cava; *SVC*, superior vena cava; *TG*, transgastric.

use of monoplane, biplane, or multiplane transesophageal transducers.[163-168] In the catheterization laboratory and in the operating room, TEE has become standard of care because it can guide the intervention and/or provide assessment of its results in real time (Figure 19).[169,170] The environment and time constraints associated with performing TEE in the catheterization or operating room often preclude a detailed comprehensive study. Ideally intraprocedural TEE should be preceded by comprehensive preoperative TTE or TEE.

When state-of-the-art cardiac magnetic resonance scanners and physicians with expertise in cardiac magnetic resonance are available, CMR is a complementary or alternative imaging modality to TEE in patients with ACHD. Although TEE is more feasible in the operating room, catheterization laboratory, or emergency department, in the ambulatory or non–critical care setting, cardiac magnetic resonance may be used in place of or complementary to TEE in patients with intracardiac or extracardiac baffles or conduits (such as the Fontan, Senning/Mustard, or Rastelli operation).[167,171] TEE is more useful than TTE to assess these complex surgically created pathways but may not be able to visualize the entire length of the pathway.[167,168] If the clinical indication includes quantitation of RV volumes, regurgitant fraction, shunt flow (i.e., repaired tetralogy of Fallot), collateral flow (coarctation or pulmonary atresia), aortic size (coarctation or ascending aorta in bicuspid AV), cardiac magnetic resonance is likely the best choice for the next test after TTE. In the catheterization laboratory, intracardiac echocardiography is used at some centers as an alternative to TEE.[172] Because the parameters required to guide intraprocedural interventions can be variable and beyond the scope of this article, operators should work with their interventional and/or surgical colleagues to ensure that the requisite information has been collected during TEE. Table 12 presents the recommended imaging views in selected ACHD diagnostic scenarios.

CONCLUSIONS

This document presents the 28 views in a comprehensive TEE examination. A suggested protocol of image acquisition is provided, with the caveat that anatomic variability may require unconventional imaging planes be used. Although the performance of a comprehensive TEE examination is recommended whenever possible, individual patient characteristics, anatomic variations, pathologic features, or time constraints imposed may limit the ability to perform all aspects of the examination described in this document. The "Specific Structural Imaging" section of this document includes additional views that can be obtained. The document is not intended to review specific indications for TEE or cover extensively abnormalities seen with this modality.

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REFERENCES

1. Side CD, Gosling RG. Non-surgical assessment of cardiac function. Nature 1971;232:335-6.
2. Frazin L, Talano JV, Stephanides L, Loeb HS, Kopel L, Gunnar RM. Esophageal echocardiography. Circulation 1976;54:102-8.
3. Hisanaga K, Hisanaga A, Hibi N, Nishimura K, Kambe T. High speed rotating scanner for transesophageal cross-sectional echocardiography. Am J Cardiol 1980;46:837-42.
4. Hisanaga K, Hisanaga A, Nagata K, Yoshida S. A new transesophageal real-time two-dimensional echocardiographic system using a flexible tube and its clinical application. Proc Jpn Soc Ultrasonics Med 1977;32:43-4.
5. Shanewise JS, Cheung AT, Aronson S, Stewart WJ, Weiss RL, Mark JB, et al. ASE/SCA guidelines for performing a comprehensive intraoperative multiplane transesophageal echocardiography examination: recommendations of the American Society of Echocardiography Council for Intraoperative Echocardiography and the Society of Cardiovascular Anesthesiologists Task Force for Certification in Perioperative Transesophageal Echocardiography. Anesth Analg 1999;89:870-84.
6. Shanewise JS, Cheung AT, Aronson S, Stewart WJ, Weiss RL, Mark JB, et al. ASE/SCA guidelines for performing a comprehensive intraoperative multiplane transesophageal echocardiography examination: recommendations of the American Society of Echocardiography Council for Intraoperative Echocardiography and the Society of Cardiovascular Anesthesiologists Task Force for Certification in Perioperative Transesophageal Echocardiography. J Am Soc Echocardiogr 1999;12:884-900.
7. Kallmeyer IJ, Collard CD, Fox JA, Body SC, Shernan SK. The safety of intraoperative transesophageal echocardiography: a case series of 7200 cardiac surgical patients. Anesth Analg 2001;92:1126-30.
8. Peterson GE, Brickner ME, Reimold SC. Transesophageal echocardiography: clinical indications and applications. Circulation 2003;107:2398-402.
9. Maffessanti F, Marsan NA, Tamborini G, Sugeng L, Caiani EG, Gripari P, et al. Quantitative analysis of mitral valve apparatus in mitral valve prolapse before and after annuloplasty: a three-dimensional intraoperative transesophageal study. J Am Soc Echocardiogr 2011;24:405-13.
10. Heidenreich PA, Stainback RF, Redberg RF, Schiller NB, Cohen NH, Foster E. Transesophageal echocardiography predicts mortality in critically ill patients with unexplained hypotension. J Am Coll Cardiol 1995;26:152-8.
11. Meier B, Frank B, Wahl A, Diener HC. Secondary stroke prevention: patent foramen ovale, aortic plaque, and carotid stenosis. Eur Heart J 2012;33:705-13.
12. Zamorano JL, Badano LP, Bruce C, Chan KL, Goncalves A, Hahn RT, et al. EAE/ASE recommendations for the use of echocardiography in new transcatheter interventions for valvular heart disease. J Am Soc Echocardiogr 2011;24:937-65.
