Indications and Guidelines in Pediatric and Congenital Heart Disease

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Abbreviations

2D	Two-dimensional
3D	Three-dimensional
ACC	American College of Cardiology
ACHD	Adult congenital heart disease
AHA	American Heart Association
ASA	American Society of Anesthesiologists
ASE	American Society of Echocardiography
CHD	Congenital heart disease
SCA	Society of Cardiovascular Anesthesiologists
TEE	Transesophageal echocardiography
TTE	Transthoracic echocardiography

Key Learning Objectives

- Define the indications for performing a transesophageal echocardiographic (TEE) study
- Describe applications of TEE in the ambulatory setting
- Outline the guidelines for TEE training and maintenance of competence
- Discuss related TEE safety concerns and potential complications
- Recognize both the absolute and relative contraindications for a TEE examination

Introduction

Transesophageal echocardiography (TEE) plays an important role in the anatomic, functional, and hemodynamic assessment of patients with congenital heart disease (CHD). This imaging modality has been employed in both children and adults over a wide range of congenital cardiovascular malformations. In the pediatric age group, the benefits of TEE are not only limited to those with structural cardiovascular defects, but also include children with acquired conditions that affect the cardiovascular system. Extensive clinical experience has demonstrated the significant and important contributions of TEE, particularly in the perioperative setting. In fact, in the current medical era it is generally recognized that this technology is an essential adjunct to perioperative management. This chapter reviews indications of TEE related primarily to diagnostic evaluation, perioperative assessment, and monitoring during interventions. Guidelines for TEE practice in children and adults with CHD are also addressed including cognitive and technical skills, in addition to training requirements. Finally, safety concerns, potential complications, and contraindications relevant to the TEE assessment in these patient populations are discussed. Where applicable, benefits and limitations of TEE as compared to transthoracic echocardiography (TTE) will be noted.

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Indications for Transesophageal Echocardiography

Adult-Based Indications Related to Congenital Heart Disease

The recognition of TEE as a specialized application of ultrasound in the 1980s led at the time to an extensive literature addressing indications for the use of this modality and documenting its applications in the adult patient [1–6]. With regard to the applications in the intraoperative setting, it was recognized that TEE could serve as a real-time monitoring technique, potentially valuable in patients at high risk for cardiovascular complications. Additional benefits of TEE acknowledged in the early experience included the evaluation of valvular surgery, its role in suspected endocarditis, and its use in the assessment of complex CHD in the adult. TEE was also noted to potentially benefit the care of critically ill patients during the postoperative period.

As the technology evolved and the use of intraoperative echocardiography became widespread, in 1996 the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists (ASA/SCA) developed practice guidelines regarding the perioperative applications of TEE [7]. These evidence-based recommendations were written primarily for anesthesiologists, and focused on the appropriate use of perioperative TEE. Among the listed indications, those supported by the strongest evidence or expert opinion included “the intraoperative use of TEE during congenital heart surgery for most lesions requiring cardiopulmonary bypass”.

Following this report, an update of prior guidelines for the clinical application of echocardiography was published by the American College of Cardiology (ACC) and American Heart Association (AHA), which was endorsed by the American Society of Echocardiography (ASE) in 1997 [8]. In contrast to the original document published in 1990 [5], the updated guidelines discussed indications for the use of TEE in pediatric patients. A subsequent multigroup statement addressing clinical competence in echocardiography, which was published in 2003, included the evaluation of a variety of congenital heart defects in both children and adults as one of the indications for TEE [9].

In 1999, the ASE/SCA published a position paper on guidelines for performing a comprehensive intraoperative multiplane TEE examination [10]. The task force defined a set of 20 TEE views with the main goal of facilitating and providing a uniform approach to training, reporting, archiving, and quality assurance. Indications were not specifically mentioned, as they had been previously addressed [7]. A report on appropriateness criteria for echocardiography conducted by the ACC Foundation and the ASE in conjunction with key specialty and subspecialty societies was originally published in 2007 and subsequently revised in 2011 [11, 12]. The criteria developed assumed indications for adult patients and was based on common clinical applications or anticipated use of these imaging modalities. The assessment of known or suspected adult CHD either in unoperated patients or following repair/operation was considered among the appropriate indications for TEE.

