

## ACC/AHA CLINICAL COMPETENCE STATEMENT

# 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

*Developed in Collaboration with the American Society of Echocardiography, the Society of Cardiovascular Anesthesiologists, and the Society of Pediatric Echocardiography*

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## PREAMBLE

The granting of clinical staff privileges to physicians is a primary mechanism used by institutions to uphold the quality of care. The Joint Commission on Accreditation of Health Care Organizations requires that the granting of continuing medical staff privileges be based on assessments of applicants against professional criteria specified in the medical staff bylaws. Physicians themselves are thus charged with identifying the criteria that constitute professional competence and with evaluating their peers accordingly. Yet, the process of evaluating physicians' knowledge and competence is often constrained by the evaluator's own knowledge and ability to elicit the appropriate information, problems compounded by the growing number of highly specialized procedures for which privileges are requested.

The American College of Cardiology/American Heart Association/American College of Physicians–American Society of Internal Medicine (ACC/AHA/ACP–ASIM) Task Force on Clinical Competence was formed in 1998 to develop recommendations for attaining and maintaining the cognitive and technical skills necessary for the competent performance of a specific cardiovascular service, procedure, or technology. These documents are evidence-based, and when evidence is not available, expert opinion is utilized to formulate recommendations. Indications and contraindications for specific services or procedures are not included in the scope of these documents. Recommendations are intended to assist those who must judge the competence of cardiovascular health care providers entering practice for the first time and/or those who are in practice and undergo periodic review of their practice expertise. The assessment of competence is complex and multidimensional; therefore, isolated recommendations contained herein may not necessarily be sufficient or appropriate for the judging of overall competence.

The ACC/AHA/ACP–ASIM Task Force makes every effort to avoid any actual or potential conflicts of interest that might arise as a result of an outside relationship or personal interest of a member of the ACC/AHA Writing Committee. Specifically, all members of the Writing Committee are asked to provide disclosure statements of all such relationships that might be perceived as real or potential conflicts of interest. These changes are reviewed by the Writing Committee and updated as changes occur.

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## A. Introduction

This document is a revision of the 1990 ACP/ACC/AHA Clinical Competence in Adult Echocardiography (1). The writing committee consisted of recognized experts in echocardiography representing the ACC, AHA, ACP-ASIM, American Society of Echocardiography (ASE), Society of Pediatric Echocardiography (SOPE), and the Society of Cardiovascular Anesthesiologists (SCA). The document has been approved for publication by the governing bodies of the ACC and the AHA, and endorsed by the ASE, SCA, and SOPE.

**Purpose of this Clinical Competence Statement.** Previous publications have focused on training requirements for clinical competence in echocardiography. The first recommendations were made in 1986 by Bethesda Conference 17: Adult Cardiology Training (2) and in 1987 by an expert panel of the ASE (3). They were followed by a previous version of the ACP/ACC/AHA physician clinical competence statement in 1990. These earlier recommendations were limited primarily to the practice of transthoracic echocardiography (TTE) in the adult patient. However, over the past 15 years echocardiography has evolved into a family of techniques (Table 1), each one with unique applications and its own set of cognitive skills and training requirements. Although the majority of these newer technologies were in their early phase of development in 1990, today they are used routinely in community hospitals all across the nation. In addition, the application of echocardiography in children and adults with congenital heart disease (CHD) has evolved into a highly specialized modality with its own set of cognitive skills and training requirements. Subspecialty societies such as the ASE have published recommendations for training and, in some cases, for competence in some of these newer techniques. In addition, guidelines for training in adult cardiovascular medicine in the form of a suggested core curriculum (COCATS) have included recommendations on training in echocardiography, first in 1995 and currently in a revised version (4). The recently formed National Board of Echocardiography (NBE) has also introduced guidelines for certification of special competence in adult echocardiography, which includes passing an examination in addition to specific training requirements. Separate certifications are granted for transesophageal echocardiography (TEE) and stress echocardiography. Recognizing the growths in technology and the increased complexity of echocardiography, the members of the ACC/AHA/ACP-ASIM Task Force on Clinical Competence commissioned this writing group to provide a new set of recommendations that recognize the different cognitive skills required for each of the new modalities and that address training, documentation and maintenance of competence.

**Document Format.** This document addresses competence in the performance and interpretation all the different modalities of echocardiography, including new applications of echocardiography in the operating room and the appli-

**Table 1.** Echocardiographic Modalities

- 
- Transthoracic two-dimensional/Doppler echocardiography
  - Transesophageal echocardiography
  - Intra-operative echocardiography
  - Stress echocardiography
  - Miniaturized hand-carried ultrasound
  - Contrast echocardiography
  - Intracardiac and intravascular ultrasound
- 

cation of echocardiography in patients with complex CHD. The document also addresses the application of echocardiography using miniaturized hand-carried ultrasound instruments. For each of the applications, there will be a brief general overview, a discussion of the cognitive skills required and recommendations on training requirements, proof of competence, and maintenance of competence. Whenever possible, these recommendations will be linked to previously published recommendations made by specialty societies. In some situations, however, the writing group provides a set of recommendation that represent the consensus of this body of experts.

This document makes an important distinction between training requirements and documentation of competence. Training requirements represent the minimal training experience that is considered necessary to achieve the skills for performance at a particular level. It is recognized that training is highly individualized and some trainees may require higher volume and more hours of exposure to a particular technique. Proof of competence, on the other hand, consists of a set of requirements that provide some assurance that physicians have gained the expertise needed to perform according to recognized standards.

The sections on training requirements refer primarily to the training needed to achieve specific levels of expertise. Such training is expected to occur under the direct supervision of a qualified Level 3 or equivalent physician/teacher and for the most part, occurs during formal fellowship training in either cardiovascular medicine or cardiovascular anesthesiology. However, the document recognizes the fact that physicians trained prior to the development of these techniques may have properly learned their use while in practice. Thus, whenever possible, the document addresses training requirements and proof of competence for this group of physicians. Maintenance of competence requires the performance of a certain minimal volume of procedures and participation in continuing medical education (CME). This document recommends that physicians practicing echocardiography obtain a minimum of 5 hours per year of CME credits in echocardiography, as recommended recently by the Intersocietal Commission for the Accreditation of Echocardiography Laboratories (ICAEL Newsletter 2001Vol 4; Issue 2; page 5).

## B. General Principles

Regardless of the echocardiographic modality utilized, there is a body of knowledge required by any physician involved in

**Table 2.** Basic Cognitive Skills Required for Competence in Echocardiography

- Knowledge of physical principles of echocardiographic image formation and blood flow velocity measurements.
- Knowledge of instrument settings required to obtain an optimal image.
- Knowledge of normal cardiac anatomy.
- Knowledge of pathologic changes in cardiac anatomy due to acquired and CHD.
- Knowledge of fluid dynamics of normal blood flow.
- Knowledge of pathological changes in blood flow due to acquired heart disease and CHD.

CHD = congenital heart disease.

performance and/or interpretation of echocardiograms that includes: ultrasound physics and use of instrumentation, anatomy, physiology, and pathology of the heart and great vessels (Table 2).

**Basic Knowledge of Ultrasound Physics.** Echocardiographic imaging and Doppler systems generate ultrasound signals that follow the laws of physics. Appropriate utilization of these instruments and interpretation of the data generated require an understanding of the fundamental principles of ultrasound physics and how they relate to the images produced and the spectral and color Doppler information. This understanding is considered to be an important requirement for clinical competence in all modalities of echocardiography.

**Technical Aspects of the Examination.** An essential component of the diagnostic accuracy of echocardiography is the skill and experience of the individual responsible for image and data acquisition. Technical skills related to echocardiographic data acquisition may be divided into two important skill sets: transducer manipulation and ultrasound system adjustments. Perhaps the most difficult and underestimated skill set to master is transducer manipulation, which is critical to obtaining optimal image quality in standard tomographic imaging planes, and optimal Doppler flow velocity signals. This is true regardless of the type of transducer utilized (i.e., transthoracic, transesophageal, or intravascular). The second set of technical skills includes appropriate knowledge of ultrasound instrument settings such as transducer frequency, use of harmonics, mechanical index, depth, gain, time-gain-compensation, dynamic range, filtering, velocity scale manipulations, and display of received signals.

**Anatomy and Physiology.** Echocardiography is a powerful diagnostic tool that provides immediate access for the evaluation of cardiac and vascular structures and assessment of heart function. Intrinsic to a competent echocardiographic examination is a thorough understanding of the anatomy and physiology of the heart and great vessels. Two-dimensional imaging can accurately quantify cardiac chamber sizes, wall thickness, ventricular function, valvular anatomy, and great vessel size. Pulsed, continuous-wave, and color-flow Doppler echocardiography, especially when combined with two-dimensional imaging, can be used to

quantify blood flow velocities and calculate blood flow; assess intracardiac pressures and hemodynamics; and detect and quantify stenosis, regurgitation, and other abnormal flow states. Documentation of normal and abnormal cardiac anatomy and physiology must be accomplished by the individual performing the examination.

**Recognition of Simple and Complex Pathology.** The ability to recognize both simple and complex pathology of the heart and great vessels is required for competence in echocardiography. A fundamental knowledge of cardiac pathology is required during data acquisition to tailor the examination appropriately and maximize demonstration of the abnormalities present. This includes the ability to modify standard imaging planes and optimize the Doppler beam angle of incidence to achieve this goal. In addition, an extensive knowledge of pathology and pathophysiology is required to interpret recorded echocardiographic data.

### C. Transthoracic Echocardiography in Adult Patients

**Overview and Indications for the Procedure.** Transthoracic two-dimensional and Doppler echocardiography is one of the most important and frequently performed diagnostic procedures for patients with cardiovascular disease. It provides highly accurate diagnostic information regarding the anatomy and physiology of the cardiac chambers, valves, major vessels, and pericardium in a noninvasive and instantaneous manner. This information can immediately affect the further diagnostic work-up for the patient, dictate therapeutic decisions, determine response to therapy, and predict patient outcome. Because transthoracic two-dimensional/Doppler echocardiography plays such a major role in the care of patients with suspected or known cardiovascular diseases, the widely accepted indications for the procedure span the breadth of cardiovascular medicine, including but not limited to the diagnosis of and guiding treatment for: coronary artery disease, valvular heart disease, heart failure, hypertensive heart disease, congenital abnormalities, complications of pulmonary disease, tumors/masses, cardiac trauma, pericardial disease, and others. Details of accepted indications have been recently revised (ACC/AHA Guidelines revision, publication pending). This section will discuss the cognitive requirements, training, proof of competence, and maintenance of competence for performance and/or interpretation of TTE in adult patients with acquired diseases and/or simple congenital heart defects. A separate section is dedicated to the use of echocardiography in pediatric patients and adults with complex congenital defects, as defined by the Task Force 1 Report from the 32nd Bethesda Conference on "Care of the Adult with Congenital Heart Disease" (5). Simple lesions are listed in Table 3.

