GUIDELINES AND STANDARDS

Recommendations for Special Competency in Echocardiographic Guidance of Structural Heart Disease Interventions: From the American Society of Echocardiography

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Transcatheter therapies for structural heart disease continue to grow at a rapid pace, and echocardiography is the primary imaging modality used to support such procedures. Transesophageal echocardiographic guidance of structural heart disease procedures must be performed by highly skilled echocardiographers who can provide rapid, accurate, and high-quality image acquisition and interpretation in real time. Training standards are needed to ensure that interventional echocardiographers have the necessary expertise to perform this complex task. This document provides guidance on all critical aspects of training for cardiology and anesthesiology trainees and postgraduate echocardiographers who plan to specialize in interventional echocardiography. Core competencies common to all transcatheter therapies are reviewed in addition to competencies for each specific transcatheter procedure. A core principle is that the length of interventional echocardiography training or achieved procedure volumes are less important than the demonstration of procedure-specific competencies within the milestone domains of knowledge, skill, and communication. (J Am Soc Echocardiogr 2023;36:350-65.)

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Abbreviations

2D = Two-dimensional

3D = Three-dimensional

ACC = American College of Cardiology

ACGME = Accreditation Council for Graduate Medical Education

AHA = American Heart Association

ASE = American Society of Echocardiography

ATS = Advanced Training Statements

CCT = Cardiac computed tomography

COCATS = Core Cardiovascular Training Statements

CS = Conscious sedation

IAS = Interatrial septum

ICE = Intracardiac echocardiography

IE = Interventional echocardiography

LAA = Left atrial appendage

LVOT = Left ventricular outflow tract

MPR = Multiplanar reconstruction

MR = Mitral regurgitation

NBE = National Board of Echocardiography

PDL = Peridevice leak

PFO = Patent foramen ovale

PVL = Paravalvular leak

SHD = Structural heart disease

TAVR = Transcatheter aortic valve replacement

TEE = Transesophageal echocardiography

TEER = Transcatheter edge-to-edge repair

THV = Transcatheter heart valve

TTE = Transthoracic echocardiography

ViR = Valve-in-ring

ViV = Valve-in-valve

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As the field of transcatheter therapy for structural heart disease (SHD) continues to mature, the imaging discipline of interventional echocardiography (IE) also continues to evolve. IE is an emerging specialty that requires a specific set of skills to support an array of transcatheter therapies. IE is unique compared with most standard echocardiographic techniques, as imaging is performed and interpreted in real time; is highly dependent on three-dimensional (3D) and nonstandard views; has immediate and profound implications for patient management; and requires candid, accurate, and timely communication with other members of the multidisciplinary SHD team. In the new era of heart team–based decision-making, rapid clinical adoption of US Food and Drug Administration–approved devices, and multimodality imaging, the demand for competent interventional echocardiographers has steadily increased. This document discusses consensus recommendations for specific knowledge, experience, and skills to be learned and demonstrated within an IE training program or during postgraduate training.

The introduction to echocardiography is usually achieved within a formal training program in adult cardiology, pediatric cardiology, or anesthesiology. The Accreditation Council for Graduate Medical Education (ACGME) is the primary regulatory body for such programs. In collaboration with the American College of Cardiology (ACC), specific learning goals have been developed as Core Cardiovascular Training Statements (COCATS) for adult cardiovascular disease training programs.[1] Such documents define the learning objectives, time commitment, and case volume generally required to achieve competency as an echocardiographer. COCATS 4 (Task Force 5) is an important document that explicitly addresses training in echocardiography within core cardiovascular training programs and defines required competencies as follows: level I (introductory experience), level II (independent interpretation of transthoracic studies), and level III (perform and interpret complex studies, lead a research program, train others in advanced echocardiography).[2]

In addition, Advanced Training Statements (ATS) have also been developed by the ACC, American Heart Association (AHA), and the American Society of Echocardiography (ASE) to describe skills and expected competencies in defined subspecialty areas of cardiology. The most recent ATS on echocardiography identified specific competencies for level III echocardiography training that go beyond what is expected of core cardiology trainees.[3] If a trainee was able to devote all available elective time to echocardiography and gain the needed experience within the 3-year core fellowship, there was an avenue to achieve such advanced echocardiography training within the core fellowship. Additional dedicated training was required for most individuals seeking to acquire specialized procedural skills.

Although the competencies defined by COCATS do not directly apply to the ACGME's expectations for training in perioperative echocardiography, a graduate from an adult cardiothoracic anesthesiology fellowship program will have reached level II competency in the independent interpretation of perioperative transesophageal echocardiographic studies. In fact, the ACGME expects trainees in adult cardiothoracic anesthesiology to meet the requirements of certification by the National Board of Echocardiography (NBE) for special competence in advanced perioperative transesophageal echocardiography (TEE).[4]

WHY THIS DOCUMENT IS NEEDED

Because the field of IE has evolved so rapidly, additional efforts have been made to further refine the level III competencies and training elements required for those individuals undergoing training to become interventional echocardiographers. Recognizing that IE is not yet performed at all echocardiography training institutions, an expert consensus group proposed a collection of SHD competencies within the level III training framework as an aid to both laboratory directors and physicians seeking advanced training in the performance of IE.[5] Importantly, the nomenclature of level III IE was adopted to denote demonstrated special competency in specific SHD procedures. The proposed training scheme and our additional recommendations are depicted in Figure 1.

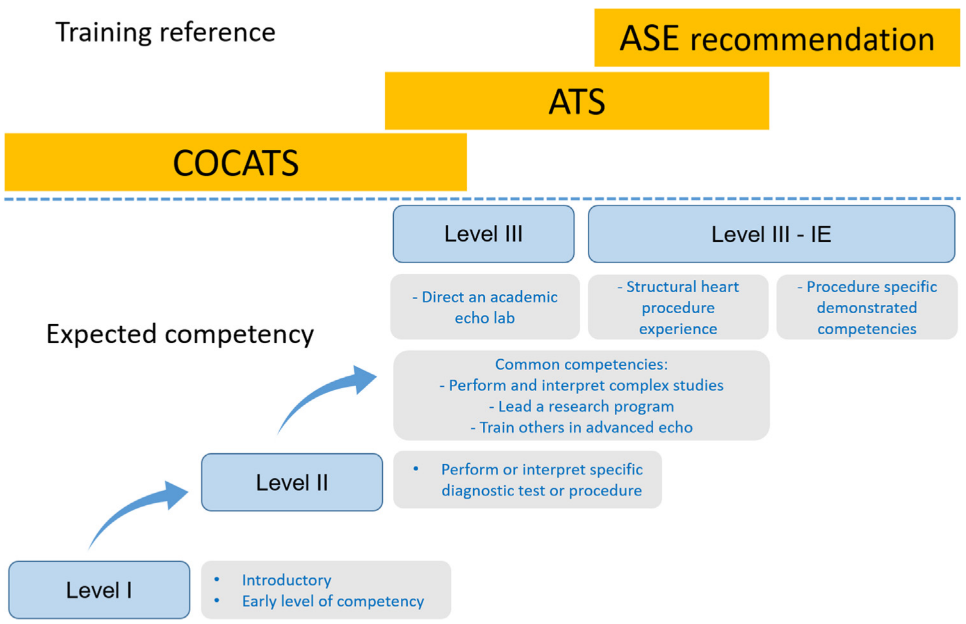


Figure 1 Cardiology training references and expected competencies in echocardiography. Modified from Hahn *et al*.[5]

In creating specific recommendations for the elements of training, one challenge is the heterogeneity in procedure volume across the United States. The potential for trainees to gain exposure to SHD procedures is highly dependent upon the breadth and depth of the institutional SHD program. Currently, there are approximately 272 ACGME-approved cardiology training programs and 80 ACGME-approved adult cardiothoracic anesthesiology training programs.[4] However, there are more than 500 US hospitals with transcatheter aortic valve replacement (TAVR) programs, mitral transcatheter edge-to-edge repair (TEER) programs, or both. A much smaller number of institutions are involved in clinical trials for investigational SHD procedures. In short, not every ACGME training site has a robust SHD program, and not every SHD program has ACGME trainees. The aforementioned challenges are outlined in Figure 2.