The publication on the subject by the ASE/SCA in 2013, entitled *Guidelines for Performing a Comprehensive Transesophageal Echocardiographic Examination: Recommendations from the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists*, represents the latest document at the time of this writing intended as a guide for adult TEE practice regarding diagnostic and intraprocedural TEE [13]. The general indications for TEE in that document as outlined in Table 3.1 are also applicable to the adult patient with CHD.

Table 3.1 General indications for TEE

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

Pediatric and Congenital-Based Indications

Hardware miniaturization and evolving technological advances over time expanded the applications of TEE from the adult to the pediatric age group (refer to Chaps. 2 and 18). At the request of the Society of Pediatric Echocardiography, a report was published in 1992 by the Committee on Standards for Pediatric TEE specifically addressing the use this imaging modality in children [14]. The goal of the document was to propose indications and guidelines for the optimal performance of TEE in this age group. In 2005, the Pediatric Council of the ASE updated this statement and reviewed clinical indications for the performance of TEE in pediatric patients with acquired or congenital cardiovascular disease [15]. Most recently, in 2019, the Pediatric Council of the ASE updated this statement, entitled *Guidelines for Performing a Comprehensive Transesophageal Echocardiographic Examination in Children and All Patients with Congenital Heart Disease* [16]. Indications for TEE in this document, as shown in Table 3.2, were subdivided into the following main categories:

- Diagnostic indications
- Perioperative indications
- TEE-guided interventions

The specific applications of TEE in children and adults with CHD, as well as the benefits of the technology in pediatric acquired heart disease, are discussed in detail throughout this textbook. The sections that follow provide a general overview of the indications of TEE in patients with CHD and in pediatric acquired heart disease.

Diagnostic Indications

Echocardiography is the primary diagnostic imaging modality in the initial and serial evaluation of most types of pediatric heart disease. In infants and young children, high-resolution transthoracic imaging generally enables excellent definition of cardiovascular anatomy, assessment of hemodynamics, and determination of ventricular performance. When TTE or other studies have not successfully elucidated the necessary clinically relevant information, TEE is able to provide diagnostic information in the majority of cases. By overcoming limitations related to poor windows, suboptimal image quality or lung interference, TEE facilitates morphologic, hemodynamic, and functional assessment of congenital and acquired cardiac abnormalities. This is of particular relevance in certain patient groups with limited acoustic windows, such as those who have undergone multiple prior cardiothoracic interventions, open-chest settings, adult patients, or suboptimal transthoracic imaging related to body habitus.

Table 3.2 Indications for TEE in children and all patients with CHD

Diagnostic indications
• Patient with suspected CHD and non-diagnostic TTE
• Presence of patent foramen ovale (PFO) with and without agitated saline contrast and direction of shunting as possible etiology for stroke
• Evaluation for cardiovascular source of embolus with no identified non-cardiac source
• Evaluation of intra- or extra-cardiac baffles following the Fontan, Senning, or Mustard procedure
• Suspected acute aortic pathology including but not limited to dissection/transection (e.g., Marfan syndrome, bicuspid aortic valve, coarctation of the aorta)
• Intra-cardiac evaluation for vegetation or suspected abscess
• Evaluation for intra-cardiac thrombus prior to cardioversion for atrial flutter/fibrillation and/or radiofrequency ablation
• Pericardial effusion or cardiac function evaluation and monitoring postoperative patient with open sternum or poor acoustic windows
• Evaluating status of prosthetic valve in the setting of inadequate TTE images
• Re-evaluation of prior TEE finding for interval change (e.g., resolution of thrombus after anticoagulation, resolution of vegetation after antibiotic therapy)
Perioperative indications
• Immediate preoperative definition of cardiac anatomy and function
• Postoperative surgical results and function
• Intraoperative monitoring of ventricular volume and function
• Monitoring of intra-cardiac/intravascular air and adequacy of cardiac de-airing
TEE-guided interventions
• Guidance for placement of occlusion device (e.g., septal defect, Fontan or intra-atrial baffle fenestration)
• Guidance for blade or balloon atrial septostomy
• Guidance for creation/stenting of interventricular communication
• Guidance during percutaneous valve interventions
• Guidance during radiofrequency ablation procedure
• Assessment of results of minimally invasive surgical incision or video-assisted cardiac procedure
• Guidance during placement of catheter-based cardiac assist device (e.g., Impella ® heart pump)