**Minimum Knowledge Required for Performance and Interpretation (Table 4).** Competence in performing and/or interpreting TTE in adult patients requires all of the basic knowledge of ultrasound physics, of instrumentation, and of cardiac anatomy, physiology and pathology described

**Table 3.** Classification of Simple Congenital Lesions

1. Valvular/Vascular
Isolated congenital aortic valve disease
Isolated sub-aortic membrane
Isolated congenital mitral valve disease (except parachute valve, cleft valve)
Isolated valvular pulmonic stenosis
Uncomplicated Ebstein's anomaly
Simple coarctation of the aorta
Sinus of valsalva aneurysm
Persistent left superior vena cava
2. Shunts
Isolated atrial septal defects or patent foramen ovale
Isolated small ventricular septal defects
Isolated patent ductus arteriosus

in the section on General Principles. Transducer manipulation is perhaps the most difficult and underestimated skill set to master when performing a transthoracic echocardiographic examination. It is the most important factor in obtaining optimal image quality in standard tomographic imaging planes and optimal Doppler flow velocity signals. As previously mentioned, appropriate knowledge of ultrasound instrument settings such as depth, gain, time-gain-compensation, dynamic range, filtering and display of received signals is essential for performing an optimal examination. Even though the majority of echocardiographic examinations are performed by sonographers and interpreted by physicians in most clinical settings in the United States, all physicians interpreting scans are required to be skilled in echocardiographic data acquisition as well. This facilitates the physician's understanding of optimal echocardiographic data acquisition and technical quality. Physicians who are ultimately responsible for the diagnostic data should play an appropriate role in quality control and teaching in the sonographer-physician relationship. The echocardiographic physician should accordingly be available for consultation with the sonographer. Furthermore, a physician properly trained in echocardiographic data acquisition should be able to perform emergency bedside echocardiographic examinations when a sonographer is not available.

**Table 4.** Cognitive Skills Required for Competence in Adult Transthoracic Echocardiography

- Basic knowledge outlined in Table 2.
- Knowledge of appropriate indications for echocardiography.
- Knowledge of the differential diagnostic problem in each case and the echocardiographic techniques required to investigate these possibilities.
- Knowledge of appropriate transducer manipulation.
- Knowledge of cardiac auscultation and electrocardiography for correlation with results of the echocardiogram.
- 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.

**Table 5.** Training Requirements for Performance and Interpretation of Adult Transthoracic Echocardiography

	Cumulative Duration of Training	Minimum Total Number of Examinations Performed	Minimum Number of Examinations Interpreted
Level 1	3 months	75	150
Level 2	6 months	150 (75 additional)	300 (150 additional)
Level 3	12 months	300 (150 additional)	750 (450 additional)

**Training Requirements (Table 5).** Training in adult TTE remains intimately linked to training in other aspects of adult cardiovascular medicine, including cardiovascular catheterization, inpatient and outpatient clinical care, electrocardiography, pacing and electrophysiology, cardiac surgery, and other noninvasive imaging. The number of procedures required to accomplish clinical competence in two-dimensional Doppler echocardiography is, in reality, somewhat arbitrary because there is individual variation in cognitive, analytical, and manual-dexterity skills. Furthermore, the breadth of the clinical experience is equally as important as the numbers themselves, in that supplemental training may be required in centers where patient populations are skewed by specific referral patterns. It is important to emphasize that the numbers of examinations refer to comprehensive two-dimensional and Doppler echocardiographic studies that are diagnostic, complete, and quantitatively accurate.

The numbers set forth in this document reflect the minimum requirements for the average trainee engaged in a training program in adult cardiovascular medicine. These numbers have been revised specifically to reflect the reality of mainstream training programs in cardiovascular medicine in the current era. A new distinction has been made between the performance of echocardiograms and interpretation of echocardiograms. Expert consensus remains that all physicians involved in the practice of the subspecialty of cardiovascular medicine or who participate in interpreting echocardiograms must be trained at a minimum level in performing echocardiograms (Table 5).

Level 1 Training (3 months, 75 examinations performed, 150 examinations interpreted). Level 1 is defined as the minimal introductory training that must be achieved by all trainees in adult cardiovascular medicine. This includes a basic understanding of the physics of ultrasound, the fundamental technical aspects of the examination, cardiovascular anatomy and physiology as it relates to echo and Doppler imaging, and recognition of simple as well as complex cardiac pathology and pathophysiology. Level 1 trainees are required to train in echocardiography for a minimum of three months and perform and interpret a minimum of 75 two-dimensional and Doppler TTEs, and interpret an additional 75 two-dimensional and Doppler TTEs (total of 150 exams interpreted). This nominal hands-on training should enable a physician to expand on or clarify the data acquired by a sonographer, and to understand potential

**Table 6.** Documentation and Maintenance of Competence in Transthoracic Echocardiography

	Training Guidelines	Proof of Competence
Documentation of Competence		
Training completed after July 1, 1998	1) Level 2 training	1) Letter or certificate from training supervisor,* <i>or</i> 2) NBE certification
Training completed between July 1, 1990, and July 1, 1998	1) Level 2 training <i>or</i> 2) 3 months training, 150 studies performed and interpreted, and 400 studies per year for 2 years	1) Letter or certificate from training supervisor* <i>or</i> 2) NBE certification <i>or</i> 3) ICAEL accreditation
Training completed prior to July 1, 1990	1) Level 2 training <i>or</i> 2) 400 studies per year for 3 years	1) Letter or certificate from training supervisor* <i>or</i> 2) NBE certification <i>or</i> 3) ICAEL accreditation <i>or</i> 4) Letter attesting to competence from Level 3 trained physician who has over read 25 studies
Maintenance of Competence		
Level 2	Performance and/or interpretation of 300 studies per year	
Level 3	Performance and/or interpretation of 500 studies per year†	

All numbers represent minimum requirements. \*Training program director, echocardiography laboratory director, or equivalent. †Periodic performance of echocardiographic studies is highly recommended.

ICAEL = Intersocietal Commission for the Accreditation of Echocardiography Laboratories; NBE = National Board of Echocardiography.

technical limitations and artifacts. Level 1 training is not sufficient for a trainee to perform or interpret echocardiograms independently.

Level 2 Training (6 months, 150 examinations performed [75 additional] and 300 interpreted [150 additional]). Level 2 training is the minimum recommended training for a physician to perform and interpret echocardiograms independently. These requirements are specifically for transthoracic two-dimensional and Doppler echocardiography. Level 2 is defined as a minimum of an additional 3 months of training in echocardiography (6 months cumulative) and the addition of 150 transthoracic two-dimensional and Doppler examinations interpreted (300 cumulative exams interpreted). Additional training in special procedures, such as TEE and stress echocardiography, is detailed subsequently in this document. Although some experience in special procedures may be attained as a part of Level 2 training, in most instances, full competence in these areas will require additional training beyond Level 2.

Level 3 Training (12 months, 300 transthoracic two-dimensional and Doppler echocardiograms performed [150 additional] and 750 interpreted [450 additional]). Level 3 represents a high level of expertise that would enable an individual to serve as a director of an echocardiography laboratory and be directly responsible for quality control and for the training of sonographers and physicians in echocardiography. Although these guidelines reflect the minimum number of TTE and Doppler studies, most physicians who are Level 3-trained will also have additional training in TEE and stress echocardiography. It should be emphasized that these numbers reflect the minimum examinations considered for clinical competence; many training programs will offer a greater experience in interpretation of transthoracic echocardiograms over the time periods previously outlined.

Physicians who trained in Cardiovascular Disease before

July 1990 (when the Level 1 to 3 guidelines were adopted) are considered clinically competent for independent performance and interpretation if they have either the equivalent of Level 2 training, as previously set forth, or have the experience of providing echocardiographic services for a minimum of 400 examinations performed and/or interpreted per year for a minimum of 3 years. Physicians who completed training in Cardiovascular Disease between July 1990 and July 1998 are considered clinically competent in echocardiography with the equivalent of Level 2 training, as previously set forth, if they completed 3 months training in echocardiography with performance and interpretation of 150 transthoracic echocardiograms, and have provided echocardiographic services of a minimum of 400 echo and Doppler examinations per year for a minimum of 2 years. Physicians who completed training in Cardiovascular Disease after July 1998 can be considered clinically competent in echocardiography with 6 months of training, a minimum of 150 examinations performed and a total of 300 examinations interpreted.

**Proof of Competence (Table 6).** The optimal evaluation of clinical competence is performed by an individual or individuals who observe the trainee directly. This is usually accomplished by the director of the echocardiography laboratory or by qualified faculty who participate in the training activities of the laboratory. Trainees are strongly encouraged to maintain a log with counts of all performed and interpreted echocardiograms that should be updated regularly. A letter or certificate from either the supervising echocardiography laboratory director or the training program director, with input from the echocardiography laboratory director, should document both the duration of training and the counts of performed and interpreted echocardiograms at the end of their training program (Table 6).

In addition to the training requirements outlined in the foregoing text, proof of competence for individuals trained

before 1990 may be established in one of the following three ways: 1) NBE Board Certification; 2) active participation by the physician in a laboratory accredited by the Intersocietal Commission for the Accreditation of Echocardiography Laboratories (ICAEL), with demonstration that the physician interprets a minimum of 300 studies per year, or 3) Endorsement by a Level 3-trained physician who has overread a minimum of 25 examinations interpreted by the individual. This Level 3-trained echocardiography physician may be either on-site or off-site in circumstances where a Level 3-trained physician is not available on-site.

**Board Examination.** The NBE was formed in December of 1998 to establish criteria for Special Competence in Adult Echocardiography. These requirements include the successful completion of a written board examination for Special Competence in Adult Echocardiography, known as the ASCeXAM, and the completion training requirements consistent with this statement and the COCATS document.

**Certification.** The NBE has established a process to issuing certification for Special Competence in Adult Echocardiography, specifically in transthoracic two-dimensional and Doppler echocardiography, to physicians who have successfully completed all training requirements and have passed the ASCeXAM. Specific details regarding certification are offered on the NBE web site: [www.echoboards.org](http://www.echoboards.org).

**Maintenance of Competence (Table 6).** Clinical competence in echocardiography requires continued maintenance of skills in two-dimensional and Doppler echocardiography. Upon completion of the training requirements as previously discussed, a minimum of performance and/or interpretations of 300 examinations per year are required to remain proficient in providing echocardiographic services at Level 2. Because Level 3 skills include the supervision and education of sonographers and physicians training in echocardiography, maintenance of these skills requires physicians to perform and/or interpret a minimum of 500 transthoracic echocardiograms annually. In addition, it is essential that Level 3 physicians maintain their skills by performing transthoracic examinations. This can be done by periodically assisting the sonographers with the performance of more complex cases. Continuing medical education in echocardiography is essential to keep pace with ongoing technical advances, refinements in established techniques, and applications of new methods. Although minimal guidelines for CME are outlined in Section A, it is recommended that Level 3 physicians exceed these minimal standards so that they can remain as true experts in echocardiography. A program for continuous quality improvement in echocardiography should be employed as outlined in the ASE Continuous Quality Improvement document (6).

#### **D. Transesophageal Echocardiography**

**Overview and Indications for the Procedure.** Transesophageal echocardiography provides an excellent window

for examining the heart and great vessels. Its clinical applications include, but are not limited to: detection and assessment of endocarditis and its complications, aortic dissection and other aortic pathologies, intracardiac thrombi and other masses, evaluation of valvular disorders including prosthetic valve function, and evaluation of a variety of CHDs in both children and adults. Transesophageal echocardiography is also of great use in patients with suspected cardiac trauma, in critically ill medical or surgical patients with unstable hemodynamics, and in patients whose clinical status necessitates echocardiographic assessment but in whom TTE studies are technically inadequate or non-diagnostic. In many large echocardiography laboratories, TEE studies represent between 5% and 10% of the total volume of echocardiographic examinations.

Transesophageal echocardiography is a minimally invasive procedure with small but definite risks (7). Therefore, it should be reserved for clinical circumstances in which the potential findings have significant implications for patient management and cannot be obtained by transthoracic evaluation.