INTENDED AUDIENCE (TRAINEES AND EDUCATORS)

IE is an emerging subspecialty within the broad disciplines of cardiology and anesthesiology. This new field of expertise requires advanced skills in performing and interpreting both transthoracic echocardiographic and TEE studies, as well as guiding interventional procedures. The 2019 ACC/AHA/ASE ATS on echocardiography[3] highlights several competencies that a level III echocardiographer should obtain. Importantly, that document offers clear recommendations for training requirements within the six general competencies defined by the ACGME. These domains of competency include medical knowledge, patient care and procedure skills, practice-based learning and improvement, systems-based practice, interpersonal and communication skills, and professionalism.

The purpose of this new document is to supplement the ATS on echocardiography with recommendations for general and procedure-specific competencies within the domains of medical knowledge, procedure skills, and communication skills as a guide to both trainees and trainers in the emerging field of IE. For the trainee interested in this subspecialty, the level III IE training pathway could diverge from the traditional pathway after level II training is achieved. Level III IE minimum procedural numbers do not differ significantly from those of the traditional level III; however, the emphasis on imaging for valvular heart disease and SHD interventions distinguishes this training from the traditional level III pathway. For practitioners out of training, this document serves as a guide to the appropriate practice-based experience that would be expected to achieve independent competency within IE.

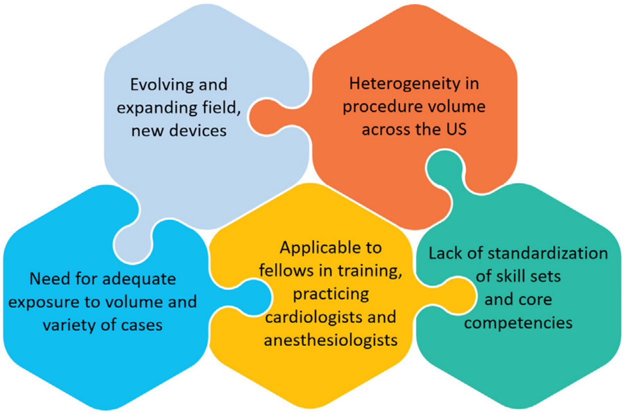


Figure 2 The challenges of training for IE.

REQUIREMENTS OF THE INSTITUTION PROVIDING IE LEVEL III IE TRAINING

The criteria for the facilities providing level III training are discussed in the ATS on echocardiography.[3] In addition to these criteria, institutions providing level III IE training are required to have an established heart valve team structure with sufficient volume, expertise, and complexity of SHD cases to provide a robust IE training experience.

Table 1 Elements of institutional support for IE training for fellows

• ACGME-accredited general cardiovascular and/or cardiothoracic anesthesiology training programs (or international equivalent) that provide exposure to a broad spectrum of patient populations and cardiovascular pathology
• Support of a multidisciplinary valve team (including but not limited to cardiac surgeon, interventional cardiologist, imaging specialist, clinical cardiologists, heart failure specialist, cardiothoracic anesthesiologist, valve coordinator) with regularly scheduled multidisciplinary heart team conferences
• Full range of diagnostic and therapeutic facilities, including ambulatory clinic, cardiac surgery operating room, cardiac catheterization laboratory, IAC-accredited (or equivalent) echocardiography laboratory or perioperative echocardiography service, CCT, vascular laboratory, CMR, and postprocedural recovery facilities
• Cardiothoracic surgery program and interventional cardiology program with appropriate procedural range and volume to support structural heart procedures[8]
• Administrative support to monitor performance and benchmark measures and ensure participation in the NCDR
• Up-to-date echocardiography equipment that allows advanced imaging capabilities, including 3D echocardiography acquisition, postprocessing, and image storage capabilities in an up-to-date PACS
• Cardiology or cardiothoracic anesthesiology faculty members capable of performing and teaching advanced echocardiographic imaging for structural cases*
• Adequate radiation safety training and protective equipment

CCT, Cardiac computed tomography; *CMR*, Cardiac magnetic resonance; *IAC*, Intersocietal Accreditation Commission; *NCDR*, National Cardiovascular Data Registry; *PACS*, picture archiving and communication system.

*Faculty members should be level III trained (or international equivalent) and have achieved NBE testamur status (or international equivalent).

Faculty members responsible for teaching and supervising trainees should have attained level III or equivalent training and maintain certification in subspecialty board examinations or equivalent as well as NBE certification. Faculty members should have achieved a level of expertise that would allow them to effectively teach case selection and procedural planning, intraprocedural guidance, recognition of complications, postprocedural follow-up, and determination of structural valve dysfunction, as well as to assess trainee competence. In general, faculty members should have previously performed the minimum requisite type and number of SHD cases that are included in this document as training requirements in level III IE and maintained the suggested yearly study volumes. Because this is an evolving field, continuing education after training is required for both faculty members and trainees.

Radiation safety is of the utmost importance during SHD cases, particularly because numerous studies have now documented the high radiation exposure of the IE.[6,7] IE trainees and faculty members should receive the appropriate radiation safety training in order to apply the "as low as reasonably achievable" principle and be provided with a lead apron with a minimum lead equivalency of 0.25 mm at the back and 0.5 mm in the front, along with a thyroid lead collar and lead goggles. All interventional echocardiographers should be provided with a direct ion storage dosimeter, which should be regularly monitored and reported. Additional shielding with a lead acrylic shield with 0.5-mm lead equivalency should be available that can either be ceiling suspended or a mobile one that can be repositioned on the ground. This has been shown to significantly decrease radiation exposure to the echocardiographer.[7]

The specific elements of institutional support for IE training are outlined in Table 1 and in Figure 3.

ENTRY REQUIREMENTS FOR TRAINING

The trainee seeking special competency in IE should either have completed a 3-year general cardiology fellowship (or equivalent if trained outside of the United States) or 12 months of a clinical fellowship in adult cardiothoracic anesthesiology before starting IE training.[4] Additionally, the cardiology trainee should meet the minimum procedural volume required to achieve COCATS level II competency in adult echocardiography and be eligible or have achieved NBE testamur status (or international equivalent).[2] Cardiothoracic anesthesiology fellows are expected to meet the requirements for board certification by the NBE for special competence in advanced perioperative TEE. The training requirement of the NBE for cardiothoracic anesthesiology fellows includes 300 complete perioperative transesophageal echocardiographic examinations, of which 150 comprehensive examinations must be personally performed, interpreted, and reported by the trainee.[9] Criteria are outlined in Table 2.

Because IE is a relatively new field with few dedicated non-ACGME IE training programs, many cardiologists and anesthesiologists will follow a postgraduate "practice experience" pathway of training. The prerequisites of IE training for experienced cardiologists and anesthesiologists who plan to receive on-the-job IE training are outlined in Tables 3 and 4.

Table 5 contains the minimum procedural volumes necessary for standard level III competence. The minimum procedural volumes given are based on consensus opinion. It should be emphasized that demonstrated procedural proficiency and outcomes, rather than length of exposure or the number of procedures performed, are the dominant requirements for advancement of the trainee. In addition, the recommended procedural volumes should be considered a minimum procedure exposure because additional volume and experience may be required for more complex interventions.[5] Table 5 also lists the minimum procedural volume expectation for stress echocardiography because this is an integral component of the ATS on echocardiography, and special training is required for the performance of stress echocardiography for the assessment of valvular heart disease.

Additional prerequisite knowledge-based competencies for trainees receiving IE training in a dedicated fellowship or practice experience are noted in Table 6.