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Transesophageal echocardiography is considered superior to TTE in the adolescent or adult for the evaluation of certain suspected pathologies such as a patent foramen ovale as the possible etiology of a stroke, evaluation for a cardiovascular source of embolus, specific types of atrial septal defects, anomalous pulmonary venous connections, and complex cardiac malformations [17–19]. This modality has been also shown to be of benefit when confirming or excluding diagnoses of major clinical relevance such as atrial baffle pathology (leak or obstruction) following Mustard or Senning atrial switch procedures, Fontan obstruction or related venous thrombus, as well as acquired conditions such as intracardiac vegetations, aortic dissection, and aortic root abscess [20–24]. Other settings in which TEE has been applied include the evaluation of potential intracardiac thrombus prior to cardioversion of atrial rhythm disturbances, the assessment of prosthetic valve function, and the re-evaluation of a prior TEE finding for interval change [25]. As the technology for mechanical circulatory support has evolved, TEE has been used to monitor catheter/cannula placement, confirm adequacy of atrial and ventricular volume status as required (decompression, venting, filling), assess aortic valve opening/closing, optimize device settings, and provide surveillance of potential complications [26–28].

Perioperative Indications

During Cardiovascular Surgery

The intraoperative evaluation represents the most common indication for TEE in patients with CHD and children with acquired cardiovascular disorders. In general, indications for intraoperative TEE include settings in which there is potential for significant residual pathology and/or myocardial dysfunction.

It is recommended that all patients undergo a comprehensive preoperative TTE prior to TEE. This study, along with any available imaging examinations of the cardiovascular system should be reviewed by the echocardiographer prior to initiating intraoperative TEE assessment. Transesophageal echocardiography should be considered a complementary imaging modality, rather than a substitute for a complete TTE. This is in recognition of the inherent limitations associated with transesophageal imaging such as windows confined to the esophagus and stomach, inability to evaluate certain cardiovascular structures, potential suboptimal conditions for interrogation, and other challenges. In fact, TTE can provide information that in some cases is not obtainable by TEE. However, the benefits of the preoperative TEE study are many, including those listed in Table 3.3.

The preoperative TEE examination provides a baseline evaluation of cardiac anatomy and function, allows for characterization of the cardiac abnormalities, and serves as a framework for later comparison in the postsurgical assessment. Also, the study can be used to address or clarify any important remaining preoperative concerns regarding intracardiac anatomy and physiology which were not apparent by other imaging modalities (e.g., valvar issues), questions in which TEE has a reasonable expectation of providing accurate and useful information. Important benefits of the study include the confirmation and/or exclusion of preoperative diagnoses and the immediate preoperative evaluation of hemodynamics. TEE demonstrates in real time the cardiac abnormalities prior to the intervention to the perioperative providers. The examination allows for refinements or modifications in the surgical plan, and facilitates anesthetic care. Performing a complete study should be the goal of a preoperative examination (refer to Chap. 4); however, a limited or focused examination might be necessary due to patient-related issues or unanticipated intraoperative circumstances that could preclude a more complete assessment.

Over the years, numerous publications have documented the impact of TEE during cardiac surgery in patients with congenital cardiovascular defects and in children with acquired pathologies [29–33]. The contributions of TEE to intraoperative management and postoperative assessment, as discussed throughout this textbook, are listed in Table 3.4. This topic is also specifically addressed in further detail in Chap. 18.