13. Beller GA, Bonow RO, Fuster V. ACCF 2008 recommendations for training in Adult Cardiovascular Medicine Core Cardiology Training (COCATS 3) (revision of the 2002 COCATS training statement). J Am Coll Cardiol 2008;51:335-8.
14. Flachskampf FA, Badano L, Daniel WG, Feneck RO, Fox KF, Fraser AG, et al. Recommendations for transoesophageal echocardiography: update 2010. Eur J Echocardiogr 2010;11:557-76.
15. Cahalan MK, Stewart W, Pearlman A, Goldman M, Sears-Rogan P, Abel M, et al. American Society of Echocardiography and Society of Cardiovascular Anesthesiologists task force guidelines for training in perioperative echocardiography. J Am Soc Echocardiogr 2002;15:647-52.

16. Beique F, Ali M, Hynes M, Mackenzie S, Denault A, Martineau A, et al. Canadian guidelines for training in adult perioperative transesophageal echocardiography. Recommendations of the Cardiovascular Section of the Canadian Anesthesiologists' Society and the Canadian Society of Echocardiography. Can J Cardiol 2006;22:1015-27.
17. Quinones MA, Douglas PS, Foster E, Gorcsan J III, Lewis JF, Pearlman AS, et al. ACC/AHA clinical competence statement on echocardiography: a report of the American College of Cardiology/American Heart Association/American College of Physicians-American Society of Internal Medicine Task Force on clinical competence. J Am Soc Echocardiogr 2003;16: 379-402.
18. Mathew JP, Glas K, Troianos CA, Sears-Rogan P, Savage R, Shanewise J, et al. American Society of Echocardiography/Society of Cardiovascular Anesthesiologists recommendations and guidelines for continuous quality improvement in perioperative echocardiography. J Am Soc Echocardiogr 2006;19:1303-13.
19. Reeves ST, Finley AC, Skubas NJ, Swaminathan M, Whitley WS, Glas KE, 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;26:443-56.
20. 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;112:1084-96.
21. American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Society of Echocardiography, American Heart Association, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, et al. ACCF/ASE/AHA/ASNC/HFSA/HRS/SCAI/SCCM/SCCT/SCMR 2011 appropriate use criteria for echocardiography. A report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Society of Echocardiography, American Heart Association, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Critical Care Medicine, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance American College of Chest Physicians. J Am Soc Echocardiogr 2011;24:229-67.
22. American College of Cardiology Foundation Appropriate Use Criteria Task Force, Hendel RC, Patel MR, Allen JM, Min JK, Shaw LJ, et al. Appropriate use of cardiovascular technology: 2013 ACCF appropriate use criteria methodology update. J Am Coll Cardiol 2013;61:1305-17.
23. Intersocietal Accrediation Commission. IAC standards for adult echocardiography accreditation. Available at: http://www.intersocietal.org/echo/standards/IACAdultEchocardiographyStandards2012.pdf. Accessed July 27, 2013.
24. Daniel WG, Erbel R, Kasper W, Visser CA, Engberding R, Sutherland GR, et al. Safety of transesophageal echocardiography. A multicenter survey of 10,419 examinations. Circulation 1991;83:817-21.
25. Khandheria BK, Seward JB, Tajik AJ. Transesophageal echocardiography. Mayo Clin Proc 1994;69:856-63.
26. Hilberath JN, Oakes DA, Shernan SK, Bulwer BE, D'Ambra MN, Eltzschig HK. Safety of transesophageal echocardiography. J Am Soc Echocardiogr 2010;23(11):1115-27.
27. Seward JB, Khandheria BK, Oh JK, Freeman WK, Tajik AJ. Critical appraisal of transesophageal echocardiography: limitations, pitfalls, and complications. J Am Soc Echocardiogr 1992;5:288-305.
28. Lennon MJ, Gibbs NM, Weightman WM, Leber J, Ee HC, Yusoff IF. Transesophageal echocardiography-related gastrointestinal complications in cardiac surgical patients. J Cardiothorac Vasc Anesth 2005;19:141-5.
29. Owall A, Stahl L, Settergren G. Incidence of sore throat and patient complaints after intraoperative transesophageal echocardiography during cardiac surgery. J Cardiothorac Vasc Anesth 1992;6:15-6.
30. Chan KL, Cohen GI, Sochowski RA, Baird MG. Complications of transesophageal echocardiography in ambulatory adult patients: analysis of 1500 consecutive examinations. J Am Soc Echocardiogr 1991;4: 577-82.
31. Practice guidelines for perioperative transesophageal echocardiography. A report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. Anesthesiology 1996;84:986-1006.
32. Picard MH, Adams D, Bierig SM, Dent JM, Douglas PS, Gillam LD, et al. American Society of Echocardiography recommendations for quality echocardiography laboratory operations. J Am Soc Echocardiogr 2011; 24:1-10.
33. Practice guidelines for sedation and analgesia by non-anesthesiologists. Anesthesiology 2002;96:1004-17.
34. Practice guidelines for preoperative fasting and the use of pharmacologic agents to reduce the risk of pulmonary aspiration: application to healthy patients undergoing elective procedures: an updated report by the American Society of Anesthesiologists Committee on Standards and Practice Parameters. Anesthesiology 2011;114:495-511.
35. Winter FS. Persistent left superior vena cava; survey of world literature and report of thirty additional cases. Angiology 1954;5:90-132.
36. Fraser RS, Dvorkin J, Rossall RE, Eidem R. Left superior vena cava: a review of associated congenital heart lesions, catheterization data and roentgenologic findings. Am J Med 1961;31:711-6.