DURATION OF TRAINING

Because there are various pathways available to achieve training in IE, flexibility in the amount of training time is needed. Figure 4 depicts training pathways to achieve SHD imaging competency. Infrequently, a training institution might have the procedure volume and teaching expertise to allow some trainees to gain significant IE

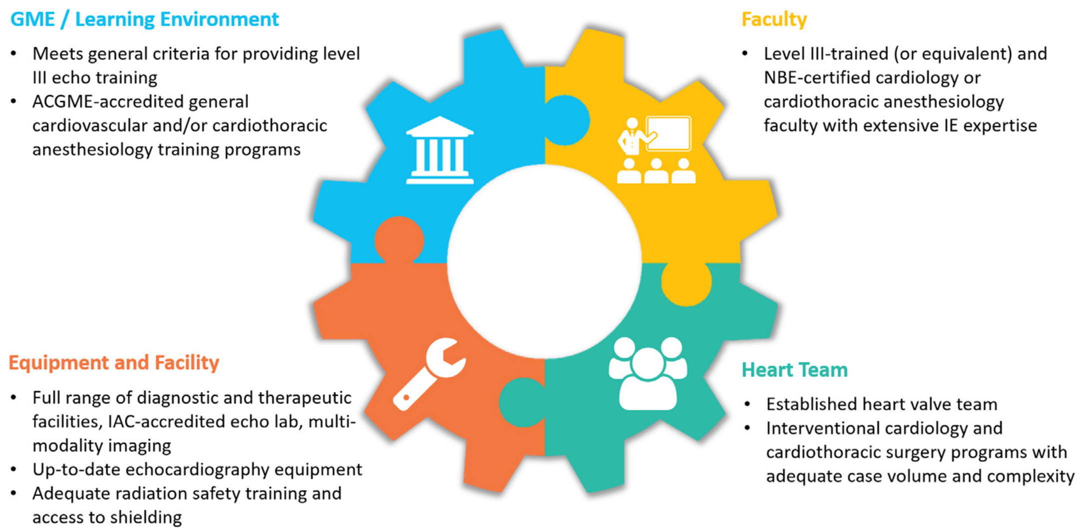


Figure 3 Required components of an IE training program. *GME*, Graduate medical education; *IAC*, Intersocietal Accreditation Commission.

experience during core cardiology or cardiothoracic anesthesiology fellowships; however, significant additional dedicated training time will be required. The recommended IE training pathway for cardiology trainees is to undergo an additional 9 to 12 months of advanced echocardiography training, irrespective of whether level II or level III training is achieved in the core cardiology training program. The recommended IE training pathway for cardiothoracic anesthesiology trainees includes active participation in ≥75 structural heart cases, of which ≥40 must be personally performed, while the remainder may be interpreted with a supervising echocardiographer to meet the requirement of a total of 75 examinations.[5] It is anticipated that these requirements will not be achieved during a regular adult ACGME-accredited cardiothoracic anesthesiology fellowship and that an additional minimal SHD-focused training period of 6 months is necessary to achieve these numbers.

Cardiologists or anesthesiologists posttraining with extensive prior imaging experience (e.g., >150 complex transesophageal echocardiographic studies performed) may demonstrate IE competencies faster than less experienced trainees. However, the competency milestones are the same for all trainees. The milestone intervals provided indicate the timing of advancement by which a typical trainee will have demonstrated specific required competencies. A core principle of each training program is that program duration and achieved procedure numbers are less important than demonstrated competency in the procedure-specific IE competencies within the milestone domains of knowledge, skill, and communication.

Table 2 Prerequisites for trainees entering a dedicated IE training program

• Completion of an ACGME-accredited cardiology or adult cardiothoracic anesthesiology fellowship (or equivalent if trained outside the United States)
• Cardiology or anesthesiology board eligibility or certification (or equivalent if trained outside the United States)
• NBE eligibility or testamur status (or international equivalent)
• Cardiology: minimum procedural volume required to achieve COCATS level II competency in adult echocardiography
• Anesthesiology: minimum procedural volume required for board certification by the NBE for special competence in advanced perioperative TEE for anesthesiologists

CORE COMPETENCIES OF IE TRAINING

At the completion of training, core competencies specific to IE should be achieved. These include general medical and procedural knowledge specific to all SHD cases as well as mastery of skills pertaining to specific SHD interventions. By the end of training, trainees should achieve expertise in advanced TEE of complex cardiac disorders before, during, and after SHD interventions. This includes expertise with intraprocedural, live 3D imaging, manipulation of 3D images, use of 3D color Doppler, and multiplane cropping. General core competencies and skills are listed in Table 7. The use of intracardiac echocardiography (ICE) to guide SHD interventions is evolving. At present, the interventional echocardiographer should be familiar with two-dimensional (2D) and 3D intracardiac echocardiographic images, especially to compare images of pathoanatomy or devices with those acquired on transthoracic echocardiography (TTE) and TEE. Training guidelines to acquire specific competencies in the performance of ICE for SHD procedural guidance have not yet been defined.

Table 3 IE prerequisites for cardiologists receiving practice experience training after fellowship

• Completion of ACGME-accredited cardiology fellowship and specialty board certification (or international equivalent)
• NBE testamur status (or international equivalent)
• Demonstration of performance and interpretation of ≥50 transesophageal echocardiograms[10] per year for 2 of the 3 years immediately preceding IE training

Table 4 Prerequisites for anesthesiologists receiving practice experience in IE training after fellowship

- Completion of ACGME-accredited adult cardiothoracic anesthesiology fellowship and specialty board certification (or equivalent if trained outside the United States)
- Examination of Special Competence in (Advanced Perioperative Transesophageal Echocardiography [Advanced PTEeXAM]) testamur status or international equivalent
- Applicants must have performed and interpreted ≥50 perioperative transesophageal echocardiograms per year in 2 of the 3 years immediately preceding IE training

MINIMAL PROCEDURAL VOLUME FOR COMPETENCY IN IE

There are no data that relay the optimal number of procedures needed for an interventional echocardiographer to gain expertise in SHD imaging. This is due in part to the rapidly evolving nature of the field, with new devices and imaging technology constantly emerging. The minimal procedural volumes for level III IE competency are suggested in the ATS document and are reproduced in Table 8. It is emphasized that this table represents the minimal numbers of procedures in each type of SHD intervention. Additional numbers of supervised procedures are likely needed for complex cases and novel devices.

MINIMUM COMPETENCIES FOR SPECIFIC SHD PROCEDURES

Transseptal Puncture

Transseptal puncture of the interatrial septum (IAS) is an essential step in all transvenous percutaneous procedures requiring access to the left heart, including percutaneous left atrial appendage (LAA) closure, mitral balloon valvuloplasty, mitral TEER, and replacement of native mitral valve, as well as implantation of transcatheter valves inside failed surgical annuloplasty rings or bioprostheses.[15,16] Minimum medical knowledge and procedural skills competencies for transseptal puncture are summarized in Table 9.

Intraprocedural imaging guidance by an interventional echocardiographer is indispensable in ensuring a safe transseptal puncture at a septal location specific for each percutaneous procedure in the left heart.[17,18] A trainee in IE should gain expertise and proficiency in the following aspects of transseptal puncture.

Knowledge of the Interatrial Septal Anatomy and Surrounding Structures. Trainees should be familiar with the display of normal interatrial septal anatomy using 2D and 3D echocardiography, including the location of the fossa ovalis, patent foramen ovale (PFO), and their relationships to surrounding structures.[11,18] Additionally, knowledge about common variants and abnormalities of the IAS and associated structures—including atrial septal aneurysm, lipomatous atrial septal hypertrophy, Eustachian valve, and Chiari network—is essential.

Visualization of the IAS in Multiple Imaging Windows. Typically, the IAS is imaged using 2D and 3D TEE in at least three midesophageal views: (1) a four-chamber view focused on the IAS (posterosuperior and atrioventricular valve interatrial septal anatomy), (2) an inflow-outflow view (posteroinferior and anterosuperior interatrial septum anatomy), and (3) a bicaval view (inferior vena cava and superior vena cava interatrial septal anatomy). These views, each obtained sequentially with about 60° to 90° of mechanical rotation, may be viewed as a single plane image or preferably in a simultaneous biplane view.[11] Trainees should also be familiar with the corresponding fluoroscopic views of the IAS.