**Minimum Knowledge Required for Performance and Interpretation (Table 7).** Competence in performing and interpreting TEE in adult patients requires all of the basic knowledge of ultrasound physics and instrumentation as well as the cardiac anatomy, physiology, and pathology described in the section on General Principles. The specific cognitive and technical skills needed to perform TEE in a competent manner are listed in Table 7 (8).

Transesophageal echocardiography requires the insertion of an endoscopic probe into the esophagus and manipulating the probe through multiple imaging planes to obtain tomographic views of the heart and great vessels. To reduce the level of discomfort associated with the procedure, a topical anesthetic spray is administered to the oropharynx, and intravenous conscious sedation is often used. Consequently, the physician performing a TEE must be knowledgeable with regard to: pharyngeal and esophageal anatomy; the proper use of conscious sedation, including the prompt recognition of possible complications; the various techniques of esophageal intubation and probe manipulation; the recognition and management of possible complications of probe insertion, including the infrequent occurrence of methemoglobinemia as a complication of benzocaine administration; and the absolute and relative contraindications to the performance of a TEE examination. The operator must also have the necessary technical knowledge required to operate the ultrasound machine. Importantly, the physician performing a TEE needs good communication skills in order to explain the TEE procedure to patients in simple terms, including its risks, benefits, and alternative approaches—and in order to obtain the patient's cooperation during the examination. In many patients, the results of a TEE examination guide urgent and definitive treatment (such as emergency surgery in a patient with an ascending aortic dissection); thus, the physician performing

**Table 7.** Cognitive and Technical Skills Required for Competence in TEE

**Cognitive Skills**

- Basic knowledge outlined in Tables 2 and 4.
- Knowledge of the appropriate indications, contraindications, and risks of TEE.
- Understanding of the differential diagnostic considerations in each clinical case.
- Knowledge of infection control measures and electrical safety issues related to the use of TEE.
- Understanding of conscious sedation, including the actions, side effects and risks of sedative drugs, and cardiorespiratory monitoring.
- Knowledge of normal cardiovascular anatomy, as visualized tomographically by TEE.
- Knowledge of alterations in cardiovascular anatomy that result from acquired and congenital heart diseases and of their appearance on TEE.
- 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.

**Technical Skills**

- Proficiency in using conscious sedation safely and effectively.
- Proficiency in performing a complete transthoracic echocardiographic examination, using all echocardiographic modalities relevant to the 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.
- Proficiency in operating correctly the ultrasonographic instrument, including all controls affecting the quality of the data displayed.
- 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.
- Proficiency in performing qualitative and quantitative analyses of the echocardiographic data.
- Proficiency in producing a cogent written report of the echocardiographic findings and their clinical implications.

Adapted from Pearlman *et al.* (8).  
TEE = transesophageal echocardiography.

a TEE needs to have a thorough knowledge of cardiovascular disorders and their accompanying hemodynamic alterations, the different diagnostic issues that require consideration given a particular clinical presentation, and the potential therapies available. The operator also needs to have mastered a thorough understanding of the basic

principles of ultrasound imaging and Doppler hemodynamic assessment described in detail in the previous sections.

Although it is usually preferable to perform a comprehensive and systematic TEE examination, it is not always possible, particularly in critically ill patients. Consequently, it is essential that the operator evaluate the most pressing diagnostic issues first. Therefore, the physician performing a TEE must be able to review available clinical and diagnostic information, including data from the TTE, in order to prioritize the most relevant issues and focus the TEE examination on resolving these issues.

**Training Requirements (Table 8).** The proper performance and interpretation of the TEE examination requires training in a number of elements such as: appropriate use of sedatives, proper and safe introduction of the TEE probe, manipulation of the TEE transducer, optimization of the echocardiographic instrument, correct interpretation of the study findings, and communication of findings to other healthcare providers in an articulate and effective manner. This training is best obtained during a formal fellowship in cardiovascular medicine, or its equivalent, and through active participation in a training program in general TTE. Alternatively, the training can be achieved as part of a cardiovascular anesthesiology or critical care medicine fellowship, with a formal period of intensive education in an affiliated diagnostic echocardiography laboratory.

Specifically, trainees must perform esophageal intubations (using a diagnostic TEE probe) under the tutelage of an experienced physician with advanced skills in TEE or under the supervision of an experienced endoscopist. Trainees must also perform a number of TEE examinations under the tutelage of an experienced TEE operator before performing TEE examinations independently. It is crucial that trainees learn to recognize normal and abnormal findings “on-line” and to manipulate the probe to obtain optimal views for evaluating the abnormalities observed. Because the results of a TEE examination are frequently considered “definitive” and used to make immediate and important management decisions, we do not believe in defining different levels of competence. Therefore, in regard to TEE, “minimum training” and “optimal training” are the same. We endorse the previously published recommendations of the ASE (8) and the ACC (4).

For physicians in formal cardiology fellowship training programs, training in TEE should include 1) attainment of at least Level 2 experience in general TTE; 2) performance

**Table 8.** Training Requirements for Performance and Interpretation of TEE

Component	Objective	Approximate Caseload
General transthoracic echo, Level 2	Background knowledge and skills	300 interpreted 150 performed
Esophageal intubation	TEE probe introduction	25
TEE examinations	Skills in performance and interpretation	50

Abbreviations same as Table 7.

**Table 9.** Documentation and Maintenance of Competence in TEE

Completion of Training	Documentation Needed
Before July 1, 1998	
Training in cardiovascular diseases	ABIM certification <i>or</i> certificate of successful completion of training, <i>or</i> letter from training program director.
Training in TTE	Documentation of Level 2 training in TTE (see section C).
Training in TEE	Documentation of performance and interpretation of 50 supervised TEE cases, via letter <i>or</i> certificate from training supervisor*, <i>or</i> notarized letter documenting performance and interpretation of at least 50 TEE studies per year for the previous 2 years, <i>or</i> NBE certification in TEE.
After July 1, 1998	
Training in cardiovascular diseases	ABIM certification <i>or</i> certificate of successful completion of training, <i>or</i> letter from training program director.
Training in TTE	Documentation of Level 2 training in TTE (see section C-Table 6).
Training in TEE	Letter <i>or</i> certificate from training supervisor* documenting performance and interpretation of 50 supervised TEE cases, <i>or</i> NBE certification in TEE.
Maintenance of competence	Performance of 25-50 TEE examinations per year.

\*Training program director, echocardiography laboratory director, *or* equivalent.

ABIM = American Board of Internal Medicine; NBE = National Board of Echocardiography; TEE = transesophageal echo; TTE = transthoracic echo.

of approximately 25 esophageal intubations with a TEE probe; and 3) performance of approximately 50 diagnostic TEE examinations under the supervision of an experienced (Level 3) echocardiographer, including the review, interpretation, and reporting of study findings. It is important to emphasize that in certain specialized clinical circumstances, even this training may not be sufficient for the independent performance of a TEE. For example, assessment of complex congenital heart lesions, and intraoperative evaluation of the suitability for and results of surgical repair of valvular regurgitation, are particularly demanding and require additional training and expertise.

Physicians who are not enrolled in a cardiology fellowship-training program need to acquire similar knowledge and to develop similar skills. This could be accomplished through an intensive period of training in an active TEE training program *or* through ongoing training under the guidance and supervision of an experienced (Level 3) echocardiographer with significant expertise in TEE.

**Proof of Competence (Table 9).** Documentation of competence can be achieved by means of a letter *or* certificate from the director of the echocardiography laboratory in which the trainee obtained TEE training *or* from the training program director, with input from the echocardiography laboratory director. This documentation should state that the trainee successfully achieved *or* surpassed each of the training elements, and the dates of training. For physicians whose training in echocardiography was completed before July 1, 1998, a Level 2 equivalence in TTE should be documented, as detailed in the previous section. In addition they must document performance of a minimum of 50 TEE cases per year, for the preceding two years. We believe that ideally, physicians should take the board examination offered by the NBE, and achieve certification in the relevant practice areas of echocardiography (i.e., general

transthoracic, TEE, stress echocardiography, *or* comprehensive certification).

**Maintenance of Competence (Table 9).** Maintenance of competence in TEE requires both ongoing continuing education and regular performance of TEE examinations. Physicians performing TEE examinations should periodically attend postgraduate courses and workshops that focus on clinical applications of TEE, especially those that emphasize new and evolving techniques and developments. In addition, physicians should seek to compare the quality, completeness, and results of their own examinations with those presented at scientific meetings and in professional publications. On-line *or* other multimedia formats give physicians increasing access to a variety of materials that can help them keep up with the field.

Ongoing performance of diagnostic TEE examinations is needed to maintain technical skills and to keep up with developments in the field. Infrequent performance of TEE increases the risk of complications *or* of inaccurate results and inappropriate patient treatment. The guidelines on training in TEE published by the ASE in 1992 recommended performing 50 to 75 TEE examinations per year (8). Given the greater exposure to training in this modality over the past 10 years and recognizing that achieving such a volume may be difficult in routine clinical practice, this writing group recommends that a minimum of 25 to 50 cases per year be required to maintain adequate cognitive and technical skills in performing and interpreting TEE. Of course, TEE examinations should not be performed simply to meet these guidelines, but they must be indicated on clinical grounds and appropriate to good patient care. Physicians at the lower end of the recommended number should work in association with a laboratory where a greater volume is performed, so that they can be exposed to an adequate variety of pathology. On the other hand, physi-

cians who cannot meet the recommended number should perform the procedure in conjunction with more experienced operators. Continuing medical education in echocardiography and TEE is essential to keep pace with ongoing technical advances, refinements in established techniques, and applications of new methods. Minimal CME requirements are outlined in Section A.

We also subscribe to the principles of Continuing Quality Improvement in Echocardiography (6), and recommend that a random sample of TEE studies performed by an individual operator periodically be reviewed by a qualified expert (from the operator's own institution or, if necessary, from the outside), as part of a quality assessment program. This review should be performed in an educational and non-punitive manner and should help to determine if TEE studies had been performed for appropriate indications, if studies were of sufficient completeness and technical quality to resolve the relevant diagnostic questions, if findings were interpreted and reported correctly, and if results were reported in an effective and timely manner. Recurring variations from the norm would then serve to highlight areas for further quality improvement and thereby help facilitate better patient care. Continuing Quality Improvement considerations also mandate that the results of TEE examinations be compared, whenever possible, with the findings from cardiac catheterization or other cardiac imaging studies, cardiac surgery, or necropsy in order to establish and maintain diagnostic accuracy.

### *E. Perioperative Echocardiography*

**Overview and Indications for the Procedure.** Perioperative echocardiography refers to the application of echocardiographic examination techniques in patients undergoing surgical procedures (intraoperative echocardiography) and during the early postoperative period. Early echocardiographic examinations used epicardial echocardiographic probes that had limited clinical applicability. Today, the examination is performed predominantly through the transesophageal approach, although epicardial and epivascular techniques continue to play a role during surgery, particularly in the echocardiographic assessment of the thoracic aorta.

Perioperative echocardiography utilizes most of the echocardiographic modalities used in the non-operative setting. They include M-mode and two-dimensional imaging techniques as well as pulsed, continuous-wave and color flow Doppler. Most modern transesophageal probes have multi-plane capabilities. The ASE and the Society of Cardiovascular Anesthesiologists (SCA) have published guidelines for the performance of a comprehensive perioperative multi-plane transesophageal examination (9).