37. Aldrete JA. Modifications to the postanesthesia score for use in ambulatory surgery. J Perianesth Nurs 1998;13:148-55.
38. Isenberg G. Topical anesthesia: to use or not to use—that is the question. Gastrointest Endosc 2001;53:130-3.
39. Soma Y, Saito H, Kishibe T, Takahashi T, Tanaka H, Munakata A. Evaluation of topical pharyngeal anesthesia for upper endoscopy including factors associated with patient tolerance. Gastrointest Endosc 2001;53: 14-8.
40. Hedenbro JL, Ekelund M, Jansson O, Lindblom A. A randomized, double-blind, placebo-controlled study to evaluate topical anaesthesia of the pharynx in upper gastrointestinal endoscopy. Endoscopy 1992; 24:585-7.
41. Froehlich F, Schwizer W, Thorens J, Kohler M, Gonvers JJ, Fried M. Conscious sedation for gastroscopy: patient tolerance and cardiorespiratory parameters. Gastroenterology 1995;108:697-704.
42. Smith JL, Opekun A, Graham DY. Controlled comparison of topical anesthetic agents in flexible upper gastrointestinal endoscopy. Gastrointest Endosc 1985;31:255-8.
43. Kane GC, Hoehn SM, Behrenbeck TR, Mulvagh SL. Benzocaine-induced methemoglobinemia based on the Mayo Clinic experience from 28 478 transesophageal echocardiograms: incidence, outcomes, and predisposing factors. Arch Intern Med 2007;167:1977-82.
44. Novaro GM, Aronow HD, Militello MA, Garcia MJ, Sabik EM. Benzocaine-induced methemoglobinemia: experience from a high-volume transesophageal echocardiography laboratory. J Am Soc Echocardiogr 2003;16:170-5.
45. Coleman MD, Coleman NA. Drug-induced methaemoglobinaemia. Treatment issues. Drug Saf 1996;14:394-405.
46. Qadeer MA, Vargo JJ, Khandwala F, Lopez R, Zuccaro G. Propofol versus traditional sedative agents for gastrointestinal endoscopy: a meta-analysis. Clin Gastroenterol Hepatol 2005;3:1049-56.
47. Carpentier AF, Lessana A, Relland JY, Belli E, Mihaileanu S, Berrebi AJ, et al. The "physio-ring": an advanced concept in mitral valve annuloplasty. Ann Thorac Surg 1995;60:1177-85.
48. Foster GP, Isselbacher EM, Rose GA, Torchiana DF, Akins CW, Picard MH. Accurate localization of mitral regurgitant defects using multiplane transesophageal echocardiography. Ann Thorac Surg 1998;65: 1025-31.
49. Lang RM, Badano LP, Tsang W, Adams DH, Agricola E, Buck T, et al. EAE/ASE recommendations for image acquisition and display using three-dimensional echocardiography. J Am Soc Echocardiogr 2012;25: 3-46.
50. Stewart WJ, Currie PJ, Salcedo EE, Klein AL, Marwick T, Agler DA, et al. Evaluation of mitral leaflet motion by echocardiography and jet direction

by Doppler color flow mapping to determine the mechanisms of mitral regurgitation. J Am Coll Cardiol 1992;20:1353-61.
51. Chandra S, Salgo IS, Sugeng L, Weinert L, Tsang W, Takeuchi M, et al. Characterization of degenerative mitral valve disease using morphologic analysis of real-time three-dimensional echocardiographic images: objective insight into complexity and planning of mitral valve repair. Circ Cardiovasc Imaging 2011;4:24-32.
52. Tsang W, Weinert L, Sugeng L, Chandra S, Ahmad H, Spencer K, et al. The value of three-dimensional echocardiography derived mitral valve parametric maps and the role of experience in the diagnosis of pathology. J Am Soc Echocardiogr 2011;24:860-7.
53. Omran AS, Woo A, David TE, Feindel CM, Rakowski H, Siu SC. Intraoperative transesophageal echocardiography accurately predicts mitral valve anatomy and suitability for repair. J Am Soc Echocardiogr 2002; 15:950-7.
54. David TE, Ivanov J, Armstrong S, Christie D, Rakowski H. A comparison of outcomes of mitral valve repair for degenerative disease with posterior, anterior, and bileaflet prolapse. J Thorac Cardiovasc Surg 2005; 130:1242-9.
55. Otsuji Y, Handschumacher MD, Liel-Cohen N, Tanabe H, Jiang L, Schwammenthal E, et al. Mechanism of ischemic mitral regurgitation with segmental left ventricular dysfunction: three-dimensional echocardiographic studies in models of acute and chronic progressive regurgitation. J Am Coll Cardiol 2001;37:641-8.
56. Lang RM, Adams DH. 3D echocardiographic quantification in functional mitral regurgitation. JACC Cardiovasc Imaging 2012;5:346-7.
57. Cosgrove DM, Stewart WJ. Mitral valvuloplasty. Curr Probl Cardiol 1989;14:359-415.
58. Ho SY. Anatomy of the mitral valve. Heart 2002;88(suppl):iv5-10.
59. Muresian H. The clinical anatomy of the mitral valve. Clin Anat 2009;22: 85-98.
60. McCarthy KP, Ring L, Rana BS. Anatomy of the mitral valve: understanding the mitral valve complex in mitral regurgitation. Eur J Echocardiogr 2010;11:i3-9.