Identification of Procedure-Specific Location of Transseptal Puncture. A trainee should recognize that transseptal puncture is typically performed only in the region of the fossa ovalis and avoids, whenever possible, surrounding structures, such as epicardial adipose tissue.[11,19] Performing a transseptal puncture through this region of adipose tissue may result in tamponade as blood may enter the pericardial space through either a right or left atrial puncture. Because the goal of the transseptal puncture is to optimize the positioning of the device for a specific target, different transseptal positions are used for different procedures, devices, and patient-specific pathology. Examples of procedure-specific location of transseptal puncture include an inferior and mid to posterior fossa ovalis location for

Table 5 Minimum procedural volume typically necessary for development of level III echocardiography competencies[3]

Type of procedure	Number performed	Change beyond level
TTE, performed	150	Represents no change beyond level II
TTE, interpreted	750	Represents an additional 450 studies beyond level II
TEE, performed and interpreted	150*	Represents an additional 100 studies beyond level II
3D echocardiography		
For valve disease, rendering/image manipulation	50 (TEE or TTE)	
For ventricular volumes, function, ejection fraction	50 (TTE)	
Contrast echocardiography	100 (TTE)	
Strain and strain rate quantification	50	
Stress echocardiography: includes 50 studies for noncoronary indications, of which 25 should be to assess severity of valvular disease	200	Represents an additional 100 studies beyond level II

*TEE performed for IE training should consist of studies to evaluate complex structural disease, including severe single or multivalvular heart disease, screening, and/or guidance of structural heart cases.

Table 6 Prerequisite general competencies of the IE trainee

• Know the basic principles of echocardiography, physics, artifacts, and best practices for image optimization for both 2D and 3D echocardiography
• Know the use of 2D and 3D and Doppler echocardiography to evaluate native and prosthetic valve disease, basic adult congenital heart disease (including atrial and ventricular septal defects), and imaging of LAA
• Know the standard views included in a comprehensive TEE for SHD assessment[11]
• Skill to independently perform comprehensive diagnostic or perioperative 2D, 3D, and Doppler TEE[12,13]
• Skill to independently perform 3D transesophageal echocardiographic image acquisition, cropping, and postprocessing[14]
• Skill to identify the potential complications of and how to manage them[12]
• Skill to effectively communicate detailed information on cardiac anatomy periprocedurally and intraprocedurally in addition to collaborating in interdisciplinary cardiovascular care teams

percutaneous LAA closure or posterior and mid to superior location for percutaneous mitral edge-to-edge repair.[16]

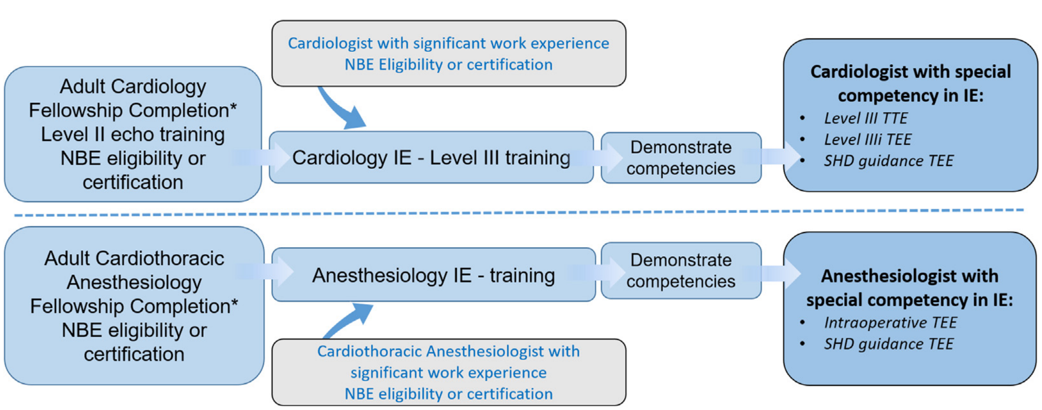
Visualization of Septal Tenting. For transseptal puncture, interventionalists use a needle concealed inside a catheter advanced transvenously into the right atrium. The catheter is positioned at the desired location on the right atrial aspect of the septum, visualized using echocardiography. The catheter is then advanced to stretch the IAS toward the left atrium to create septal tenting. Expertise in recognizing the proper location and the extent of septal tenting, as well as proficiency in visualizing the subsequent steps of transseptal puncture, is required.

Recognition of Transseptal Puncture Complications. A trainee should gain proficiency in monitoring for and recognizing procedural complications, including hemorrhagic pericardial effusion and puncturing of surrounding structures such as the aorta.

Mitral Procedures

The current ACC/AHA guideline for the management of patients with valvular heart disease[20] gives mitral TEER repair a class IIa level of recommendation for patients at high surgical risk with primary mitral regurgitation (MR) and patients with secondary MR who fulfill the COAPT (Cardiovascular Outcomes Assessment of the MitraClip Percutaneous Therapy for Heart Failure Patients With Functional Mitral Regurgitation) trial criteria.[21] This procedure has become an essential treatment option for patients with both primary and secondary MR but with different indications for each classification of disease as well as different anatomic criteria for device suitability. Thus, the medical knowledge essential to the determination of appropriateness of TEER therapy is to know the morphologic differences that define the major classification of mitral valve pathology into primary and secondary disease. This also requires an understanding of the Carpentier classification of leaflet mobility, which falls into these major classifications.[22] Primary disease includes Carpentier type I (i.e., perforation or cleft or indentations of a leaflet), type II (i.e., excessive motion of the margin of a leaflet segment above the annular plane), and type IIIa (i.e., both diastolic and systolic restriction of leaflet mobility as with rheumatic disease). Secondary disease includes Carpentier type I (i.e., annular dilatation, also known as atrial functional MR) and type IIIb (i.e., systolic restriction of leaflet motion, also known as ventricular functional MR).

The appropriateness of various devices for specific patients may depend on both disease classification as well as leaflet morphology. In addition to quantification of disease severity, TEE is the imaging modality of choice for determining anatomic suitability for TEER device implantation[20] as well as procedural guidance.[23-25] As with other SHD, 3D TEE is useful for defining complex mitral anatomy[26-28] as well as MR severity[29,30] and is particularly useful for the procedural planning of both surgical and transcatheter devices.[13,31] For TEER device therapy, preprocedural cardiac computed tomography (CCT) is not required.[32] However, for therapies involving direct or indirect annular repair, or transcatheter valve replacement, preprocedural imaging with CCT is essential.[33] The interventional echocardiographer should thus understand the correlation between cardiac computed tomographic and echocardiographic assessment of device approach (i.e., transapical or transseptal) and anchoring (i.e., coronary sinus, annulus, ventricle, or atrium), mitral annular size, left atrial and ventricular size and



**ACGME or international equivalent*

Figure 4 Training pathways to achieve level III IE competency.

Table 7 Medical knowledge and procedural skills competency components for level III IE training: common to all procedures

Medical knowledge

- Know the comprehensive anatomy of the structure being treated and its relationship to surrounding structures
- Know standard and nonstandard imaging with TTE and TEE of native and prosthetic valve disease, LAA, and basic congenital lesions before, during, and after SHD interventions
- Know the limitations and advantages of 3D vs 2D echocardiographic imaging for SHD assessment and procedural guidance
- Know the physical characteristics, sizing requirements, and expected functional characteristics of available surgical and percutaneous devices
- Know the indications, contraindications, and complications for each device procedure
- Know the strengths and limitations of each type of noninvasive imaging (i.e., echocardiography, CCT, and CMR) for assessing cardiac structure and function (i.e., valves, chambers, septa, and appendage)
- Know the intraprocedural imaging protocols for device implantation, including the assessment of postdevice technical success and evaluation of complications
- Know the postprocedural imaging protocols required to assess the structure and function of each device
- Know the strengths, limitations, and correlation of invasive and noninvasive assessment of native and postdevice valve function
- Know the fluoroscopic landmarks in relation to transesophageal echocardiography imaging landmarks
- Know when to use alternative intraprocedural imaging modalities, including but not limited to fusion imaging and ICE
- Know the fundamentals of radiation safety and the ALARA principle and the methods of reducing radiation exposure
- Know when TEE for SHD is contraindicated and the clinical and patient-specific factors that may increase the risk for a complication

Procedure skills

- Skill to appropriately apply the use of 2D and 3D imaging and Doppler hemodynamics, as well as 3D MPR, for preprocedural assessment of SHD
- Skill to appropriately and expeditiously apply the use of 2D and 3D imaging and Doppler hemodynamics, as well as 3D MPR, for intraprocedural guidance
- Skill to anticipate the procedural steps for device implantation and appropriately image moving wires, catheters, and devices during procedures
- Skill to assess postdevice technical success and procedural complications
- Skill to communicate effectively and guide the interventionalist for the safe and precise implantation of devices
- Skill to implement radiation safety measures and ergonomic considerations
- Skill to adopt new and emerging imaging technologies

ALARA, As low as reasonably achievable.

function, and risk for complications (i.e., valve embolization, paravalvular regurgitation, circumflex coronary artery occlusion or left ventricular outflow tract [LVOT] obstruction).