The indications for perioperative echocardiography have been summarized by a task force of the American Society of Anesthesiologists/Society of Cardiovascular Anesthesiologists (ASA/SCA) and published as practice guidelines in 1996 (10). They can be divided into two broad categories: 1)

indications that lie within the customary practice of anesthesiology, such as the perioperative diagnosis of myocardial ischemia and infarction, the perioperative assessment of hemodynamics and ventricular function, and the perioperative diagnosis and management of cardiovascular collapse; and 2) indications that guide surgical decisions in the operating room. In this regard, cardiovascular lesions are diagnosed, and the information is used to influence the patient's surgical management. The results of surgical interventions may be assessed by echocardiography, and the findings may guide additional surgical therapy, if necessary. A physician should perform the perioperative echocardiographic examination. Although a sonographer may assist the physician, the physician must always be present to interpret the echocardiographic data and assist the surgeon in planning the surgical procedure.

**Minimum Knowledge Required for Performance and Interpretation (Table 10).** Competence in performing and interpreting perioperative echocardiography in adult patients requires basic knowledge of ultrasound physics, instrumentation, and cardiac anatomy, physiology, and pathology outlined in the section on General Principles. Although several guidelines describe the knowledge necessary to perform echocardiography, few have focused on the specific knowledge and skills necessary for the practice of perioperative echocardiography. Specific guidelines on training in perioperative TEE have been recently published by an ASA/SCA Task Force (11). These recommendations which were developed mainly for anesthesiologists, recognized that perioperative echocardiography was practiced at different levels. Some anesthesiologists predominantly use echocardiography for monitoring purposes in the detection of myocardial ischemia or the evaluation of intracardiac hemodynamics and ventricular function (basic level), while others use the full diagnostic potential of echocardiography in the perioperative period (advanced level). The knowledge and skills necessary to practice perioperative echocardiography at the basic and advanced levels are summarized in Tables 10 and 11, respectively. For non-anesthesiologists who practice perioperative echocardiography, any necessary knowledge beyond what is listed in the tables relates to physiologic changes induced by anesthetic agents, mechanical ventilation, and cardiopulmonary bypass.

**Training Requirements (Table 12).** We endorse the recent ASA/SCA task force recommendation of two levels of training for perioperative echocardiography, basic and advanced (10,11). Both basic and advanced TEE training refer to specialized TEE training that extends beyond the minimum exposure to echocardiography that occurs during normal anesthesia residency training. Anesthesiologists with basic training are considered able to use TEE for indications that lie within the customary practice of anesthesiology. Anesthesiologists with advanced training are, in addition, able to utilize the full diagnostic potential of perioperative TEE.

The essential components of training include indepen-

**Table 10.** Cognitive and Technical Skills Needed to Perform Perioperative Echocardiography at a Basic Level

**Cognitive Skills**

- Basic knowledge outlined in Table 2.
- Knowledge of the equipment handling, infection control, and electrical safety recommendations associated with the use of TEE.
- Knowledge of the indications and the absolute and relative contraindications to the use of TEE.
- General knowledge of appropriate alternative diagnostic modalities, especially transthoracic and epicardial echocardiography.
- Knowledge of the normal cardiovascular anatomy as visualized by TEE.
- Knowledge of commonly encountered blood flow velocity profiles as measured by Doppler echocardiography.
- Detailed knowledge of the echocardiographic presentations of myocardial ischemia and infarction.
- Detailed knowledge of the echocardiographic presentations of normal and abnormal ventricular function.
- Detailed knowledge of the physiology and TEE presentation of air embolization.
- Knowledge of native valvular anatomy and function, as displayed by TEE.
- Knowledge of the major TEE manifestations of valve lesions and of the TEE techniques available for assessing lesion severity.
- Knowledge of the principal TEE manifestations of cardiac masses, thrombi, and emboli; cardiomyopathies; pericardial effusions and lesions of the great vessels.

**Technical Skills**

- Ability to operate the ultrasound machine, including controls affecting the quality of the displayed data.
- Ability to perform a TEE probe insertion safely in the anesthetized, intubated patient.
- Ability to perform a basic TEE examination.
- Ability to recognize major echocardiographic changes associated with myocardial ischemia and infarction.
- Ability to detect qualitative changes in ventricular function and hemodynamic status.
- Ability to recognize echocardiographic manifestations of air embolization.
- Ability to visualize cardiac valves in multiple views and recognize gross valvular lesions and dysfunction.
- Ability to recognize large intracardiac masses and thrombi.
- Ability to detect large pericardial effusions.
- Ability to recognize common artifacts and pitfalls in TEE examinations.
- 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.

Abbreviation same as Table 7.

dent work, supervised activities, and assessment programs. Through a structured independent reading and study program, trainees must acquire an understanding of the principles of ultrasound and indications for perioperative echocardiography. This independent work should be supplemented by regularly scheduled didactics such as lectures and seminars designed to reinforce the most important aspects of perioperative echocardiography. Under appropriate supervision, trainees undergoing basic training learn to place the TEE probe, operate the ultrasound machine, and perform a TEE examination. Trainees should be encouraged to master the comprehensive examination

**Table 11.** Skills Necessary to Perform Perioperative Echocardiography at the Advanced Level

**Cognitive Skills**

- All the cognitive skills defined for the basic level.
- Knowledge of the principles and methodology of quantitative echocardiography.
- 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.
- Knowledge of the echocardiographic manifestations of CHD\*.
- 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).
- Detailed knowledge of other cardiovascular diagnostic methods for correlation with TEE findings.

**Technical Skills**

- All the technical skills defined for the basic level.
- Ability to perform a complete TEE examination.
- Ability to quantify subtle echocardiographic changes associated with myocardial ischemia and infarction.
- Ability to utilize TEE to quantify ventricular function and hemodynamics.
- 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.
- 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.

\*Requires additional training as outlined in the Section on CHD.  
CHD = congenital heart disease.

defined by the ASE and SCA (9). A basic practitioner should be able to acquire all 20 of the recommended cross-sections, although not always needed for a basic examination, in the event they are needed for remote consultation with an advanced practitioner. For basic training, 150 complete examinations should be studied under appropriate supervision. These examinations must include the full spectrum of commonly encountered perioperative diagnoses and at least 50 comprehensive perioperative TEE examinations personally performed, interpreted, and reported by each trainee (Table 12).

For advanced practice, the comprehensiveness of training is paramount. The ASE/SCA Task Force (11) recommends that 300 complete examinations be studied under appropriate supervision. These examinations must include a wide spectrum of cardiac diagnoses and at least 150 comprehensive perioperative TEE examinations that are personally performed, interpreted, and reported by the trainee (Table

**Table 12.** Training Recommendations for Basic and Advanced Perioperative Echocardiography

	Basic	Advanced
Minimum number of examinations studied	150	300
Minimum number personally performed	50	150
Program director qualifications	advanced perioperative echocardiography training	advanced perioperative echocardiography training, plus at least 150 additional perioperative TEE examinations
Program qualifications	wide variety of perioperative applications of echocardiography	full spectrum of perioperative applications of echocardiography

Abbreviations same as in Table 7.

12). For both basic and advanced training, trainees must be taught how to convey and document the results of their examination effectively. Periodic formal and informal evaluations of trainees' progress should be conducted during training. Trainees should keep a log of the examinations they performed and reviewed to document the depth and breadth of their training. The experience and case numbers acquired during basic training may be counted toward advanced training if the basic training was completed in an advanced training environment.

The ASE/SCA Task Force and this writing group recognize that trainees from different specialties will allocate their training schedules somewhat differently depending on their backgrounds. A cardiologist-echocardiographer with little operating room experience will need to spend more time in this environment to fully understand cardiac surgical techniques. A cardiac anesthesiologist or surgeon working in a center with a limited variety of cardiac surgery will need to spend more time in the echocardiographic laboratory to fully understand all of the diagnostic techniques in echocardiography.

Advanced training should take place after basic training in a training program designed specifically to accomplish comprehensive training in perioperative echocardiography. The director of the training program must be a physician with advanced training and proven expertise in perioperative echocardiography, who has performed at least 450 complete examinations, including 300 perioperative TEE examinations or equivalent experience. As advanced trainees acquire more experience, they may be allowed to work with more independence, but the immediate availability and direct involvement of an advanced practitioner is an essential component of advanced training. The supporting surgical program must have the volume and diversity to ensure that trainees will experience the wide spectrum of diagnostic challenges encountered in perioperative echocardiography

and learn to use TEE effectively in all its established perioperative applications. The perioperative echocardiography training program should have an affiliation with an echocardiography laboratory so that trainees can gain regular and frequent exposure to teaching and clinical resources within that laboratory.

**Proof of Competence (Table 13).** Documentation of competence can be achieved by means of letters or certificates from the director of the perioperative echocardiography training program. This documentation should state the dates of training and that trainees have successfully achieved or surpassed each of the training elements.

Physicians already in practice can achieve appropriate training in perioperative echocardiography without enrolling in a formal training program. However, the same prerequisite medical knowledge, medical training, and goals for cognitive and technical skills apply to them as they apply to physicians in formal training programs. They should work with other physicians who have advanced TEE training or equivalent experience to achieve the same training goals and case numbers as the training levels previously delineated. It is the consensus of this writing group that physicians seeking basic training via this pathway should have at least 20 hours of CME devoted to echocardiography. Physicians seeking advanced training via this pathway should have at least 50 hours of CME devoted to echocardiography. The CME in echocardiography should be obtained during the time that trainees are acquiring the requisite clinical experience in TEE. Trainees should document their experience in detail and be able to demonstrate training equivalent in depth, diversity, and case numbers to the training levels previously delineated. Physicians who provide the training should document the successful completion of the training elements and the dates of training. We believe that, ideally, physicians should take the periop-

**Table 13.** Documentation and Maintenance of Competence in Perioperative TEE

Documentation of Competence	Maintenance of Competence
Letter or certificate from the director of the perioperative echocardiography-training program (For physicians in practice: a letter from the physician providing the training documenting the successful completion of the training elements and the dates of training)	Performance and interpretation of at least 50 examinations
	Participation in Continuous Quality Improvement
	Participation in Continuous Medical Education as outlined in Section A
<i>or</i>	
NBE certification	

erative TEE board examination offered by the NBE and achieve certification in perioperative echocardiography.

**Maintenance of Competence (Table 13).** Clinical competence in perioperative echocardiography requires continued maintenance of skills in perioperative TEE including two-dimensional and Doppler examination. Upon completion of above training requirements, a minimum of performance and interpretation of 50 examinations per year is required to remain proficient in performing perioperative echocardiography. A program for continuous quality improvement in echocardiography should be employed as outlined in the ASE Continuous Quality Improvement document (6). Continuing medical education in perioperative TEE is essential to keep pace with ongoing technical advances, refinements in established techniques, and applications of new methods. Minimal CME requirements are outlined in Section A.

#### *F. Stress Echocardiography*

**Overview and Indications for Procedure.** Exercise electrocardiography is the standard noninvasive technique for the diagnosis of coronary artery disease. However, several situations (such as baseline ECG abnormalities and inability to exercise), reduce the sensitivity or specificity of exercise testing, or preclude its use entirely. In these situations, stress echocardiography is an important alternative.