61. Quinones MA, Otto CM, Stoddard M, Waggoner A, Zoghbi WA, Doppler Quantification Task Force of the Nomenclature and Standards Committee of the American Society of Echocardiography, et al. Recommendations for quantification of Doppler echocardiography: a report from the Doppler Quantification Task Force of the Nomenclature and Standards Committee of the American Society of Echocardiography. J Am Soc Echocardiogr 2002;15:167-84.
62. Lewis JF, Kuo LC, Nelson JG, Limacher MC, Quinones MA. Pulsed Doppler echocardiographic determination of stroke volume and cardiac output: clinical validation of two new methods using the apical window. Circulation 1984;70:425-31.
63. Ormiston JA, Shah PM, Tei C, Wong M. Size and motion of the mitral valve annulus in man. I. A two-dimensional echocardiographic method and findings in normal subjects. Circulation 1981;64:113-20.
64. Foster GP, Dunn AK, Abraham S, Ahmadi N, Sarraf G. Accurate measurement of mitral annular dimensions by echocardiography: importance of correctly aligned imaging planes and anatomic landmarks. J Am Soc Echocardiogr 2009;22:458-63.
65. Sadik M, Rundqvist B, Selimovic N, Bech-Hanssen O. Improved stroke volume assessment in the aortic and mitral valves with a new method in subjects without regurgitation. Eur J Echocardiogr 2005;6: 210-8.
66. Hyodo E, Iwata S, Tugcu A, Oe Y, Koczo A, Shimada K, et al. Accurate measurement of mitral annular area by using single and biplane linear measurements: comparison of conventional methods with the three-dimensional planimetric method. Eur Heart J Cardiovasc Imaging 2012;13:605-11.
67. Legget ME, Bashein G, McDonald JA, Munt BI, Martin RW, Otto CM, et al. Three-dimensional measurement of the mitral annulus by multiplane transesophageal echocardiography: in vitro validation and in vivo demonstration. J Am Soc Echocardiogr 1998;11:188-200.
68. Grewal J, Suri R, Mankad S, Tanaka A, Mahoney DW, Schaff HV, et al. Mitral annular dynamics in myxomatous valve disease: new insights with real-time 3-dimensional echocardiography. Circulation 2010;121: 1423-31.
69. Zoghbi WA, Enriquez-Sarano M, Foster E, Grayburn PA, Kraft CD, Levine RA, et al. Recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and Doppler echocardiography. J Am Soc Echocardiogr 2003;16:777-802.
70. Baumgartner H, Hung J, Bermejo J, Chambers JB, Evangelista A, Griffin BP, et al. Echocardiographic assessment of valve stenosis: EAE/ASE recommendations for clinical practice. J Am Soc Echocardiogr 2009;22:1-23.
71. Thavendiranathan P, Phelan D, Thomas JD, Flamm SD, Marwick TH. Quantitative assessment of mitral regurgitation: validation of new methods. J Am Coll Cardiol 2012;60:1470-83.
72. Thavendiranathan P, Liu S, Datta S, Rajagopalan S, Ryan T, Igo SR, et al. Quantification of chronic functional mitral regurgitation by automated 3-D peak and integrated proximal isovelocity surface area and stroke volume techniques using real-time 3-D volume color Doppler echocardiography: in vitro and clinical validation. Circ Cardiovasc Imaging 2013;6:125-33.
73. Messika-Zeitoun D, Serfaty JM, Brochet E, Ducrocq G, Lepage L, Detaint D, et al. Multimodal assessment of the aortic annulus diameter: implications for transcatheter aortic valve implantation. J Am Coll Cardiol 2010;55:186-94.
74. Anderson RH. Clinical anatomy of the aortic root. Heart 2000;84:670-3.
75. Piazza N, de Jaegere P, Schultz C, Becker AE, Serruys PW, Anderson RH. Anatomy of the aortic valvar complex and its implications for transcatheter implantation of the aortic valve. Circ Cardiovasc Interv 2008;1: 74-81.
76. Leye M, Brochet E, Lepage L, Cueff C, Boutron I, Detaint D, et al. Size-adjusted left ventricular outflow tract diameter reference values: a safeguard for the evaluation of the severity of aortic stenosis. J Am Soc Echocardiogr 2009;22:445-51.
77. Shiran A, Adawi S, Ganaeem M, Asmer E. Accuracy and reproducibility of left ventricular outflow tract diameter measurement using transthoracic when compared with transesophageal echocardiography in systole and diastole. Eur J Echocardiogr 2009;10:319-24.
78. Zoghbi WA, Chambers JB, Dumesnil JG, Foster E, Gottdiener JS, Grayburn PA, et al. Recommendations for evaluation of prosthetic valves with echocardiography and doppler ultrasound: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Task Force on Prosthetic Valves, developed in conjunction with the American College of Cardiology Cardiovascular Imaging Committee, Cardiac Imaging Committee of the American Heart Association, the European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography and the Canadian Society of Echocardiography, endorsed by the American College of Cardiology Foundation, American Heart Association, European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography, and Canadian Society of Echocardiography. J Am Soc Echocardiogr 2009;22: 975-1014.
79. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr 2005;18:1440-63.
80. Lopez L, Colan SD, Frommelt PC, Ensing GJ, Kendall K, Younoszai AK, et al. Recommendations for quantification methods during the performance of a pediatric echocardiogram: a report from the Pediatric Measurements Writing Group of the American Society of Echocardiography Pediatric and Congenital Heart Disease Council. J Am Soc Echocardiogr 2010;23:465-95.