Intraprocedural guidance for mitral valve interventions requires a comprehensive understanding of each device approach and anchoring mechanism. For all transfemoral venous approaches, an extensive understanding of the anatomy of the IAS is a prerequisite and is discussed in another section. The use of 3D multiplanar reconstruction (MPR) or echocardiography-fluoroscopy fusion for precise transseptal positioning should be considered.[34] For device implantation, 3D modalities of biplane (simultaneous multiplane) imaging, as well as live 3D MPR, can not only improve technical success but shorten procedure times.

Because of the procedural skills necessary to appropriately guide transcatheter mitral valve device implantation, additional training and competence assessment are required. The recent Centers for Medicare and Medicaid Services national coverage decision memo for transcatheter mitral valve repair[35] states that a qualified interventional cardiologist should have professional experience of ≥50 career SHD procedures or ≥30 left-sided structural procedures per year with participation in ≥20 career transseptal interventions, including 10 as primary or coprimary operator. The final 2021 Centers for Medicare and Medicaid Services national coverage decision memo for TEER states that the interventional echocardiographer should have professional experience of ≥10 transseptal guidance procedures and ≥30 structural heart procedures.[35] Whereas operator and institutional experience in mitral TEER is evidence based,[36,37] the case requirements for the interventional

Table 8 Minimum procedural volume typically necessary for the development and demonstration of level III IE[3]

Procedure/technical skill	Number*
Echocardiographic guidance of interventional procedures,† which include	75
Structural valvular interventions‡	30
Transseptal catheterization guidance	10
Percutaneous closure of septal defects and perivalvular leaks	15
Alcohol septal ablation	10
Placement of devices to exclude the LAA	10
Intraoperative TEE, which includes	75
Surgical valve repair or replacement	50
Ventricular assist device placement and assessment	20
ICE	10

*Numbers are based on consensus; are intended as general guidance, on the basis of the educational needs and progress of typical level III echocardiography trainees; and represent the cumulative experience that may occur at any time during training. Competency to perform each procedure must be based on evaluation by the supervising echocardiography laboratory director and may exceed or be below the threshold number shown in this table.

†The experience represented by these numbers must include exposure to a broad range of adult patient ages, pathologies, modalities, and therapies, including complex congenital heart disease, mechanical circulatory support devices and transplantation, ultrasound enhancing agents, and 3D and speckle -racking to achieve the competencies outlined in the competency components and curricular milestones for level III training in echocardiography. Additional training may occur at centers with high volumes of complex congenital heart disease or mechanical assist devices and transplantation to achieve the outlined competencies.

‡The range of experience must include exposure to a broad range of indications, settings, and pathologies, inclusive of operative and intraprocedural studies and the use of 3D echocardiography to achieve the competencies outlined in the competency components and curricular milestones for level III training in echocardiography.

Table 9 Medical knowledge and procedural skills competency components for level III IE training: transseptal puncture

Medical knowledge
• Know the interatrial septal anatomy, including the location of the fossa ovalis, PFO, and their relationships to surrounding structures
• Know common variants and abnormalities of the IAS and associated structures, including atrial septal aneurysm, lipomatous atrial hypertrophy, Eustachian valve, and Chiari network
• Know the ideal sites of transseptal puncture for specific devices and procedures
Procedure skills
• Skill to visualize the IAS using 2D and 3D echocardiography during all phases of the transseptal puncture
• Skill to guide the transseptal puncture in the location of the fossa ovalis that is specific to the type of percutaneous procedure, device used, and location of pathology

Table 10 Medical knowledge and procedural skills competency components for level III IE training: transcatheter mitral valve interventions

Medical knowledge
• Know the anatomy of the mitral valve and adjacent structures
• Know the mechanisms of mitral valve disease and morphologic differences that define primary and secondary MR
• Know the comprehensive echocardiographic evaluation (TTE, TEE, 3D echocardiography, and 3D MPR) of mitral valve disease, including the identification of mitral valve morphology, grading of severity, and suitability for transcatheter intervention
• Know the role of multimodality imaging for identification of mitral valve morphology, grading of severity, and procedural planning
• Know the anatomic predictors of technical and procedural success of transcatheter mitral valve interventions and how to assess for procedural candidacy
• Know the steps for mitral device deployment and the required imaging for guidance
Procedure skills
• Skill to optimally guide transseptal puncture, delivery of guide catheter and transcatheter mitral valve devices into the left atrium and optimal device positioning
• Skill to perform rapid and accurate assessment of complications during the interventional procedure (i.e., leaflet injury, single-leaflet device attachment, device malposition, pericardial effusion)
• Skill to evaluate the technical and hemodynamic success of the mitral valve procedure and the need for further intervention

echocardiographer have not been studied and thus are not supported by specific data. Given the complexity of the disease process and the requirement of anatomic suitability for TEER by current guidelines,[22] it is the consensus of this writing group that an interventional echocardiographer providing imaging guidance for TEER should have procedure volume experience similar to the interventional cardiologist operator. Specifically, the TEER experience for the interventional echocardiographer should also include ≥10 transseptal guidance procedures and ≥30 structural heart procedures (Table 8). A prior study of the Society of Thoracic Surgeons/ACC Transcatheter Valve Therapy Registry reporting a site average of six cases over the 10-month study period (interquartile range, four to 10 cases; range, one to 58 cases)[38] suggests that to fulfill these requirements, the IE trainee will likely require additional years of training. Importantly, the Society of Thoracic Surgeons/ACC Transcatheter Valve Therapy Registry study[36] showed that interventionalists' learning curve to obtain optimal results appears to flatten at 50 cases, although the overall duration of the learning curve may exceed 200 cases. Thus, despite the relatively low minimum numbers, ongoing training and learning will likely be required.

Minimum medical knowledge and procedural skills competencies for level III IE training for mitral TEER are summarized in Table 10.

Transcatheter Aortic Valve Interventions

More than a decade after the initial approval of TAVR to treat inoperable patients with severe aortic stenosis, the procedure has become widely available, and indications have now expanded to patients at low surgical risk as an alternative to surgical valve replacement.[20] The current ACC, AHA, and European Society of Cardiology practice guidelines for valvular heart disease highlight the role of the imaging specialist as an integral part of the heart team.[20,39] As such, the interventional echocardiographer's role expands beyond intraprocedural guidance for TAVR and becomes fundamental for preprocedural evaluation, procedural planning, and postprocedural surveillance of these patients. The interventional echocardiographer should understand the indications, contraindications, and criteria for patient selection for TAVR and the characteristics and sizing requirements of the different transcatheter heart valves (THVs) that are commercially available.[20,40]

As part of the preprocedural evaluation for TAVR, the interventional echocardiographer should have an in-depth understanding of the complex anatomy of the aortic valve and aortic root, including unfavorable or challenging anatomic characteristics such as bulky left ventricular outflow and leaflet calcification, a bicuspid aortic valve with asymmetric calcification, or native aortic valve regurgitation in a noncalcified annulus. Furthermore, the interventional echocardiographer should be highly competent in evaluating and grading normal-flow and low-flow aortic stenosis, left ventricular function, and associated valve lesions and understanding the use of multimodality imaging, particularly CCT, for patient evaluation and preprocedural planning per current society guidelines.[41,42] A thorough understanding of CCT becomes particularly important in patients with challenging aortic root features, the use of TAVR for valve-in-valve (ViV) interventions in whom, in addition to precise annular and valve sizing, a thorough understanding of the surgical prosthesis characteristics (i.e., leaflet mounting, position of the surgical implant, and potential for fracture) is required, and in determining whether a patient presently being considered for TAVR could undergo a ViV procedure in the future. Three-dimensional TEE with MPR can be used for sizing of the aortic annulus and aortic root, as well as coronary height measurement, especially when the CCT is challenging or produces inconclusive findings, and the interventional echocardiographer should be proficient with 3D image acquisition, cropping, and reformatting to achieve this goal.