Transesophageal echocardiography allows for assessment of ventricular function and loading conditions throughout the intraoperative period [34, 35]. Volume replacement and changes in inotropic and vasoactive strategy have also been reported as a direct result of intraoperative TEE [36, 37]. Prior to weaning from cardiopulmonary bypass, TEE ensures the adequacy of cardiac de-airing [38].

The postoperative TEE study encompasses a complete analysis of the surgical results, hemodynamics, and functional status. The main goal is the assessment of hemodynamically significant residual defects that may need reintervention prior to leaving the operating room, in order to improve overall outcomes. The clinical status of the patient, in conjunction with the TEE findings, available hemodynamic information, and other factors such as anatomy observed by the surgeon and likelihood of a successful revision, are all considered in the determination of whether the surgical repair is acceptable or reinstitution of cardiopulmonary bypass is indicated to revise the repair or to address unsatisfactory results. Although an "acceptable" result—a repair with residual defects not considered to be major—does not equate an "echo perfect" result—one without discernible residual defect)—it should be recognized that both would be consistent with a good outcome, as highlighted by

Table 3.3 Benefits of preoperative TEE

Baseline evaluation of anatomy and function
Confirmation of preoperative diagnoses
Identification of new or different pathology
Exclusion of additional or suspected defects
Influence on surgical plan
Influence on anesthetic management

Table 3.4 Benefits of TEE in intraoperative management and postoperative assessment

Guidance during placement of intravascular and intracardiac catheters
Evaluation of ventricular preload
Monitoring of ventricular function
Ensuring the adequacy of cardiac de-airing
Identification of problems associated with weaning from cardiopulmonary bypass
Assessment of the adequacy of the surgical intervention
Guidance during revision of the surgical repair
Influence on anesthetic and medical managements
Planning and optimizing postoperative care

Ungerleider and colleagues in the early intraoperative TEE experience [39]. In all patients, the risks associated with return to bypass and potential additional perioperative morbidity or even mortality should be considered, versus the potential benefits of an intraoperative revision.

Additional perioperative settings where TEE has been shown to be useful include: during minimally invasive surgery when adequate visualization of structures may be limited [40–43]; in the postoperative patient with limited transthoracic windows; in a patient with an open sternum [44, 45]; in a patient undergoing mechanical circulatory support [46]; and other situations in the critical care setting in the period immediately following surgery. These applications are addressed briefly in this chapter and in further detail in Chaps. 19 and 20.

Over the past several decades, the contributions of TEE have accounted for improved perioperative care, by limiting morbidity and likely reducing mortality in many patients. The experience has been so compelling that the technology has been incorporated into clinical practice by essentially all centers that specialize in pediatric cardiovascular medicine and congenital cardiovascular disorders and has now become accepted as standard of care in the intraoperative CHD setting.

During Noncardiac Surgery

The use of TEE during noncardiac surgery has been recommended when a patient has known or suspected cardiovascular pathology that might result in hemodynamic, pulmonary, or neurologic compromise during the procedure [47, 48]. Although the role of TEE in the noncardiac surgical setting has not been extensively documented in children, nor in adults with CHD, the limited experience suggests that it can facilitate perioperative management in these patient subgroups [49–51]. Individuals that can benefit from a TEE study during noncardiac surgery include those with untreated or palliated CHD, single ventricle physiology or other complex structural abnormalities, as well as patients with significant hemodynamic abnormalities, myocardial dysfunction, cardiomyopathies, or pulmonary hypertension. Noncardiac operative procedures where significant fluid shifts are anticipated, or perturbations might occur, could result in hemodynamic compromise that can place patients at risk. In these settings, TEE can play a vital role in the monitoring of intravascular volume status, and for fluid management. Rarely, TEE may also be performed in pediatric patients without known cardiac pathology, such as during scoliosis surgery, liver transplantation, and other interventions, when considered of benefit for intraoperative monitoring related to a high risk of procedural morbidity.