81. Hiratzka LF, Bakris GL, Beckman JA, Bersin RM, Carr VF, Casey DE Jr, et al. 2010 ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM

guidelines for the diagnosis and management of patients with thoracic aortic disease. A report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. J Am Coll Cardiol 2010;55:e27-129.
82. Roman MJ, Devereux RB, Kramer-Fox R, O'Loughlin J. Two-dimensional echocardiographic aortic root dimensions in normal children and adults. Am J Cardiol 1989;64:507-12.
83. Bloomfield GS, Gillam LD, Hahn RT, Kapadia S, Leipsic J, Lerakis S, et al. A practical guide to multimodality imaging of transcatheter aortic valve replacement. JACC Cardiovasc Imaging 2012;5:441-55.
84. Konstadt SN, Reich DL, Quintana C, Levy M. The ascending aorta: how much does transesophageal echocardiography see? Anesth Analg 1994; 78:240-4.
85. Otani K, Takeuchi M, Kaku K, Sugeng L, Yoshitani H, Haruki N, et al. Assessment of the aortic root using real-time 3D transesophageal echocardiography. Circ J 2010;74:2649-57.
86. Saitoh T, Shiota M, Izumo M, Gurudevan SV, Tolstrup K, Siegel RJ, et al. Comparison of left ventricular outflow geometry and aortic valve area in patients with aortic stenosis by 2-dimensional versus 3-dimensional echocardiography. Am J Cardiol 2012;109:1626-31.
87. Doddamani S, Bello R, Friedman MA, Banerjee A, Bowers JH Jr., Kim B, et al. Demonstration of left ventricular outflow tract eccentricity by real time 3D echocardiography: implications for the determination of aortic valve area. Echocardiography 2007;24:860-6.
88. Shahgaldi K, Manouras A, Brodin LA, Winter R. Direct measurement of left ventricular outflow tract area using three-dimensional echocardiography in biplane mode improves accuracy of stroke volume assessment. Echocardiography 2010;27:1078-85.
89. Zamorano JL, Badano LP, Bruce C, Chan KL, Goncalves A, Hahn RT, et al. EAE/ASE recommendations for the use of echocardiography in new transcatheter interventions for valvular heart disease. Eur Heart J 2011;32:2189-214.
90. Santos N, de Agustin JA, Almeria C, Goncalves A, Marcos-Alberca P, Fernandez-Golfin C, et al. Prosthesis/annulus discongruence assessed by three-dimensional transoesophageal echocardiography: a predictor of significant paravalvular aortic regurgitation after transcatheter aortic valve implantation. Eur Heart J Cardiovasc Imaging 2012;13:931-7.
91. Janosi RA, Kahlert P, Plicht B, Wendt D, Eggebrecht H, Erbel R, et al. Measurement of the aortic annulus size by real-time three-dimensional transesophageal echocardiography. Minim Invasive Ther Allied Technol 2011; 20:85-94.
92. Tsang W, Bateman MG, Weinert L, Pellegrini G, Mor-Avi V, Sugeng L, et al. Accuracy of aortic annular measurements obtained from three-dimensional echocardiography, CT and MRI: human in vitro and in vivo studies. Heart 2012;98:1146-52.
93. Gripari P, Ewe SH, Fusini L, Muratori M, Ng AC, Cefalu C, et al. Intraoperative 2D and 3D transoesophageal echocardiographic predictors of aortic regurgitation after transcatheter aortic valve implantation. Heart 2012;98:1229-36.
94. Kasel AM, Cassese S, Bleiziffer S, Amaki M, Hahn RT, Kastrati A, et al. Standardized imaging for aortic annular sizing: implications for transcatheter valve selection. JACC Cardiovasc Imaging 2013;6: 249-62.
95. Martinez RM, Anderson RH. Echocardiographic features of the morphologically right ventriculo-arterial junction. Cardiol Young 2005;15(suppl): 17-26.
96. Kurup V, Perrino A Jr., Barash P, Hashim SW. Infundibular pulmonary stenosis. Anesth Analg 2007;104:507-8.
97. Prabhu MR. Trans-esophageal echocardiography for tricuspid and pulmonary valves. Ann Card Anaesth 2009;12:167.
98. Stoddard MF, Liddell NE, Vogel RL, Longaker RA, Dawkins PR. Comparison of cardiac dimensions by transesophageal and transthoracic echocardiography. Am Heart J 1992;124:675-8.
99. Antunes MJ, Barlow JB. Management of tricuspid valve regurgitation. Heart 2007;93:271-6.
100. Rogers JH, Bolling SF. The tricuspid valve: current perspective and evolving management of tricuspid regurgitation. Circulation 2009;119: 2718-25.
101. Shah PM, Raney AA. Tricuspid valve disease. Curr Probl Cardiol 2008; 33:47-84.
102. Nath J, Foster E, Heidenreich PA. Impact of tricuspid regurgitation on long-term survival. J Am Coll Cardiol 2004;43:405-9.
103. Voelkel NF, Quaife RA, Leinwand LA, Barst RJ, McGoon MD, Meldrum DR, et al. Right ventricular function and failure: report of a National Heart, Lung, and Blood Institute Working Group on Cellular and Molecular Mechanisms of Right Heart Failure. Circulation 2006;114:1883-91.
104. Bustamante-Labarta M, Perrone S, De La Fuente RL, Stutzbach P, De La Hoz RP, Torino A, et al. Right atrial size and tricuspid regurgitation severity predict mortality or transplantation in primary pulmonary hypertension. J Am Soc Echocardiogr 2002;15:1160-4.