TAVR procedures were initially performed under direct guidance on TEE, with patients under general anesthesia. As clinical trials have moved from high- and extreme-risk to intermediate- and low-risk patients, monitored anesthesia care or conscious sedation (CS) and TTE are now more common.[43] In a recent study of the Transcatheter Valve Therapy Registry database between 2016 and 2019, the use of CS increased from 33% to 64%. However, there was significant practice variability by region and hospital system, and the magnitude of benefit with CS was smaller than had previously been reported.[44] Importantly, the most recent PARTNER (Placement of Aortic Transcatheter Valve) analysis showed no significant differences between CS and general anesthesia use in either the 30-day or 1-year rates of death, stroke, rehospitalization, or moderate or greater paravalvular aortic regurgitation.[45]

During the intervention, the interventional echocardiographer should be familiar with the procedural steps and the individualized procedure plan, know how to perform a focused echocardiographic examination to confirm the pathology, and reassess baseline left ventricular function, wall motion, and associated valve lesions.[46] Although much of the TAVR procedure is guided by fluoroscopy, TTE and TEE can aid in positioning the pacer wire, guidewire, and transcatheter valve before deployment. Immediately after deployment, postprocedural evaluation includes confirmation of adequate valve positioning and a determination of (1) the presence of paravalvular aortic regurgitation, (2) the integrity of the aortic annulus, (3) the presence of new wall motion abnormalities, and (4) the presence and hemodynamic severity of a pericardial effusion.[30,46] Proficiency with 2D and 3D echocardiographic imaging techniques, including live 3D MPR, is essential to perform a rapid but accurate assessment and communicate findings to the proceduralist, as additional procedural steps may be required.[11] In cases in which TTE during TAVR is performed by sonographers, a standard protocol should be developed by the interventional echocardiographer. Those seeking IE competency should be familiar with the protocol and how to interpret the images.

Table 11 Medical knowledge and procedural skills competency components for level III IE training: transcatheter aortic valve interventions

Medical knowledge
• Know the aortic valve and root anatomy for both tricuspid and bicuspid morphologies, and the anatomic predictors of procedural complications
• Know the comprehensive multimodality evaluation of aortic stenosis for grading of severity and procedural planning
• Know the effects of stroke volume and blood pressure on the assessment of aortic stenosis severity
• Know the anatomic features that increase complication risk for transcatheter intervention (e.g., coronary obstruction, aortic root disruption, heart block, perivalvular regurgitation), and features that predict procedural success
• Know the anatomic and clinical features that may favor surgical or transcatheter intervention
Procedure Skills
• Skill to size the aortic annulus, root, coronary height, and determine the risk for coronary obstruction, using 3D echocardiography with MPR
• Skill to guide predeployment valve position and assess immediate postdeployment valve position and function
• Skill to perform a rapid and accurate assessment for complications, including annular rupture, aortic dissection, pericardial effusion, acute aortic or MR, and coronary flow compromise, and promptly communicate findings
• Skill to quantify valvular function, including the presence and severity of central or paravalvular aortic regurgitation

Follow-up serial valve assessment involves evaluating transcatheter valve structure, leaflet mobility, transvalvular gradients, effective orifice area, and paravalvular aortic regurgitation. The interventional echocardiographer should understand device-specific parameters of normal valve function, compare findings with prior studies, and be able to identify hemodynamically significant changes that may require additional imaging and/or intervention.[30,46,47]

Minimum medical knowledge and procedural skills competencies for level III IE training for aortic valve interventions are summarized in Table 11.

Tricuspid Procedures

Tricuspid valve intervention is a burgeoning new field, with >20 new devices in preclinical or early feasibility studies, three ongoing randomized clinical trials, and four devices having received Conformité Européenne Mark status in Europe.[48] Thus, there is an urgent need to develop tricuspid valve imaging training for both faculty and fellows. In general, the tricuspid valve is more difficult to image than the mitral valve, given its position in the chest relative to the esophagus; however, standardized imaging protocols using 2D and 3D echocardiographic modalities have been developed, which should help with training.[11] Nonetheless, in the absence of a commercially available device to treat native tricuspid valve disease in the United States, the current numbers of procedures are limited to off-label use of the mitral valve TEER device or implantation of a balloon-expandable transcatheter aortic valve in the inferior vena cava. Although is it not possible to define the minimum procedure volume for tricuspid devices at this time, the volume will likely be greater than that for mitral procedures, given the increased difficulty imaging the valve, as well as the variability of anatomic morphologies and classification systems related to tricuspid regurgitation.[49]

The suggested medical knowledge and procedural skill competencies for level III IE training for tricuspid valve interventions are summarized in Table 12. These competencies will likely expand as the field of tricuspid valve transcatheter therapies matures.

Interventions on Replaced and Repaired Valves

General Principles. The echocardiographic assessment and guiding of catheter-based procedures can be challenging because of acoustic reverberation or shadowing from a replaced valve or other prosthetic structures such as annuloplasty rings. The interventional echocardiographer needs to possess all aspects of medical knowledge and be facile with all procedural skills summarized in Table 13. These include but are not limited to the ability to appropriately apply the use of all 2D, 3D, and 3D multiplanar transesophageal echocardiographic imaging techniques for preprocedural screening and assessment as well as intraprocedural image guidance.

In patients referred to the heart team with replaced or repaired heart valves, TEE is used to assess for the mechanism of valve failure, whether it be stenosis, regurgitation (valvular or paravalvular), both stenosis and regurgitation, or endocarditis. In addition, TEE is used to accurately quantify the severity of any structural and nonstructural dysfunction of replaced and repaired valves. Although multidetector CCT is the primary modality used to measure the internal diameter of a failed prosthesis, 3D TEE can be used to confirm device-specific sizing parameters such as inner diameter, valve area, and circumference. The interventional echocardiographer should be facile in measuring the internal diameter of the prosthesis using MPR and

Table 12 Medical knowledge and procedural skills competency components for level III IE training: imaging for transcatheter tricuspid valve interventions

Medical Knowledge
• Know the anatomy of the tricuspid valve apparatus and adjacent structures
• Know the mechanisms of tricuspid valve disease and morphologic differences that define primary, secondary, and cardiac implantable electronic device–related tricuspid regurgitation
• Know the comprehensive echocardiographic evaluation (TTE, TEE, 2D, 3D echocardiography, and 3D MPR) of tricuspid valve disease, including the identification of tricuspid valve morphology, grading of severity, and suitability for transcatheter intervention
• Know the role of multimodality imaging for identification of tricuspid valve morphology, grading of severity, and procedural planning
• Know the imaging characteristics of transcatheter tricuspid valve devices
• Know the anatomic predictors of technical and procedural success of transcatheter tricuspid valve interventions and how to assess for procedural candidacy
• Know the steps for tricuspid valve device deployment and the required imaging for guidance
Procedure skills
• Skill to determine appropriateness of specific device therapies
• Skill to perform a rapid and accurate assessment for complications (i.e., leaflet injury, single-leaflet device attachment, device malposition, pericardial effusion)
• Skill to evaluate the technical and hemodynamic success of tricuspid valve device implantation

Table 13 Medical knowledge and procedural skills competency components for level III IE training: interventions on replaced and repaired valves

Medical knowledge
• Know the assessment of the mechanism and accurate quantification of severity of structural and nonstructural dysfunction of replaced and repaired valves
• Know the device-specific sizing techniques for transcatheter management of prosthetic valve dysfunction
• Know the anatomic features that pose increased risk for adverse outcomes after device therapy for prosthetic valve dysfunction
• Know the characteristics of available septal occluder devices
Procedure skills
• Skill to distinguish between prosthetic paravalvular and valvular regurgitation
• Skill to accurately quantify and describe the location of a PVL and provide imaging guidance for percutaneous closure
• Skill to rapidly display and interpret multiplanar imaging to guide positioning of the percutaneous device

avoiding acoustic artifacts. As part of the comprehensive preprocedural evaluation, the interventional echocardiographer needs to be able to identify anatomic and pathologic features that need to be factored in when assessing the risks for adverse outcomes after a transcatheter device therapy such as a ViV implantation or paravalvular leak (PVL) closure.