There are two main modalities for performing stress echocardiography: 1) exercise stress echocardiography performed either during upright or supine bicycle exercise or immediately following treadmill exercise, and 2) pharmacologic stress echocardiography, most commonly performed using an intravenous infusion of dobutamine at a dose ranging from 5 mcg per kg per min to a maximum of 40 to 50 mcg per kg per min. Atropine is added at peak infusion dose if needed to achieve at least 85% of target heart rate. Side effects of dobutamine stress echocardiography include nausea, vomiting, headache, tremor, and anxiety. Serious complications such as myocardial infarction and death are very rare. Adenosine and dipyridamole can also be used as pharmacologic stressors. Atrial pacing using an esophageal lead or an implanted pacemaker is a third modality for performing stress echocardiography. Although it is not commonly used, this modality can provide an effective and safe method for inducing ischemia.

The normal cardiac response to stress is an increase in heart rate and myocardial contractility. Inducible myocardial ischemia is detected as failure to increase myocardial contractility or development of a new segmental wall motion abnormality. Indications for stress echocardiography include diagnosis of ischemic heart disease, evaluation of patients with known ischemic disease, and assessment of valvular heart disease.

Stress echocardiography can also be performed with spectral and color Doppler for the hemodynamic evaluation of patients with valvular heart disease. Ultrasonic contrast agents have been used to improve endocardial border

detection. In the future, these agents might be used to evaluate myocardial perfusion.

Transesophageal dobutamine stress echocardiography has been used to improve endocardial visualization, but because of its invasive nature and the general improvement in transthoracic imaging with the use of contrast agents, this modality has not gained wide acceptance in clinical practice. **Minimum Knowledge Requirements for Performance and Interpretation (Table 14).** Competence in performing and/or interpreting stress echocardiograms in adult patients requires all of the basic knowledge of ultrasound physics, instrumentation, and cardiac anatomy, physiology and pathology described in the section on General Principles. In addition, the requirements for stress echocardiography contain two distinct components: 1) stress testing supervision; and 2) performance and interpretation of the echocardiographic images for wall motion analysis. Stress testing supervision requires the ability to safely monitor stress in an individual with potentially severe cardiovascular disease. A recent ACC/AHA Clinical Competence Statement on Stress Testing document by Rodgers *et al.* (12) addressed the cognitive skills, training requirements for establishing competence and requirements for maintaining competence in stress echocardiography. The document separates the skills needed to perform and supervise the stress portion of the test from those needed to perform and interpret the echocardiographic images. Recognition and treatment of life threatening arrhythmias is particularly relevant with dobutamine stress echocardiography. This writing group has decided to adopt the recommendations made by Rodgers *et al.* (12) which are summarized in this section.

Assessment of segmental wall motion remains one of the most challenging aspects of echocardiographic interpretation. Thus, intensive training in echocardiography with a minimum of Level 2 training or equivalent is a prerequisite for acquiring the skills necessary to perform and interpret stress echocardiography studies (13).

**Training Requirements (Table 15).** Specific recommendations for training in stress echocardiography have been published recently (12–14) and consist of achieving Level 2 training in echocardiography plus a minimum of 100 stress studies performed under the supervision of an echocardiographer with Level 3 training and expertise in stress echocardiography, including the independent interpretation of more than 200 stress echocardiograms, and maintenance of skills as outlined Table 16 (12).

**Proof of Competence (Table 16).** A letter from the program training director or training supervisor is expected to document the required training activity and competence. Physicians who intend to perform stress echocardiography and who completed training before the establishment of training levels are expected to achieve training equivalent to that acquired during formal fellowship. This should be achieved in a laboratory with sufficient volume to expose the physician to the same minimum of 100 stress echocardiograms, as previously outlined, under the direct supervision

**Table 14.** Cognitive Skills Required for Performance and Interpretation of Stress Echocardiography

**Performance**

- Basic knowledge outlined in Tables 2 and 4.
- Skills for supervision of standard exercise testing, including competence in cardiopulmonary resuscitation and successful completion of an American Heart Association-sponsored course in cardiopulmonary resuscitation and renewal on a regular basis.
- Knowledge of the indications and limitations of exercise echocardiography.
- Knowledge of the different types of pharmacologic stress agents, including advantages and disadvantages of the different agents.
- Knowledge of the indications for pharmacologic stress echocardiography.
- Knowledge of limitations and contraindications of pharmacologic stress echocardiography with different types of pharmacological stress agents.
- Knowledge of pharmacokinetics and physiologic responses of the different pharmacologic stress agents.
- Knowledge of the side effects of different pharmacologic agents and how to manage them.
- Knowledge of the complications of different pharmacologic stress agents and how to manage them.
- Knowledge of cardiovascular drugs and their effects on responses to pharmacological stress.
- Knowledge of electrocardiography and changes that may occur in response to pharmacologic stress.
- Knowledge of the end points of pharmacologic stress echocardiography and indications for termination of a stress echocardiographic examination.
- Knowledge of the sensitivity, specificity, and diagnostic accuracy of pharmacologic stress echocardiographic testing in different patient populations.
- Ability to apply Doppler data to the physiologic changes that occur during pharmacologic stress.

**Image Interpretation**

- Basic interpretative skills outlined in Tables 2 and 4.
- Ability to identify left ventricular wall segments and recognize wall motion abnormalities at rest and during stress.
- Knowledge of common pitfalls in the interpretation of digitally acquired images, such as arrhythmias, improper capture, and foreshortening of left ventricular cavity.
- Knowledge of coronary anatomy and relationship to echocardiographic findings.
- Knowledge of the relationship of imaging results to the presence or absence of myocardial viability.
- Knowledge of specificity, sensitivity, and diagnostic accuracy of stress echocardiographic testing in different patient populations.
- Knowledge of conditions and circumstances that can cause false-positive, indeterminate, or false-negative test results.
- Ability to apply Doppler data to the physiologic changes that occur during exercise or pharmacologic stress.
- Knowledge of prognostic value of stress echocardiographic testing.
- Knowledge of alternative diagnostic procedures to stress echocardiography.

Modified from Rodgers *et al.* (12).

of an echocardiographer with Level 3 training and expertise in stress echocardiography.

Certification by the NBE is highly desirable. Certification requires successful completion of the Adult Special Competence Examination in Echocardiography as well as documentation of training and maintenance of skills. For

**Table 15.** Training Requirements for Performance and Interpretation of Stress Echocardiography

- Understanding of the basic principles, indications, applications, and technical limitations of echocardiography.
- Level 2 training in transthoracic echocardiography.
- Specialized training in stress echocardiography with performance and interpretation of 100 stress studies under appropriate supervision by a Level 3 echocardiographer.

individuals completing training after 1998, a letter from the training director or section head documenting Level 2 training and performance/interpretation of 100 or more stress echocardiograms is required. For physicians completing cardiovascular training before 1998, a letter documenting performance and interpretation of 400 or more transthoracic echocardiograms and 100 or more stress echocardiograms during each of the two preceding years is required. This letter should be obtained from the laboratory medical director or the hospital chief of staff.

**Maintenance of Competence (Table 16).** The accurate assessment of regional wall motion during stress is difficult enough to require continuous exposure to an adequate mix of normal and abnormal cases in order to maintain competence. The ASE document recommended a volume of 15 stress echoes per month to remain competent (14). However, it was the consensus of the experts writing the ACC/AHA Competence Statement on Stress Testing that an individual with established skills could maintain competence with a volume of 100 studies per year (12). We endorse this recommendation. Physicians with a lesser volume should perform and/or interpret stress echoes in association with an experienced echocardiographer who achieves the recommended volume of studies in his or her practice. Continuing medical education in stress echocardiography is essential to keep pace with ongoing technical advances, refinements in established techniques, and applications of new methods. Minimal CME requirements are outlined in Section A. A program for continuous quality improvement in stress echocardiography should be employed, as outlined in the ASE Continuous Quality Improvement document (6).

**G. Echocardiography for CHD Patients**

**Overview and Indications for Procedure.** Echocardiography is an important resource used in the evaluation of infants, children, and adults with suspected or documented

**Table 16.** Demonstration and Maintenance of Competence in Stress Echocardiography

Demonstration of Competence	Maintenance of Competence
Letter or certificate from training supervisor* or NBE certification in stress echocardiography	Performance and interpretation of 100 stress studies per year. Participation in continuing medical education in echocardiography as outlined in Section A.

\*Training program director, echocardiography laboratory director, or equivalent.  
NBE = National Board of Echocardiography.

CHD. It has been widely applied for the last several decades and has become a mainstay in daily clinical use. As applied to infants, children, and adults with CHD, echocardiography is comprised of all of the previously described modalities. When combined, they provide a comprehensive anatomic diagnosis along with the assessment of associated flow disturbances. Such information is obtained noninvasively, without patient risk or discomfort. The high accuracy of the information is often sufficient to preclude the need for further invasive diagnostic studies such as cardiac catheterization. Numerous echocardiographic methods have been developed with high sensitivity and specificity for individualized diagnosis and assessment of disease severity. In addition to the method's high accuracy, it has prime utility in serial evaluation of patients for surveillance of the severity and progression of the disease, and the response to therapy.

Echocardiography is indicated in the evaluation of the cardiac anatomy and physiology of infants and children in whom cardiac concerns are present, and in adults with known or suspected CHD. This includes patients in whom cardiac malformations are suspected because a heart murmur has been detected or because of concerns about cyanosis, or congestive failure, or abnormal findings on chest X-ray or ECG. The frequency of repeat echocardiographic examination depends on the severity of the disease, the type of intervention performed, and the age of the patient. Whether it is performed in infants, children, or adults, echocardiography of patients with CHD requires a special knowledge base that is usually acquired during a fellowship in pediatric cardiology. In most cases, a properly trained adult cardiologist with Level 2 or 3 competence in echocardiography should be capable of recognizing simple congenital heart defects (Table 3) and treating affected patients appropriately. However, the same does not apply to complex lesions. Few adult cardiology training programs have a sufficient caseload and case mix of complex lesions to ensure an adequate level of training. Although adult cardiologist echocardiographers may often recognize the presence of a complex CHD, the comprehensive evaluation and management of these lesions require special skills not usually acquired during a conventional adult cardiology fellowship. With the growing number of adults with complex CHD, there is an acknowledged need for cardiologists trained specifically in the care of these patients (15). Practitioners in adult CHD require special expertise in echocardiography similar to that possessed by pediatric echocardiographers. This section describes the skills required for performing echocardiography in pediatric patients and in adults with complex CHD, along with the training requirements and criteria for proof of competence and maintenance of competence in this area. The definition of "complex CHD" is any congenital lesion other than those mentioned in Table 3.

**Minimum Knowledge Required for Performance and Interpretation (Table 17).** Competence in performing and/or interpreting echocardiograms in pediatric patients and in adults with complex CHD requires all of the basic

**Table 17.** Cognitive Skills Required for Performance and Interpretation of Echocardiography in Patients With Complex CHD

**For the Pediatric Patient**

- Basic knowledge outlined in Table 2.
- Understanding of the cardiac structural and physiologic changes that take place during human growth and development from infancy to adulthood.
- Knowledge of the anatomical and physiologic spectrum of CHD and its manifestations during different stages of human growth and development.
- Knowledge of the spectrum of acquired heart disease in the pediatric age group.
- Knowledge of the spectrum of surgical palliation and surgical repair for CHD and its manifestations in the pediatric echocardiogram.
- Knowledge of the spectrum of catheter based interventions for CHD and its manifestations in the pediatric echocardiogram.
- Knowledge of the indications for performance of the pediatric echocardiogram.