105. Hung J, Koelling T, Semigran MJ, Dec GW, Levine RA, Di Salvo TG. Usefulness of echocardiographic determined tricuspid regurgitation in predicting event-free survival in severe heart failure secondary to idiopathic-dilated cardiomyopathy or to ischemic cardiomyopathy. Am J Cardiol 1998;82:1301-3.
106. Tang GH, David TE, Singh SK, Maganti MD, Armstrong S, Borger MA. Tricuspid valve repair with an annuloplasty ring results in improved long-term outcomes. Circulation 2006;114(suppl):I577-81.
107. Dreyfus GD, Corbi PJ, Chan KM, Bahrami T. Secondary tricuspid regurgitation or dilatation: which should be the criteria for surgical repair? Ann Thorac Surg 2005;79:127-32.
108. Martinez RM, O'Leary PW, Anderson RH. Anatomy and echocardiography of the normal and abnormal tricuspid valve. Cardiol Young 2006; 16(suppl):4-11.
109. Kostucki W, Vandenbossche JL, Friart A, Englert M. Pulsed Doppler regurgitant flow patterns of normal valves. Am J Cardiol 1986;58: 309-13.
110. Anwar AM, Geleijnse ML, Soliman OI, McGhie JS, Frowijn R, Nemes A, et al. Assessment of normal tricuspid valve anatomy in adults by real-time three-dimensional echocardiography. Int J Cardiovasc Imaging 2007;23: 717-24.
111. Fukuda S, Saracino G, Matsumura Y, Daimon M, Tran H, Greenberg NL, et al. Three-dimensional geometry of the tricuspid annulus in healthy subjects and in patients with functional tricuspid regurgitation: a real-time, 3-dimensional echocardiographic study. Circulation 2006;114(suppl): I492-8.
112. Skiles JA, Griffin BP. Transesophageal echocardiographic (TEE) evaluation of ventricular function. Cardiol Clin 2000;18:681-97.
113. Roelandt JR, Thomson IR, Vletter WB, Brommersma P, Bom N, Linker DT. Multiplane transesophageal echocardiography: latest evolution in an imaging revolution. J Am Soc Echocardiogr 1992;5:361-7.
114. Ho SY. Anatomy and myoarchitecture of the left ventricular wall in normal and in disease. Eur J Echocardiogr 2009;10:iii3-7.
115. Hozumi T, Shakudo M, Shah PM. Quantitation of left ventricular volumes and ejection fraction by biplane transesophageal echocardiography. Am J Cardiol 1993;72:356-9.
116. Colombo PC, Municino A, Brofferio A, Kholdarova L, Nanna M, Ilercil A, et al. Cross-sectional multiplane transesophageal echocardiographic measurements: comparison with standard transthoracic values obtained in the same setting. Echocardiography 2002;19:383-90.
117. Lappas DG, Skubas NJ, Lappas GD, Ruocco E, Tambassis E, Pasque M. Prevalence of left ventricular diastolic filling abnormalities in adult cardiac surgical patients: an intraoperative echocardiographic study. Semin Thorac Cardiovasc Surg 1999;11:125-33.
118. Denault AY, Couture P, Buithieu J, Haddad F, Carrier M, Babin D, et al. Left and right ventricular diastolic dysfunction as predictors of difficult separation from cardiopulmonary bypass. Can J Anaesth 2006;53: 1020-9.
119. Swaminathan M, Nicoara A, Phillips-Bute BG, Aeschlimann N, Milano CA, Mackensen GB, et al. Utility of a simple algorithm to grade

diastolic dysfunction and predict outcome after coronary artery bypass graft surgery. Ann Thorac Surg 2011;91:1844-50.
120. Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K, et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. J Am Soc Echocardiogr 2010;23:685-713.
121. Blackshear JL, Odell JA. Appendage obliteration to reduce stroke in cardiac surgical patients with atrial fibrillation. Ann Thorac Surg 1996;61:755-9.
122. Manning WJ, Weintraub RM, Waksmonski CA, Haering JM, Rooney PS, Maslow AD, et al. Accuracy of transesophageal echocardiography for identifying left atrial thrombi. A prospective, intraoperative study. Ann Intern Med 1995;123:817-22.
123. Donal E, Yamada H, Leclercq C, Herpin D. The left atrial appendage, a small, blind-ended structure: a review of its echocardiographic evaluation and its clinical role. Chest 2005;128:1853-62.
124. Halperin JL, Gomberg-Maitland M. Obliteration of the left atrial appendage for prevention of thromboembolism. J Am Coll Cardiol 2003;42: 1259-61.
125. Damiano RJ Jr., Gaynor SL, Bailey M, Prasad S, Cox JL, Boineau JP, et al. The long-term outcome of patients with coronary disease and atrial fibrillation undergoing the Cox maze procedure. J Thorac Cardiovasc Surg 2003;126:2016-21.
126. Healey JS, Crystal E, Lamy A, Teoh K, Semelhago L, Hohnloser SH, et al. Left Atrial Appendage Occlusion Study (LAAOS): results of a randomized controlled pilot study of left atrial appendage occlusion during coronary bypass surgery in patients at risk for stroke. Am Heart J 2005;150: 288-93.
127. Holmes DR, Reddy VY, Turi ZG, Doshi SK, Sievert H, Buchbinder M, et al. Percutaneous closure of the left atrial appendage versus warfarin therapy for prevention of stroke in patients with atrial fibrillation: a randomised non-inferiority trial. Lancet 2009;374:534-42.