Following the transcatheter intervention, TEE is used to assess transcatheter valve position, stability, leaflet excursion, presence of regurgitation, and forward gradients. Besides ruling out complications of the procedure, the interventional echocardiographer should also assess for residual paravalvular or valvular regurgitation.

Aortic ViV. Echocardiography is essential in aortic ViV not only to guide the procedure but also to help assess complications. Because the valve sizing is most frequently determined by CCT, 3D MPR can be used to confirm appropriate sizing. In addition, ViV procedures are associated with coronary obstruction, especially with stentless valves,[50,51] and intraprocedural echocardiography is crucial in guiding transcatheter laceration of aortic leaflets to prevent coronary obstruction during ViV deployment and in assessing for wall motion abnormalities.[52,53] Also, 3D TEE is useful to assess and confirm coronary height, especially in patients with renal insufficiency who may not be able to get iodinated contrast for CCT. The interventional echocardiographer should also be facile in quickly detecting other complications during this procedure, such as tamponade, valve embolization, acute MR, acute changes in regional wall motion, and significant paravalvular regurgitation.

The THV is positioned in relation to the existing prosthesis and thus fluoroscopy is used to assess landmarks for proper positioning. Positioning of the THV depends on the type of existing prosthesis. Certain valves, such as stentless valves and homografts, have radiolucent sewing rings, and in these cases, biplane or multiplane TEE is useful in assessing the landing zone.[54] Malpositioning of the THV leads to various complications, as high implantation poses a risk for valve embolization and low implantation may lead to impingement of the mitral valve, aortic regurgitation, or loss of optimal hemodynamics of the valve because of a lack of supra-annular implantation.[55]

As was mentioned previously, positioning of the THV usually is done under fluoroscopic guidance. If TEE is used (as is the case in stentless valves), imaging should focus on the aortic end of the THV so that the original valve leaflets are covered; balloon-expandable valves are generally longer than surgical valves, and the ventricular end usually extends past the surgical valve, ensuring adequate anchoring.[54] In the case of self-expanding valves, positioning with TEE should focus on the lowest edge of the THV, which should be below the sewing ring of the surgical valve. In general, ViV procedures are associated with higher postprocedural gradients and thus every effort should be taken to assess for other causes of elevated gradients (aortic regurgitation, underexpansion, suboptimal positioning).[55]

Mitral ViV. One of the biggest complications of the mitral ViV procedure is LVOT obstruction. Preprocedural CCT is always performed to predict the risk for LVOT obstruction and measurement of the "neo-LVOT."[33] Three-dimensional TEE can be used to confirm the LVOT area, estimating the risk for LVOT obstruction by assessing the aortomitral angle, the length of the anterior mitral valve leaflet, and the thickness of the basal septum. These cases are primarily performed via a transseptal approach, although with unfavorable septal anatomy, a transapical approach is used. The interventional echocardiographer should be able to guide the transseptal puncture as described in previous sections in this document. In addition, the interventional echocardiographer should be able to guide transapical access, which involves avoidance of the interventricular septum and mitral papillary muscles. After valve implantation, it is essential to ensure that the valve was not implanted too superiorly, posing risk for atrial embolization, or too far into the ventricle, posing risk for LVOT obstruction or ventricular embolization. With a balloon-expandable valve, positioning with TEE during a mitral ViV case involves visualization of the atrial edge of the THV above the atrial edge of the preexisting valve. The ventricular aspect of the THV should be positioned far enough into the left ventricle to cover the surgical valve, but care should be taken to avoid LVOT obstruction. The interventional echocardiographer should be able to assess for PVLs, transmitral and transaortic gradients, and leaflet excursion.

Tricuspid and Pulmonic ViV. Transcatheter ViV procedures for tricuspid bioprosthetic valve dysfunction have become a viable alternative to redo surgery. Transcatheter ViV in a preexisting tricuspid bioprosthesis requires similar skill sets as described for the mitral position.[56] Imaging of the tricuspid valve during the ViV procedure may require imaging from the lower esophageal probe position as well as multiplanar imaging.

The appropriate post-ViV hemodynamic assessment includes evaluation of peak E velocity, mean transvalvular gradients, diastolic velocity-time integral and velocity-time integral ratio with the LVOT, pressure halftime, and an estimate of effective orifice area.

The interventional echocardiographer should have knowledge of appropriate imaging views of the pulmonic valve. Frequently, patients with pulmonic valve disease have congenital heart disease and have had several previous surgical procedures; thus, ViV replacement of the prosthetic pulmonic valve has shown to be beneficial in this group.[57] The pulmonic valve is usually imaged from either the upper esophageal arch view, the midesophageal view, or the transgastric view, visualizing the right ventricular outflow tract. The interventional echocardiographer should be able to perform a baseline echocardiographic assessment along with intraprocedural imaging to guide device implantation and postprocedural assessment of device function. The interventional echocardiographer should be aware that left coronary system compression is a known risk during transcatheter right ventricular–pulmonary arterial conduit interventions and may occur during pulmonic ViV implantation.[57-59]

Valve-in-Ring and Band Procedures. Valve-in-ring (ViR) procedures are technically more challenging than ViV procedures. Semirigid and noncircular rings offer a much smaller landing zone and require substantial flaring of the THV.[60,61]

TEE is essential to confirm the preprocedural stability of the ring, to confirm the inner diameter of the ring, to guide transseptal or transapical access, to assess postprocedural results, and to recognize complications. Given the presence of an intact anterior leaflet, which will be displaced toward the LVOT by the expanding THV, the risk for LVOT obstruction is significantly higher during ViR compared with ViV procedures. In patients with prohibitive risk for LVOT obstruction before ViR, periprocedural laceration of the anterior mitral leaflet to prevent outflow obstruction is performed. This is a novel percutaneous method aimed at preventing LVOT obstruction in ViR-eligible patients. The technique resembles a surgical maneuver to lacerate the anterior mitral leaflet with chordal sparing so that when the THV is placed, blood continues to flow unobstructed through the sliced anterior mitral leaflet and the open cells of the THV device framework.[60]

PVL Closures. Effective closure of PVL requires that the interventional cardiologist and the interventional echocardiographer have a common language for communicating the location and size of the defect.[62] There is currently no standard nomenclature to describe the location of a PVL. The nomenclature most commonly used describes the location of the PVL in terms of the face of a clock on the basis of the orientation of the 3D en face view of the prosthesis.[12] The interventional echocardiographer should be able to accurately locate and describe the location of the PVL by 2D and 3D TEE. Also, 3D color Doppler MPR should be used to size the defect. Depending on the access route, the interventional echocardiographer should be able to guide maneuvers of the guidewire into the defect using standard and nonstandard imaging windows. Once the device has been deployed, the interventional echocardiographer should be able to assess for residual PVL, interaction of the closure device with the prosthetic valve leaflets and disks, final prosthetic valve function, and any other complications.