An executive summary regarding perioperative cardiovascular evaluation and care for noncardiac surgery in the adult patient was published as a joint effort of the ACC and AHA in 2007 [52] and updated in 2014 [53]. The document indicated that certain patients might be at higher risk during noncardiac surgical procedures, including adults with congenital heart disease (ACHD) [54–60]. Their risk is influenced by the specific type of congenital pathology, the surgical procedure, and the urgency of the intervention. Factors associated with increased risk of perioperative morbidity and mortality in these patients during noncardiac surgery were further expanded upon in the *2018 AHA/ACC Guidelines for the Management of Adults with Congenital Heart Disease* as listed in Table 3.5 [62].

Table 3.5 Factors associated with increased risk of perioperative morbidity and mortality during noncardiac surgery in adults with CHD

Cyanosis
Congestive heart failure
Poor general health
Younger age
Pulmonary hypertension
Operations of the respiratory and nervous systems
Complex CHD
Urgent/emergent procedures

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TEE-Guided Interventions

Interventional procedures have become increasingly employed in the nonsurgical management of CHD. TEE allows for safer and more effective application of catheter-based approaches and may reduce radiation exposure, amount of contrast material administered, and duration of the interventional procedure. Major contributions of TEE during catheter-based interventions include: (1) acquisition of detailed anatomic and hemodynamic data prior to and during the procedure, (2) real-time visualization of catheter placement across valves, vessels, and cardiac structures, (3) immediate assessment of the results, and (4) monitoring and detection of complications associated with the interventions [63, 64]. The refinements in interventional cardiac catheterization techniques, coupled with advances in TEE technology, now allow for a high success rate of these procedures, as well as a low incidence of complications.

In the cardiac catheterization laboratory, TEE has been applied to procedures such as closure of atrial septal defects [65–73], ventricular septal defects [61, 74], occlusion of patent ductus arteriosus [75, 76], as well as closure of Fontan baffle leaks, and creation of Fontan fenestrations [77, 78]. Additional procedures suitable for TEE monitoring/guidance include: balloon/blade atrial septostomy [79–81], stenting of restrictive atrial communications or other cardiovascular structures [82], balloon valvuloplasty [83, 84], radiofrequency perforation of atretic valve or atrial septum, endomyocardial biopsy [85], pericardiocentesis [86, 87], and retrieval of devices/foreign bodies [88] (refer to Chap. 21). TEE is also used to facilitate transcatheter placement of ventricular assist devices, guidance of perventricular septal defect closure, and other interventions performed by combining catheter techniques and operative procedures, otherwise known as hybrid approaches [89, 90].

Applications of Three-Dimensional Transesophageal Echocardiography

The last several years have witnessed the evolution of three-dimensional (3D) echocardiography, and concurrently, expanding important applications of this modality to CHD imaging [91–100]. Advances in 3D imaging, particularly in transducer technology, have also extended to TEE [101–104], and likewise, live/real-time 3D TEE has been increasingly used in the assessment of CHD (refer to Chaps. 23 and 24) [13, 105–108]. The added value of 3D TEE imaging has been documented in both the intraoperative [104, 109] and cardiac catheterization settings [19, 110–113]. Procedures in which 3D TEE has been recommended or noted to have been used effectively in CHD, as addressed in the recently published pediatric and congenital TEE guidelines, are listed in Table 3.6 [16]. The benefits of 3D TEE have also been demonstrated in the functional evaluation of the heart, as discussed later in this textbook in Chaps. 5 and 18 [114, 115].

Several issues related to 3D TEE should be emphasized as follows:

- 3D TEE is considered a complementary imaging technique rather than a substitute for two-dimensional (2D) TEE.
- The use of the technique requires additional knowledge, training, and expertise beyond conventional 2D TEE, allowing for image acquisition and optimization to examine the specific malformations or guide appropriate therapies (refer to Chaps. 23 and 24).
- At the time of this writing, 3D TEE imaging is not yet feasible in infants and small children <20 kg due to the lack of suitable imaging hardware for these age groups.