**For the Adult Patient**

- Basic knowledge outlined in Tables 2 and 4.
- Understanding of the limitations of the echocardiogram in the adult.
- Knowledge of the anatomical and physiologic spectrum of CHD and its manifestations in the adult.
- Knowledge of the spectrum of surgical palliation and surgical repair for CHD and its manifestations on the adult echocardiogram.
- Knowledge of the spectrum of catheter based interventions for CHD and its manifestations in the adult echocardiogram.
- Knowledge of the impact of acquired heart disease on the physiology of the underlying congenital lesion.

CHD = congenital heart disease.

knowledge of ultrasound physics, of instrumentation, and of cardiac anatomy, physiology, and pathology described in the section on General Principles. In addition, a pediatric echocardiographer must be skilled in observing and understanding the behavioral and developmental aspects of infants and children of all ages, in order to alleviate patient fear, establish patient confidence, and be persuasive enough to allow the proper completion of a cardiac ultrasound examination. At times, echocardiographers may be required to administer sedation to obtain adequate examinations, and knowledge of these agents is necessary. These skills are specific to those practitioners performing examinations in children and do not apply to individuals performing examinations only in adults with CHD.

**Technical Aspects of the Examination.** An echocardiographer must be personally skilled in all aspects of the technical performance and recording of the examination. This includes a review of the indications and goals of the study and the formulation of a plan to accomplish those goals. One must know how to use ultrasound probes of different frequencies to obtain the most comprehensive information possible in a given patient, particularly infants and premature babies. An echocardiographer must be able to scan from all available echo windows and integrate the information from each view. In addition, he/she must be familiar with the use of ultrasound contrast agents, which can enhance the detection of intracardiac shunts. These

**Table 18.** Training Requirements for Performance and Interpretation of Echocardiography in Pediatric Patients

Level	Minimum Number of Studies to Be Performed and Interpreted*	Minimum Additional Number of Studies To Be Either Performed and Interpreted or Reviewed*
Level 1	100	100
Level 2	200	200
Level 3	500	500

\*At least 25% of these should be in children less than 1 year of age.

skills are required even when a physician has access to a sonographer for performance of the examination. Supervising physicians cannot supervise adequately unless they themselves, are capable of performing echocardiograms on infants and children.

**Anatomy and Physiology.** An echocardiographer examining a patient with complex CHD must be skilled in recognizing anatomic features that identify and characterize specific cardiac structures and allow for diagnosis of specific cardiac malformations. Echocardiographers must be able to identify the abdominal and thoracic situs and perform an anatomic assessment in a segmental anatomic sequence that identifies not only anatomy but also connections. He or she must be fully familiar with associated disease processes and their effect on anatomic findings.

The physiology of many congenital lesions and combinations of lesions is interrelated. The echocardiographer must be familiar with the influence of age, patient size, and hemodynamic state in each lesion, and they must understand the transitional physiology of the neonate, shunt physiology, and the concepts and manifestations of pulmonary hypertension throughout the full pediatric and adult-age spectrum. The echocardiographer must be familiar with established techniques used to quantify cardiac function and evaluate different physiologic states and must know how to evaluate the consistency (or lack thereof) of results obtained with these techniques in a given patient.

**Recognition of Simple and Complex Pathology.** An echocardiographer must have sufficient knowledge and experience to be aware of defects or problems that may cluster together. He/she must be aware of cardiac defects associated with various syndromes and be able to recognize the dysmorphic features of those syndromes.

An echocardiographer must know how to evaluate the several anatomic and physiologic abnormalities that coexist in patients with complex malformations and recognize the

effects of altered physiology. They will commonly encounter patients who have undergone surgical intervention for a variety of cardiac problems and for each, they must be aware of the type of surgical procedure and its specific echocardiographic findings. For some lesions, surgical techniques have evolved over the years, so echocardiographers must be aware not only of contemporary surgical approaches but also procedures performed differently in the past. For many of these surgical evaluations, a substantial modification of examination techniques may be required. Interventional procedures for palliation of CHD have become increasingly common. The echocardiographer must have knowledge of the residua and sequelae of these surgical and non-surgical procedures.

**Training Requirements (Tables 18 and 19).** Training in pediatric echocardiography today involves exposure to echocardiographic principles and techniques during a pediatric cardiology fellowship. One may elect to spend additional time in echocardiography, depending on the fellowship program. Close supervision and guidance by experienced pediatric echocardiographers is essential for proper education, training, and development of technical experience. Training involves not only observation, but also actual hands-on performance of the examination.

Echocardiographic training for cardiologists specializing in adult CHD varies according to the level of training. We recognize that minimum numbers are difficult to define and standardize. However, we endorse the recommendations of the 32nd Bethesda Conference that only cardiologists with Level 2 or 3 training should care for such patients independently (5). Training in complex adult congenital disease requires a minimum of 150 complete TTE and 25 TEE (10 intraoperative) studies performed and interpreted in patients with CHD, as well as participation in the interpretation of at least 300 TTE and 50 TEE studies (20 intraoperative) (16). Case mix is an important aspect of the training experience, and when adequate diversity is not available among adult patients, training should include echocardiographic examinations in children.

**Proof of Competence (Table 20).** Letter or certificate from training supervisor, or other means of documentation (i.e., log) of fulfillment of the training requirements as outlined above. No test is presently available for evaluating competence in pediatric echocardiography or in assessing complex CHD in adults.

**Table 19.** Training Requirements for Performance and Interpretation of Echocardiography in Adults With Complex Congenital Heart Disease\*

Procedure	Minimum Number of Studies to be Performed and Interpreted	Minimum Additional Number of Studies to be either Performed and Interpreted or Reviewed
Transthoracic echocardiography	150	300
Transesophageal echocardiography	25	50

\*Level 2 or 3, as defined in Table 5, required before training.

**Table 20.** Demonstration and Maintenance of Competence in Pediatric Echocardiography\*†

Demonstration of Competence	Maintenance of Competence
Letter or certificate from training supervisor*	Minimum number of studies per year to be performed and/or interpreted* Level 2: 400 Level 3: 800

\*Training program director, echocardiography laboratory director, or equivalent. †At least 25% of these should be in children less than 1 year of age. Maintenance of competence for echocardiographers in adults with congenital heart disease is outlined in the narrative.

**Maintenance of Competence (Table 20).** Maintenance of competence in pediatric echocardiography requires a minimum of 400 studies annually for Level 2 practitioners and 800 studies annually for Level 3, with at least 25% of the studies performed in patients under a month of age. For cardiologists caring for patients with adult CHD, the number of examinations performed annually to maintain competence has not been defined. Our recommendation is a minimum of 100, as long as an adequate case mix is assured.

### H. Fetal Echocardiography

**Overview and Indications for Procedure.** Fetal echocardiography is the ultrasonic evaluation of the developing human cardiovascular system prior to birth. Non-invasive in nature, and highly accurate when used by skilled operators, it is presently the standard method used for the detection of fetal cardiovascular disease. A complete imaging evaluation of the fetal cardiovascular system can be obtained utilizing a maternal trans-abdominal approach at 18 to 22 weeks gestation; however, some images can be obtained as early as 14 to 16 weeks. Trans-vaginal fetal echocardiography can be performed as early as 12 weeks gestation. The increasing national trends toward routine performance of second trimester obstetrical ultrasound, and toward overall improvements in the field of obstetrical diagnostics have led to a greater number of referrals to specialists knowledgeable in the field of fetal cardiovascular abnormalities and skilled in the performance of fetal echocardiography. Recent data demonstrate an improved postnatal outcome for CHD when a prenatal diagnosis via fetal echocardiography is made (17,18).

The practice of fetal echocardiography is unique for a number of reasons. Management of fetal heart disease involves multiple services that care for both mother and fetus. The practice of fetal echocardiography must therefore take place within the context of a multidisciplinary approach offering expertise in pediatric cardiology, maternal-fetal medicine, genetics, neonatology, and pediatric cardiac surgery. The practitioner of fetal echocardiography must have a basis of clinical understanding in all of these fields in order to interact knowledgeably and coordinate care. The detection of fetal cardiovascular disease via fetal echocardiography can have a significant impact on the course of the pregnancy. Information generated by the fetal echocardiographer will commonly result in parental counseling, which may contribute to decisions concerning the continuation of pregnancy, initiation of treatment, or determination of the

place for labor and delivery. Due to the physiologic differences inherent in postnatal and prenatal life, congenital anomalies of the fetal heart are observable but do not commonly manifest clinically until after birth. The time lag between the detection of structural CHD in the fetus and intervention after birth provides an opportunity to offer counseling, genetics evaluation, and education to expectant parents, all of which contributes to appropriate preparation.

Many disease processes including congenital fetal anomalies, acquired fetal disorders, maternal disorders, and exposure to offending agents can lead to abnormalities in fetal cardiovascular development and can thereby warrant examination by a qualified fetal echocardiographer. Indications for fetal echocardiography can be categorized as either maternal or fetal in nature. Examples of maternal indications include: a family history of CHD, diabetes, connective tissue disease, and teratogen exposure. Examples of fetal indications include: an abnormal-appearing heart on routine obstetrical ultrasound, non-immune hydrops, an irregularity of fetal heart beat, chromosomal abnormality, and the discovery of extra-cardiac anomalies (i.e., congenital lung lesions, diaphragmatic hernia).

**Minimum Knowledge Required for Performance and Interpretation (Table 21).** Competence in performing and/or interpreting fetal echocardiography requires all of the

**Table 21.** Cognitive Skills Required for Performance and Interpretation of Fetal Echocardiograms

- Basic knowledge outlined in Table 2.
- All of the cognitive skills required for performance and interpretation of echocardiography in patients with complex CHD (Table 16).
- Knowledge of the technical aspects of performing a complete fetal echocardiogram.
- The ability to recognize fetal cardiovascular anomalies that will require immediate care and management at birth (i.e., prostaglandin infusion, surgery).
- Knowledge of maternal-fetal physiology and maternal disease that may affect the developing fetal cardiovascular system.
- Knowledge of human embryology and cardiovascular development.
- Knowledge of the evolution of cardiovascular malformations during the 2nd and 3rd trimesters of pregnancy.
- Knowledge of the latest developments in obstetrical diagnostics, including invasive and non-invasive techniques.
- Knowledge of the relationship between fetal CHD and chromosomal, genetic, and non-cardiac organ system abnormalities.
- Knowledge of the most recent developments in surgical correction and current data concerning long-term outcome for complex CHD, in order to counsel expectant parents effectively and objectively.
- Knowledge of the signs of congestive heart failure in the fetus.

CHD = congenital heart disease.

basic knowledge of ultrasound physics, of instrumentation, and of cardiac anatomy, physiology, and pathology described in the section on General Principles. In addition, the physician performing fetal echocardiography must be knowledgeable in the principles of biological ultrasound instrumentation and its application in human pregnancy. A thorough understanding of maternal-fetal physiology, as well as maternal diseases that may affect the developing fetus, is necessary. The physician performing fetal echocardiography should be familiar with the latest developments in obstetrical diagnostics, including which invasive and non-invasive tests are available throughout the trimesters of pregnancy. A thorough understanding of and an ability to recognize the full spectrum of simple and complex, acquired and congenital, heart disease are mandatory. The physician must have knowledge of cardiac embryology and the anatomy and physiology of the developing cardiovascular system throughout the stages of human development. A thorough understanding of fetal physiology and the impact of heart disease on fetal physiology is necessary, along with an understanding of the potential impact that labor and delivery have on the fetal cardiovascular system.