Minimum medical knowledge and procedural skills competencies for level III IE training for interventions on replaced and repaired valves are listed in Table 13.

LAA Occlusion Procedures

Percutaneous LAA closure with a device is used to prevent thromboembolism in patients with nonvalvular atrial fibrillation who are intolerant of anticoagulation. A trainee in IE should gain expertise and proficiency in pre-, intra-, and postprocedural assessment of LAA closure.[63]

Preprocedural Assessment. Trainees should have a thorough knowledge of the anatomy of the LAA and its variants.[64] Typically, the LAA is visualized in at least four imaging windows on 2D TEE at the following imaging angles: 0°, 45°, 90°, and 135°. This allows measurement of LAA landing zone diameter and the LAA depth as well as visualization of LAA shape and width.[11] These measurements are essential in choosing the appropriate closure device size. Trainees should also be familiar with the corresponding fluoroscopic views of the LAA.

Three-dimensional TEE further enhances imaging by providing en face views of the LAA to judge its orifice shape, long-axis views to better characterize LAA lobe anatomy, and multiplane reconstruction views to ensure that landing zone diameters are measured at the same plane level at all imaging angles.

Intraprocedural Guidance. The interventional echocardiographer should know the ideal position of the transseptal puncture for LAA closure device delivery, which often depends on the variable shape and exact location of the LAA for a given patient. Intraprocedural guidance also includes determination of the appropriate device (e.g., single-lobe device, disk-lobe device), confirmation of device size, and proposed implant location.[65] The interventional echocardiographer should know the device-specific release criteria. For single-lobe devices, that protocol requires the assessment of device position, device stability (with anchor engagement), adequate device compression, and absence of peridevice leak (PDL). For disk-lobe devices, the protocol requires that at least two-thirds of the device lobe should be distal to the left circumflex coronary artery, compressed with apposition to the LAA wall and oriented in line with the axis of intended landing zone. The disk of a disk-lobe device should be separated from the lobe and have a concave shape. Absence of PDL is a parameter of implantation success, with recent studies associating PDL width >3 mm with a greater incidence of neurologic events.[66]

Postprocedural Assessment. LAA device closure is assessed on follow-up TEE at time intervals that are device specific. A trainee should gain expertise in recognizing optimal device placement versus potential device complications such as residual PDL and device-associated thrombus. Recent studies have shown device-related thrombus is related to a number of clinical factors, as well as an implantation depth >10 mm from the pulmonary vein limbus.[67]

Minimum medical knowledge and procedural skills competencies for level III IE training for LAA occlusion procedures are listed in Table 14.

Transcatheter Septal Occluder Procedures

Percutaneous transcatheter closure of hemodynamically significant secundum atrial septal defects and ventricular septal defects is generally indicated when the size of the defect and adjacent tissue rims are appropriate for device closure and no associated findings require surgical intervention.[68] Percutaneous closure of a PFO is indicated in select patients with an embolic-appearing ischemic stroke and no other identifiable cause or mechanism after a thorough evaluation.[69] As part of the heart team, the interventional echocardiographer should understand the indications and contraindications for device closure of a septal defect and the characteristics of available devices for this purpose.

The interventional echocardiographer should understand the anatomy of the fossa ovalis, interatrial and interventricular septum, and relationship with adjacent structures.[70] They should demonstrate the ability to independently and comprehensively image these structures with 2D and 3D echocardiographic imaging to determine the feasibility of percutaneous septal defect closure, confirm the presence of adequate tissue rims, and select an optimal device.[11,71] During the procedure, the interventional echocardiographer should guide the delivery system through the PFO or septal defect, using a combination of live 2D and 3D echocardiography, including ICE as required, and ensuring adequate device position, stability, and function, as well as the absence of significant PDL after device deployment and before final release.[11]

The trainee should demonstrate proficiency in providing echocardiographic guidance for various septal defect occlusion procedures, including PFO, atrial septal defect, and ventricular septal defect closures, independently and from start to end. Therefore, the procedural volume should be sufficient to achieve this goal. The 2019 ATS document recommends a minimum of 15 guidance procedures for the percutaneous closure of septal defects or PVLs.[3] Although many septal defect closure procedures are currently performed via the use of ICE under monitored anesthesia care without the presence of an interventional echocardiographer, therefore potentially limiting the number of these procedures, it is the consensus of this writing group that the requirement for this combined procedural volume is appropriate and should be considered an absolute minimum.

Minimum medical knowledge and procedural skills competencies for level III IE training for transcatheter septal occluder procedures are listed in Table 15.

Table 14 Medical knowledge and procedural skills competency components for level III IE training: LAA occlusion procedures

Medical knowledge
• Know the key anatomic features of the LAA, including its ostium, body, and accessory lobes
• Know the variety of LAA shapes (windsock, chicken wing, cauliflower, etc.) and their impact on percutaneous LAA closure
• Know the anatomic relationships of the LAA to the surrounding structures, including the mitral valve, pulmonary artery, pericardial space, and left-sided pulmonary veins
• Know the characteristics of available LAA occluder devices
Procedure Skills
• Skill to visualize the LAA in multiple 2D and 3D transesophageal echocardiographic views for LAA sizing and procedural guidance specific to each closure device
• Skill to evaluate the technical success and complications of the LAA closure device implantation and the need for further intervention

USE OF SIMULATORS

Virtual and Simulation Training

Given the competing factors of relatively low numbers of structural heart interventions that require the greatest competency and expertise, it is possible that the learning curve for trainees could be shortened with the use of simulation training. Simulation training has a long history of benefit in exactly these situations. Multimedia-based training has been shown to improve surgical performance.[72] In the era of coronavirus disease 2019, access to training has become particularly problematic, and a recent review found a number of available resources for remote surgical training with attention to the three core skills: psychomotor, cognitive, and visual-spatial.[73] Prat *et al.*[74] showed that computerized TEE simulation training allowed competency for hemodynamic assessment of ventilated patients in the intensive care unit to be achieved after an average of 32.5 ± 10 supervised studies in the control group compared with only 13.6 ± 8.5 in the group trained using simulators ($P < .0001$). Matyal *et al.*[75] showed that simulator TEE training allowed the novice to obtain the same image capture success rate as a more advanced trainee. Thus, the task force believes that simulator training has a role in this new subspecialty, which, when combined with remote learning, could permit societies to standardize a teaching curriculum and allow the trainee to complete training in a reasonable time frame.[76] Simulator training may also improve access to training and thus promote diversity and inclusivity.

Table 15 Medical knowledge and procedural skills competency components for level III IE training: transcatheter septal occluder procedures

Medical knowledge
• Know the characteristics of available septal occluder devices
• Know the anatomy of the fossa ovalis, IAS and interventricular septum, and relationship with adjacent structures
Procedure Skills
• Skill to perform agitated saline contrast study to assess for intracardiac shunt
• Skill to size ASD, PFO, and VSD and adjacent anatomy using 2D and 3D echocardiography, as well as 3D MPR
• Skill to guide the delivery system through the septal defect using a combination of 2D and 3D imaging, including ICE
• Skill to perform a comprehensive assessment for appropriate device position, stability, function, and presence of PDL

ASD, Atrial septal defect; *VSD*, ventricular septal defect.

SUMMARY

Treatment strategies for patients with SHD are rapidly evolving. The explosive development of percutaneous devices has allowed patients to undergo treatment for cardiac diseases that was previously only possible with surgery. Percutaneous treatments for SHD are heavily reliant on imaging for preprocedural planning, device implantation, and long-term follow-up. This document expands upon the previously published ACC ATS on advanced echocardiography to provide specific recommendations for training interventional echocardiographers. This document provides the minimum competencies and standards for training institutions to design high-quality programs and for individuals pursuing IE training to understand basic procedural and knowledge-based benchmarks. A core principle of each training program is that the length of program duration or achieved procedure numbers are less important than demonstrated competency in the procedure-specific IE competencies within the milestone domains of knowledge, skill, and communication.

NOTICE AND DISCLAIMER

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