Table 3.6 Reported clinical use of 3D TEE in CHD

3D TEE has been recommended for:
ASD device closure guidance
VSD device closure guidance
Visualization of catheters, delivery systems, and devices
Measurement of defects visualized in *en face* views
Analysis of the anatomy and function of atrioventricular valves
Visualization of the aortic valve and left ventricular outflow tract
3D TEE has been used effectively during:
Fontan fenestration closure
Ruptured sinus of Valsalva aneurysm device closure
Coronary artery fistula device closure
Prosthetic valve paravalvular leak device closure
Atrial switch baffle leak device closure and baffle obstruction stenting
Atrial septum trans-septal puncture during various procedures
Biventricular pacemaker synchrony assessment and lead placement guidance

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Applications of Transesophageal Echocardiography in the Ambulatory Setting

In the adult, TEE is routinely and regularly utilized in the ambulatory setting. This is due in large part to the more frequently suboptimal transthoracic windows and marginal imaging quality encountered in many adults, which limits the amount of information obtainable by TTE. However, it also reflects the fact that ambulatory TEE is easier to perform in adult patients, because in most cases it can be undertaken with conscious sedation. For example, in the ACHD patient, TEE can be performed in the outpatient setting to exclude the presence of intra-cardiac thrombus prior to elective cardioversion.

Ambulatory TEE is rarely performed in the pediatric patient, and when done, it is generally more involved in younger patients due to many practical considerations. Even with sedation, children and adolescents are rarely able to cooperate and lie still. This not only can compromise patient safety, but also adds the potential for damage to the TEE probe. Thus, a deeper level of sedation than that required in the adult, or alternatively endotracheal intubation and general anesthesia, is necessary in the majority of TEE examinations performed in this patient population. This is particularly true for children with significant cyanosis and/or myocardial dysfunction, where airway patency is critically important, or in those with potential ventilatory abnormalities [116].

Another reason why ambulatory TEE is rarely used in children is because, as indicated previously, in this patient group transthoracic imaging generally provides high quality diagnostic images. In young children, rarely does TEE offer any significant advantage compared to TTE for diagnostic purposes; in addition, the greater accessibility of multiple transthoracic windows means that a more thorough evaluation of the entire cardiovascular system can generally be performed, including those areas not consistently imaged by TEE (e.g., the branch pulmonary arteries and aortic arch).

When standard TTE imaging is unsatisfactory, the need for ambulatory TEE must be ascertained after a risk versus benefit analysis, which includes consideration of the type of information needed and alternative diagnostic imaging modalities, along with their attendant advantages and disadvantages. Despite a good safety profile, TEE is a semi-invasive procedure with important potential risks and relative/absolute contraindications. Cardiac catheterization, cardiac magnetic resonance imaging, and chest computed tomography provide certain types information (e.g., hemodynamic measurements, aortic arch imaging) that cannot be obtained by TEE. These alternative modalities can provide comparable or superior information to TEE for certain cardiac structures, such as coronary arteries. In many cases these other diagnostic studies are preferable to TEE and in fact, should be considered or used before TEE is performed, particularly in children.

Nonetheless, there are a number of instances in which ambulatory TEE can provide superior diagnostic information in the patient with CHD, even compared to other imaging modalities. Abnormal atrioventricular valves, for example, are much better evaluated by TEE than other diagnostic approaches, as are prosthetic valves (refer to Chaps. 8, 9 and 19). Conditions such as subaortic membrane, subaortic stenosis, and aortic valve abnormalities, are clearly shown by TEE. The same is the case for atrial septal defects, ventricular septal defect morphology, and the relationship of ventricular septal defects to the semilunar valves (of value in certain forms of complex CHD such as double outlet right ventricle; refer to Chap. 14). There are many postoperative settings in which TEE delivers extremely useful—if not essential—information, for example, in complex atrial baffle procedures (Mustard/Senning), and following Fontan and Rastelli operations.