128. Nakai T, Lesh MD, Gerstenfeld EP, Virmani R, Jones R, Lee RJ. Percutaneous left atrial appendage occlusion (PLAATO) for preventing cardioembolism: first experience in canine model. Circulation 2002; 105(18):2217-22.
129. Sievert H, Lesh MD, Trepels T, Omran H, Bartorelli A, Della Bella P, et al. Percutaneous left atrial appendage transcatheter occlusion to prevent stroke in high-risk patients with atrial fibrillation: early clinical experience. Circulation 2002;105:1887-9.
130. Qamruddin S, Shinbane J, Shriki J, Naqvi TZ. Left atrial appendage: structure, function, imaging modalities and therapeutic options. Expert Rev Cardiovasc Ther 2010;8:65-75.
131. Su P, McCarthy KP, Ho SY. Occluding the left atrial appendage: anatomical considerations. Heart 2008;94:1166-70.
132. Risk factors for stroke and efficacy of antithrombotic therapy in atrial fibrillation. Analysis of pooled data from five randomized controlled trials. Arch Intern Med 1994;154:1449-57.
133. Nucifora G, Faletra FF, Regoli F, Pasotti E, Pedrazzini G, Moccetti T, et al. Evaluation of the left atrial appendage with real-time 3-dimensional transesophageal echocardiography: implications for catheter-based left atrial appendage closure. Circ Cardiovasc Imaging 2011; 4:514-23.
134. Veinot JP, Harrity PJ, Gentile F, Khandheria BK, Bailey KR, Eickholt JT, et al. Anatomy of the normal left atrial appendage: a quantitative study of age-related changes in 500 autopsy hearts: implications for echocardiographic examination. Circulation 1997;96:3112-5.
135. Ho SY, McCarthy KP, Faletra FF. Anatomy of the left atrium for interventional echocardiography. Eur J Echocardiogr 2011;12:i11-5.
136. Block M, Hourigan L, Bellows WH, Reeves J III, Romson JL, Tran M, et al. Comparison of left atrial dimensions by transesophageal and transthoracic echocardiography. J Am Soc Echocardiogr 2002;15:143-9.
137. Castello R, Pearson AC, Fagan L, Labovitz AJ. Spontaneous echocardiographic contrast in the descending aorta. Am Heart J 1990;120: 915-9.
138. Lelorier P, Humphries KH, Krahn A, Connolly SJ, Talajic M, Green M, et al. Prognostic differences between atrial fibrillation and atrial flutter. Am J Cardiol 2004;93:647-9.
139. The SPAF III Writing Committee for the Stroke Prevention in Atrial Fibrillation Investigators. Patients with nonvalvular atrial fibrillation at low risk of stroke during treatment with aspirin: Stroke Prevention in Atrial Fibrillation III Study. JAMA 1998;279:1273-7.
140. Sigurdsson G, Troughton RW, Xu XF, Salazar HP, Wazni OM, Grimm RA, et al. Detection of pulmonary vein stenosis by transesophageal echocardiography: comparison with multidetector computed tomography. Am Heart J 2007;153:800-6.
141. Samdarshi TE, Morrow WR, Helmcke FR, Nanda NC, Bargeron LM Jr., Pacifico AD. Assessment of pulmonary vein stenosis by transesophageal echocardiography. Am Heart J 1991;122:1495-8.
142. Nakajima H, Seo Y, Ishizu T, Yamamoto M, Machino T, Harimura Y, et al. Analysis of the left atrial appendage by three-dimensional transesophageal echocardiography. Am J Cardiol 2010;106:885-92.
143. Latcu DG, Rinaldi JP, Saoudi N. Real-time three-dimensional transoesophageal echocardiography for diagnosis of left atrial appendage thrombus. Eur J Echocardiogr 2009;10:711-2.
144. Shah SJ, Bardo DM, Sugeng L, Weinert L, Lodato JA, Knight BP, et al. Real-time three-dimensional transesophageal echocardiography of the left atrial appendage: initial experience in the clinical setting. J Am Soc Echocardiogr 2008;21:1362-8.
145. Hagen PT, Scholz DG, Edwards WD. Incidence and size of patent foramen ovale during the first 10 decades of life: an autopsy study of 965 normal hearts. Mayo Clin Proc 1984;59:17-20.
146. Schneider B, Hanrath P, Vogel P, Meinertz T. Improved morphologic characterization of atrial septal aneurysm by transesophageal echocardiography: relation to cerebrovascular events. J Am Coll Cardiol 1990;16: 1000-9.
147. Pearson AC, Nagelhout D, Castello R, Gomez CR, Labovitz AJ. Atrial septal aneurysm and stroke: a transesophageal echocardiographic study. J Am Coll Cardiol 1991;18:1223-9.
148. Gallet B, Malergue MC, Adams C, Saudemont JP, Collot AM, Druon MC, et al. Atrial septal aneurysm—a potential cause of systemic embolism. An echocardiographic study. Br Heart J 1985;53: 292-7.
149. Belkin RN, Hurwitz BJ, Kisslo J. Atrial septal aneurysm: association with cerebrovascular and peripheral embolic events. Stroke 1987;18:856-62.
150. Mugge A, Daniel WG, Angermann C, Spes C, Khandheria BK, Kronzon I, et al. Atrial septal aneurysm in adult patients. A multicenter study using transthoracic and transesophageal echocardiography. Circulation 1995;91:2785-92.