Commonly, parental counseling is offered to expectant parents by fetal echocardiographers. Hence, fetal echocardiographers must have good communicative skills, a high level of compassion, and a thorough understanding of the prognosis and outcome of CHD in the 21<sup>st</sup> century. This understanding must include knowledge of the most recent developments in surgical correction for complex CHD, and the most current data concerning long-term outcome. The highest standards of ethics are expected, and fetal echocardiographers should be able to deliver information in an objective, non-directive manner.

Physicians performing fetal echocardiography must be skilled in the technical aspects of the examination. The fetal echocardiogram involves imaging in multiple tomographic planes that provide a three-dimensional understanding of fetal cardiac structure, function, and flow. Two-dimensional imaging should be followed by color Doppler imaging and pulsed-, or continuous-wave Doppler imaging of the inflow and outflow portions of the heart, the atrial and ventricular septae, and the venous and arterial structures. Doppler analysis of umbilical cord vessels, which can provide important information concerning placental function, should be included. Observation and analysis of the fetal heart rate and rhythm via Doppler techniques or M-Mode techniques should be performed.

**Training Requirements (Table 22).** Training for fetal echocardiography should take place under the direction of a skilled and dedicated expert in fetal echocardiography. The training center should be one in which a large number of fetal echocardiographic studies are performed and which has a strong integrated relationship with specialists in maternal-fetal medicine. In order to obtain the necessary knowledge base and breadth of understanding of CHD, board certification in, or eligibility for pediatric cardiology should be

**Table 22.** Training Requirements for Performance and Interpretation of Fetal Echocardiography

	Total Number of Examinations to Be Performed and Interpreted	Total Number of Examinations to Be Performed and/or Interpreted or Reviewed
Level 2	25	50
Level 3	100	100

achieved. Familiarization with fetal cardiovascular disease and exposure to the interpretation of fetal echocardiograms take place during fellowship training in pediatric cardiology. This introductory experience (Level 1 competence) may be spread throughout the fellowship training period and should consist of exposure to a variety of fetal echocardiographic cases. Since fetal echocardiography is a complex, specialized form of echocardiographic examination requiring a high level of skill, such minimal exposure does not provide sufficient training to independently perform, or clinically interpret, fetal echocardiograms.

Guidelines for physician training in fetal echocardiography were offered by the Society of Pediatric Echocardiography Committee on Physician Training in 1990 (19). We endorse these recommendations. In order to achieve the minimal skills necessary to independently perform and interpret fetal echocardiograms, advanced training beyond that offered during the standard pediatric cardiology fellowship is necessary. Trainees interested in obtaining these minimal skills (Level 2 competence) should perform and interpret 25 fetal echocardiography cases and participate in the interpretation or review of an additional 25 cases under the supervision of a skilled, dedicated fetal echocardiographer. These cases should include a wide variety of simple and complex CHD, as well as extra-cardiac diseases affecting the fetal cardiovascular system. During this period, trainees should be exposed to multidisciplinary maternal-fetal clinical care conferences and participate in the care and management of the fetus with cardiovascular disease.

In order to achieve sufficient skills and the confidence necessary to perform and interpret fetal echocardiograms independently, assume responsibility for training other physicians, and direct a fetal echocardiography laboratory (Level 3 competence), a supplemental period of time dedicated to fetal echocardiography training beyond the three years of pediatric cardiology fellowship training is recommended. This should be performed under the supervision of a skilled and experienced fetal echocardiographer. During this period of time, trainees should participate in the performance and interpretation of at least 100 fetal echocardiography cases. These cases should include a wide variety of simple and complex CHD as well as extra-cardiac diseases affecting the fetal cardiovascular system. A portion of this training period should be spent in the performance and interpretation of general obstetrical ultrasound examinations in cooperation with maternal-fetal medicine services. Trainees should participate in multidisciplinary maternal-fetal clinical care

**Table 23.** Demonstration and Maintenance of Competence in Fetal Echocardiography

Demonstration of Competence	Maintenance of Competence
Letter or certificate from program training director	Level 2: Performance and/or interpretation/review of 25 cases per year Level 3: Performance and/or interpretation/review of 100 cases per year

ferences and in the care and management of the fetus with cardiovascular disease. Trainees should be encouraged to participate in research endeavors that will enhance the field of fetal cardiovascular disease.

**Proof of Competence (Table 23).** Proof of competency is achieved by a letter or certificate from the program training director or physician responsible for supervising trainees, confirming the time dedicated to training in fetal echocardiography and the number of fetal echocardiograms performed. For individuals who completed training before 1990, documentation of performance and interpretation of a similar number of cases as previously indicated is required, along with documentation of participation in maternal-fetal clinical care conferences in which cases concerning fetal cardiovascular disease were reviewed. There is presently no examination available to test competence in fetal echocardiography.

**Maintenance of Competence (Table 23).** Maintenance of competence in fetal echocardiography should be achieved by continuing activity in performance and interpretation of studies as well as active participation in the care of the fetus with cardiovascular disease. Minimal competence (Level 2) can be maintained by performance and/or interpretation of at least 25 fetal echocardiography cases per year, while those seeking to maintain Level 3 skills should perform and/or interpret a minimum of 100 fetal echocardiography cases per year. Evidence of continued learning and acquisition of new knowledge in the field via attendance at scientific meetings and conferences is required.

### I. Emerging New Technologies

Over the past few years several new technologies or applications for echocardiography have emerged that continue to improve our ability to care for cardiac patients. Because they are new, there has not been sufficient experience with all of them for specialty societies to provide written recommendations regarding training requirements, documentation,

and maintenance of competence. However, it is the consensus of this writing group that, because these new technologies are in current use, this document should provide, in as much as it is possible, a set of recommendations for training requirements and establishment of competence.

**1. Hand-Carried Ultrasound Devices. OVERVIEW AND INDICATIONS FOR THE PROCEDURE.** The era of an “ultrasound-assisted” physical examination has arrived, having been brought about by improvements on an old concept of a “hand-carried ultrasound (HCU) scanner.” A HCU device is defined as a small ultrasound machine (typically less than six pounds), with limited diagnostic capabilities designed for evaluating gross structural or functional abnormalities of the cardiovascular system, which does not fulfill the criteria for a current state-of-the-art limited or comprehensive echocardiographic examination (Table 24).

The ASE has defined the principal use of HCU as a method of extending the accuracy of bedside physical examination (20). The instrument is designed primarily for a “focused” user-specific ultrasound examination. The intent is to appropriately reduce under- and over-utilization of more expensive technology. This definition implies that a state-of-the-art instrument is not always necessary to answer specific pertinent user questions. However, the words, “targeted” and “focused” are often equated with incomplete, inadequate, or inaccurate information, which may lead to inappropriate over- or under-utilization of this and other diagnostic methods or technology. It is the consensus opinion of this writing committee that “extension of the physical examination” should not be interpreted as a license for untrained individuals to use poor imaging techniques that will result in inaccurate diagnosis. The user of an HCU determines which image or information is important to the specific clinical question asked and must take personal responsibility for the quality and use of the obtained information. Consequently, the user should be held ac-

**Table 24.** HCU versus Current State-of-the-Art Echocardiographic Examinations

	Hand-Carried Ultrasound	Limited Examination	Comprehensive Examination
Scope	brief, extension of physical exam	goal-directed, limited	complete
Report	limited, if any	permanent and complete	permanent and complete
Minimum training	Level 1	level 2	level 2-3
ICAEL lab accreditation	N/A	recommended	recommended
Duration of exam	brief, less than 15 min	15-30 min	long, greater than 30 min
Archived image	limited and optional	yes	yes

HCU = hand-carried ultrasound; ICAEL = Intersocietal Commission for the Accreditation of Echocardiography.

countable for appropriate training, application, documentation, and interpretation of HCU data.

**MINIMUM KNOWLEDGE REQUIRED FOR PERFORMANCE AND INTERPRETATION.** Competence in performing and/or interpreting echocardiography using an HCU requires all of the basic knowledge of ultrasound physics, instrumentation, cardiac anatomy, physiology, and pathology described in the sections on General Principles and Adult Transthoracic Examination.

**TRAINING REQUIREMENTS.** Training and credentialing recommendations for physicians performing and interpreting adult TTE have been discussed in detail in Section C. We endorse the ASE recommendations that individuals employing an HCU specifically for cardiovascular education or self-instruction should have at least a basic Level 1 of training, as outlined on Table 5. However, Level 1 training may not be adequate for the independent performance and interpretation of a clinical HCU examination. In this setting, we recommend Level 2 training as defined in Table 5. Individuals with less training must consult directly with an echocardiographer with Level 2 or 3 training. This will safeguard the patients' interests and ensure accurate diagnoses, optimal management, and appropriate use of more expensive comprehensive examinations when necessary.

**PROOF OF COMPETENCE.** Depending on its use (i.e., adult transthoracic, pediatrics, or adult congenital) the user of an HCU is expected to meet the full competence requirements of that specific application.

**MAINTENANCE OF COMPETENCE.** Recommendations for maintenance of competence are identical to those outlined under the specific application, such as transthoracic, pediatric, or adult congenital. Physicians with competence in each of these areas automatically have competence in using an HCU for these applications.

**2. Contrast Echocardiography. OVERVIEW AND INDICATIONS FOR THE PROCEDURE.** Intravenous contrast agents are available for enhancing endocardial border delineation and improving the Doppler signal. The use of contrast with harmonic imaging provides opacification of the left ventricular cavity and improved endocardial border detection. The technique is especially useful in obese patients and those with lung disease. Stress echocardiography examinations can be challenging, and a short acquisition time is essential in delineating regional wall motion abnormalities induced by peak exercise. The use of contrast can improve the ability to obtain diagnostic information and/or increase diagnostic accuracy. The ASE Task Force on Contrast Echocardiography states that "Intravenous contrast agents demonstrate substantial value in the difficult-to-image patient with comorbid conditions that limit an ultrasound evaluation of the heart" (21). Future applications may include the evaluation of myocardial perfusion at rest or during exercise or pharmacologic stress.

**MINIMUM KNOWLEDGE REQUIRED FOR PERFORMANCE AND INTERPRETATION.** Competence in the performance and interpretation of contrast echocardiography requires all of the basic knowledge of ultrasound physics, instrumentation, cardiac anatomy, physiology, and pathology described in the preceding sections. Unique to contrast echocardiography is the need to understand microbubble characteristics and their interactions with cardiac ultrasound, along with the indications and contraindications for various contrast agents.

**TRAINING REQUIREMENTS.** The basic prerequisites for independent competence in echocardiography (Level 2 training) must be met before or during the training experience with contrast. The operator performing contrast echocardiography in conjunction with other special cardiovascular ultrasound examinations, such as stress, perioperative, and TEE, must be in the process of completing or must have completed, the additional subspecialty training credentials recommended in this document.

**PROOF AND MAINTENANCE OF COMPETENCE.** Contrast echocardiography technology is currently evolving, and proof-of-competence and maintenance of competence recommendations have not been established. For now, it is accepted that physicians with Level 2 competence in echocardiography who have learned how to apply contrast agents and interpret contrast-enhanced studies are competent.