151. Hanley PC, Tajik AJ, Hynes JK, Edwards WD, Reeder GS, Hagler DJ, et al. Diagnosis and classification of atrial septal aneurysm by two-dimensional echocardiography: report of 80 consecutive cases. J Am Coll Cardiol 1985;6:1370-82.
152. Loukas M, Sullivan A, Tubbs RS, Weinhaus AJ, Derderian T, Hanna M. Chiari's network: review of the literature. Surg Radiol Anat 2010;32: 895-901.
153. Schneider B, Hofmann T, Justen MH, Meinertz T. Chiari's network: normal anatomic variant or risk factor for arterial embolic events? J Am Coll Cardiol 1995;26:203-10.
154. Hausmann D, Mugge A, Daniel WG. Identification of patent foramen ovale permitting paradoxic embolism. J Am Coll Cardiol 1995;26: 1030-8.
155. Faletra FF, Ho SY, Auricchio A. Anatomy of right atrial structures by real-time 3D transesophageal echocardiography. JACC Cardiovasc Imaging 2010;3:966-75.
156. Marriott K, Manins V, Forshaw A, Wright J, Pascoe R. Detection of right-to-left atrial communication using agitated saline contrast imaging: experience with 1162 patients and recommendations for echocardiography. J Am Soc Echocardiogr 2013;26:96-102.
157. Soliman OI, Geleijnse ML, Meijboom FJ, Nemes A, Kamp O, Nihoyannopoulos P, et al. The use of contrast echocardiography for the detection of cardiac shunts. Eur J Echocardiogr 2007;8:S2-12.

158. Belvis R, Leta RG, Marti-Fabregas J, Cocho D, Carreras F, Pons-Llado G, et al. Almost perfect concordance between simultaneous transcranial Doppler and transesophageal echocardiography in the quantification of right-to-left shunts. J Neuroimaging 2006;16:133-8.
159. Mas JL, Arquizan C, Lamy C, Zuber M, Cabanes L, Derumeaux G, et al. Recurrent cerebrovascular events associated with patent foramen ovale, atrial septal aneurysm, or both. N Engl J Med 2001; 345:1740-6.
160. Homma S, Sacco RL, Di Tullio MR, Sciacca RR, Mohr JP. PFO in Cryptogenic Stroke Study (PICSS) Investigators. Effect of medical treatment in stroke patients with patent foramen ovale: patent foramen ovale in Cryptogenic Stroke Study. Circulation 2002;105:2625-31.
161. Holmes DR Jr., Cohen HA, Ruiz C. Patent foramen ovale, systemic embolization, and closure. Curr Probl Cardiol 2009;34:483-530.
162. Baker GH, Shirali G, Ringewald JM, Hsia TY, Bandisode V. Usefulness of live three-dimensional transesophageal echocardiography in a congenital heart disease center. Am J Cardiol 2009;103:1025-8.
163. Sreeram N, Stumper OF, Kaulitz R, Hess J, Roelandt JR, Sutherland GR. Comparative value of transthoracic and transesophageal echocardiography in the assessment of congenital abnormalities of the atrioventricular junction. J Am Coll Cardiol 1990;16:1205-14.
164. Hausmann D, Daniel WG, Mugge A, Ziemer G, Pearlman AS. Value of transesophageal color Doppler echocardiography for detection of different types of atrial septal defect in adults. J Am Soc Echocardiogr 1992;5: 481-8.
165. Feltes TF, Friedman RA. Transesophageal echocardiographic detection of atrial thrombi in patients with nonfibrillation atrial tachyarrhythmias and congenital heart disease. J Am Coll Cardiol 1994;24:1365-70.
166. Fyfe DA, Kline CH, Sade RM, Gillette PC. Transesophageal echocardiography detects thrombus formation not identified by transthoracic echocardiography after the Fontan operation. J Am Coll Cardiol 1991;18: 1733-7.
167. Hirsch R, Kilner PJ, Connelly MS, Redington AN. St John Sutton MG, Somerville J. Diagnosis in adolescents and adults with congenital heart disease. Prospective assessment of individual and combined roles of magnetic resonance imaging and transesophageal echocardiography. Circulation 1994;90:2937-51.
168. Ayres NA, Miller-Hance W, Fyfe DA, Stevenson JG, Sahn DJ, Young LT, et al. Indications and guidelines for performance of transesophageal echocardiography in the patient with pediatric acquired or congenital heart disease: report from the task force of the Pediatric Council of the American Society of Echocardiography. J Am Soc Echocardiogr 2005;18:91-8.
169. Stevenson JG, Sorensen GK, Gartman DM, Hall DG, Rittenhouse EA. Transesophageal echocardiography during repair of congenital cardiac defects: identification of residual problems necessitating reoperation. J Am Soc Echocardiogr 1993;6:356-65.
170. Stevenson JG. Utilization of intraoperative transesophageal echocardiography during repair of congenital cardiac defects: a survey of North American centers. Clin Cardiol 2003;26:132-4.
171. Hoppe UC, Dederichs B, Deutsch HJ, Theissen P, Schicha H, Sechtem U. Congenital heart disease in adults and adolescents: comparative value of transthoracic and transesophageal echocardiography and MR imaging. Radiology 1996;199:669-77.
172. Mullen MJ, Dias BF, Walker F, Siu SC, Benson LN, McLaughlin PR. Intracardiac echocardiography guided device closure of atrial septal defects. J Am Coll Cardiol 2003;41:285-92.