**3. Intracoronary and Intracardiac Ultrasound. OVERVIEW AND INDICATIONS FOR THE PROCEDURE.** Intracoronary ultrasound is performed with a miniaturized flexible ultrasound catheter that provides detailed information of the vessel wall (22). The high frequency transducers (e.g., 20 to 40 MHz) enable the acquisition of high-resolution images with limited depth of penetration. Today, this technology is not considered as an alternative to angiography but, rather, a complementary diagnostic technique. The clinical advantages associated with the use of intracoronary ultrasound have not yet been fully established in randomized trials. However, there is increasing evidence from large prospective studies that ultrasound guidance improves the results of catheter-based intracoronary interventions in terms of immediate lumen enlargement, reduced procedure-related complications, and long-term prevention of restenosis (23-25). Although intracoronary ultrasound has become a routinely applied diagnostic technique in interventional cardiology, few attempts have been made to standardize the examination procedure, the definitions, and the format of reporting qualitative and quantitative data. Indications for intracoronary ultrasound in association with coronary interventions include: 1) lesion assessment and selection of treatment; 2) detection and characterization of vascular/plaque calcium; 3) delineation of plaque eccentricity; 4) identification of type of vessel remodeling; and 5) intracoronary guidance during balloon angioplasty, directional atherectomy, and stent placement.

Intracardiac ultrasound catheters are of larger caliber and are suitable for entering larger vessels and fluid-filled cavities (26). This technology has been used to define cardiovascular anatomy, to guide procedures, and to assess the results of interventions. There are currently two catheter-tipped ultrasound transducer technologies: 1) radially arranged piezoelectric elements or rotating element transducers, which generate a two-dimensional radial image; and 2) linear or phased array transducers, which generate a longitudinal two-dimensional image. The intracardiac transducers are of lower frequency (5 to 10 MHz) to enable a greater depth of image penetration into blood or fluid containing cavities and contiguous structures. The phased-array technology also incorporates a full complement of imaging, Doppler, and articulation features.

The use of intracardiac ultrasound has not been fully tested in randomized trials. However, it is reported that this technology can be used to: 1) guide and access the result of an interventional procedure and better visualize cardiovascular anatomy and physiology; 2) reduce radiation exposure; 3) substitute for TEE during interventional procedures; 4) aid in positioning interventional devices; 5) provide echo and Doppler anatomic and hemodynamic information; and 6) direct an atrial septostomy.

**MINIMUM KNOWLEDGE REQUIRED FOR PERFORMANCE AND INTERPRETATION.** There are no currently published standards defining the minimum requirements for performance and interpretation of intracoronary or intracardiac ultrasound. However, similar to other emerging new technologies, competence in performing and/or interpreting the ultrasound examination requires all of the basic knowledge of ultrasound physics, instrumentation, cardiovascular anatomy, physiology, and pathology described in the sections on General Principals and TTE. Physicians performing the examination must also have skills in inserting and manipulating the catheter to obtain the required views and knowledge of normal anatomy and pathology of the structures seen with the ultrasound catheter.

**TRAINING AND COMPETENCE REQUIREMENTS.** Training and competence requirements have not been defined. However, competence will assuredly require a minimum training comparable to Level 2 and a repetitive exposure to the technique consistent with the recommendations for other emerging technologies.

**4. Echo-Directed Pericardiocentesis. OVERVIEW AND INDICATIONS FOR THE PROCEDURE.** Cardiac tamponade is a serious, potentially life threatening, condition that can be clinically challenging from both diagnostic and therapeutic perspectives. Presenting symptoms can be diverse and non-specific (i.e., tachycardia, hypotension, increased jugular venous pressure, pulsus paradoxus) and may therefore be misinterpreted. Two-dimensional and Doppler echocardiography can readily confirm the presence of an effusion and provide accurate assessment of its hemodynamic significance.

Historically the percutaneous pericardiocentesis procedure was essentially "blind," and serious complications were common. The introduction of echo-guided pericardiocentesis has substantially decreased both the major (1.2%) and minor complications (3.5%) of this procedure (27). Echo-guided pericardiocentesis is much less expensive and traumatic than a surgical pericardiocentesis. In addition, the echo-guided approach has resulted in the common use of a pericardial catheter for intermittent drainage, which has further reduced recurrence rates and the need for surgical management of the effusion. Echo-guided pericardiocentesis is considered to be the primary therapy for patients with clinically significant effusions, and it is often the definitive therapy. Success in the relief of tamponade is reported to be 97%, single needle passage provides access to the effusion in 89% of patients.

**MINIMUM KNOWLEDGE REQUIRED FOR PERFORMANCE AND INTERPRETATION.** Competence in performing an echo-directed pericardiocentesis requires a basic knowledge of ultrasound physics, instrumentation, cardiac anatomy, physiology, and pathology as described in the sections on General Principals and TTE. In addition, physicians performing the procedure must have procedural skills in localizing the optimal entry site (i.e., where the fluid is closest to the skin surface), introducing the needle into the pericardial space, passing the guiding wire, and introducing a draining catheter when required.

**TRAINING REQUIREMENTS.** Physicians performing an echo-guided pericardiocentesis must meet established training and credentialing recommendations for performing a state-of-the-art limited or complete echocardiographic examination. Although training requirements have not been formally published, we recommend that trainees have at least a Level 2 echocardiography training and be personally tutored by an experienced Level 2 or 3 echocardiographer in the performance of at least 5 to 10 echo-guided pericardiocenteses.

**MAINTENANCE OF COMPETENCE.** There are no established competence criteria beyond those for adult TTE. However, it is essential to maintain a high level of echocardiographic skill and review the essentials of the echo-guided pericardiocentesis technique frequently.

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## REFERENCES

1. Popp RL, Winters WL, Jr. Clinical competence in adult echocardiography. A statement for physicians from the ACP/ACC/AHA Task Force on Clinical Privileges in Cardiology. *J Am Coll Cardiol* 1990;15:1465-8.
2. 17th Bethesda Conference. Adult cardiology training. November 1-2, 1985. *J Am Coll Cardiol* 1986;7:1191-218.
3. Pearlman AS, Gardin JM, Martin RP, et al. Guidelines for optimal physician training in echocardiography. Recommendations of the American Society of Echocardiography Committee for Physician Training in Echocardiography. *Am J Cardiol* 1987;60:158-63.
4. Beller GA, Bonow RO, Fuster V. ACC revised recommendations for training in adult cardiovascular medicine. Core Cardiology Training II (COCATS 2). (Revision of the 1995 COCATS training statement). *J Am Coll Cardiol* 2002;39:1242-6.
5. Warnes CA, Liberthson R, Danielson GK, et al. Task force 1: the changing profile of congenital heart disease in adult life. *J Am Coll Cardiol* 2001;37:1170-5.
6. Recommendations for continuous quality improvement in echocardiography. American Society of Echocardiography. *J Am Soc Echocardiogr* 1995;8:S1-28.
7. Daniel WG, Erbel R, Kasper W, et al. Safety of transesophageal echocardiography. A multicenter survey of 10,419 examinations. *Circulation* 1991;83:817-21.
8. Pearlman AS, Gardin JM, Martin RP, et al. Guidelines for physician training in transesophageal echocardiography: recommendations of the American Society of Echocardiography Committee for Physician Training in Echocardiography. *J Am Soc Echocardiogr* 1992;5:187-94.
9. Shanewise JS, Cheung AT, Aronson S, et al. ASE/SCA guidelines for performing a comprehensive perioperative multiplane transesophageal echocardiography examination: recommendations of the American Society of Echocardiography Council for Perioperative Echocardiography and the Society of Cardiovascular Anesthesiologists Task Force for Certification in Perioperative Transesophageal Echocardiography. *Anesth Analg* 1999;89:870-84.
10. 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.
11. Cahalan MK, Abel M, Goldman M, et al. American Society of Echocardiography and Society of Cardiovascular Anesthesiologists task force guidelines for training in perioperative echocardiography. *Anesth Analg* 2002;94:1384-8.
12. Rodgers GP, Ayanian JZ, Balady G, et al. American College of Cardiology/American Heart Association Clinical Competence statement on stress testing: 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 Coll Cardiol* 2000;36:1441-53.
13. Armstrong WF, Pellikka PA, Ryan T, Crouse L, Zoghbi WA. Stress echocardiography: recommendations for performance and interpretation of stress echocardiography. Stress Echocardiography Task Force of the Nomenclature and Standards Committee of the American Society of Echocardiography. *J Am Soc Echocardiogr* 1998;11:97-104.
14. Popp R, Agatston A, Armstrong W, et al. Recommendations for training in performance and interpretation of stress echocardiography. Committee on Physician Training and Education of the American Society of Echocardiography. *J Am Soc Echocardiogr* 1998;11:95-6.
15. Webb GD, Williams RG. Care of the adult with congenital heart disease: introduction. *J Am Coll Cardiol* 2001;37:1166.
16. Child JS, Collins-Nakai RL, Alpert JS, et al. Task force 3: workforce description and educational requirements for the care of adults with congenital heart disease. *J Am Coll Cardiol* 2001;37:1183-7.
17. Kumar RK, Newburger JW, Gauvreau K, Kamenir SA, Hornberger LK. Comparison of outcome when hypoplastic left heart syndrome and transposition of the great arteries are diagnosed prenatally versus when diagnosis of these two conditions is made only postnatally. *Am J Cardiol* 1999;83:1649-53.
18. Tworetzky W, McElhinney DB, Reddy VM, Brook MM, Hanley FL, Silverman NH. Improved surgical outcome after fetal diagnosis of hypoplastic left heart syndrome. *Circulation* 2001;103:1269-73.
19. Meyer RA, Hagler D, Huhta J, et al. Guidelines for physician training in fetal echocardiography: recommendations of the Society of Pediatric Echocardiography Committee on Physician Training. *J Am Soc Echocardiogr* 1990;3:1-3.
20. Seward JB, Douglas PS, Erbel R, et al. Hand-carried cardiac ultrasound (HCU) device: recommendations regarding new technology. A report from the echocardiography task force on new technology of the nomenclature and standards committee of the American Society of Echocardiography. *J Am Soc Echocardiogr* 2002;15:369-73.
21. Mulvagh SL, DeMaria AN, Feinstein SB, et al. Contrast echocardiography: current and future applications. *J Am Soc Echocardiogr* 2000;13:331-42.
22. Di Mario C, Gorge G, Peters R, et al. Clinical application and image interpretation in intracoronary ultrasound. Study Group on Intracoronary Imaging of the Working Group of Coronary Circulation and of the Subgroup on Intravascular Ultrasound of the Working Group of Echocardiography of the European Society of Cardiology. *Eur Heart J* 1998;19:207-29.
23. Frey AW, Hodgson JM, Muller C, Bestehorn HP, Roskamm H. Ultrasound-guided strategy for provisional stenting with focal balloon combination catheter: results from the randomized Strategy for Intracoronary Ultrasound-guided PTCA and Stenting (SIPS) trial. *Circulation* 2000;102:2497-502.
24. Haude M, Baumgart D, Verna E, et al. Intracoronary Doppler- and quantitative coronary angiography-derived predictors of major adverse cardiac events after stent implantation. *Circulation* 2001;103:1212-7.
25. Ahmed JM, Mintz GS, Waksman R, et al. Serial intravascular ultrasound assessment of the efficacy of intracoronary gamma-radiation therapy for preventing recurrence in very long, diffuse, in-stent restenosis lesions. *Circulation* 2001;104:856-9.
26. Mintz GS, Nissen SE, Anderson WD, et al. American College of Cardiology Clinical Expert Consensus Document on Standards for Acquisition, Measurement and Reporting of Intravascular Ultrasound Studies (IVUS). A report of the American College of Cardiology Task Force on Clinical Expert Consensus Documents. *J Am Coll Cardiol* 2001;37:1478-92.
27. Tsang TS, Freeman WK, Sinak LJ, Seward JB. Echocardiographically guided pericardiocentesis: evolution and state-of-the-art technique. *Mayo Clin Proc* 1998;73:647-52.