Role of the Sonographer in Transesophageal Echocardiography

The majority of pediatric TEE studies are performed under general anesthesia in the operating room or catheterization suite as previously noted. In the ACHD population, these studies may be undertaken with conscious sedation in the outpatient environment, as also mentioned. Regardless of setting, TEE imaging often dictates the need for timely scanning and optimization to achieve the acquisition of diagnostic information. Depending on the setting, the process may involve real-time communication of the findings to the surgeon or interventionalist to facilitate clinical decision making. The sonographer can play an integral and important supporting role in this process, one that falls within their currently defined professional scope of practice [117]. Their expertise in instrumentation and digital acquisition can expedite the study by maximizing image quality, manipulating controls that facilitate the modalities used for hemodynamic assessment, and overall enhancing the efficiency of the study. The experienced sonographer with advanced practice skills in TEE is well aware of the protocol, recognizes the anatomy in all views, and anticipates the physician's focus for the study. This allows for rapid optimization with instrumentation as the study progresses through multiple views, allowing the physician to focus primarily on probe manipulation, findings, and clinical consultation with the surgeon or interventionalist, as warranted.

There is currently no professional practice standard or process in place for sonographer education, guidelines, or credentialing that includes TEE probe intubation or manipulation. In recognition of regional or institutional differences in clinical practice models, particularly with respect to adult TEE practice, and in response to informal discussions regarding the role of sonographers in such studies, in 2017 the ASE Board of Directors developed a position statement with respect to this which reads as follows:

> ASE recognizes that sonographers are an integral part of the cardiac imaging team and support their active role during the performance of a TEE. However, that role should be limited to their scope of practice. Specifically, ASE supports sonographers using their expertise and skills to optimize images (i.e. adjust gain, contrast, and other machine settings) during the TEE exam. ASE does not advocate for sonographers to perform TEE intubation or manipulation of the probe (https://www.asecho.org/ase-policy-statements/; February 17, 2017).

A communication by the Council on Cardiovascular Sonography in response to this statement acknowledged the lack of published guidelines, practice standards, and training for sonographer's hands-on involvement in TEE [118]. At the same time, it highlighted the fact that ASE recognizes that the future of healthcare continues to advance and as such, position statements will need to be revised and adapted as educational and practice standards that impact the sonographer's scope of practice continue to evolve. Whether the ASE position regarding this issue changes in the future, it is unlikely that an updated statement will apply to TEE imaging in all age groups, given the fact that infants and children will always be regarded a fragile and potentially more vulnerable patient population.

Guidelines for Training and Maintenance of Competence in Transesophageal Echocardiography

Knowledge Base and Skills

Standards for core training in echocardiography have been published for both adult and pediatric cardiology trainees [119, 120] and for advanced adult cardiology fellows [121]. These documents address in detail competency components and curricular milestones. With respect to TEE, core fellowship or minimum training goals in the specialty of pediatric cardiology include knowledge of:

- *Indications and use in all settings*
- *Strengths and limitations*
- *Contraindications and potential complications*
- *Familiarity with views obtainable from major esophageal and gastric positions*

Specific TEE imaging guidelines, published and updated over time, have also focused on the subject of knowledge base and skill requirements for physician training and maintenance of competence [13–16, 122]. In these documents, the recommendations for core competencies share many of the same requirements with the more general echocardiography guidelines mentioned above, such as medical knowledge, patient care and procedural skills, and other aspects. However, they also vary according to the type of trainee—whether adult cardiology-based, pediatric cardiology-based, or anesthesiology-based—and the specific patient population being examined, namely adults with structurally normal hearts in most cases (*ASE/SCA Comprehensive TEE Guidelines,* published in 2013) versus children with congenital and acquired cardiovascular diseases as well as ACHD patients (*Guidelines for Comprehensive TEE in Children and all patients with CHD,* published in 2019) [13, 16]. In addition to the TEE guidelines developed for physicians practicing in the United States, other societies in Canada and Europe have also developed training recommendations for TEE, mostly focusing on the adult [106, 123].

While the use of TEE is considered an advanced aspect of echocardiography, performance and competency in patients with CHD or pediatric acquired heart disease requires even more specialized knowledge, skills and training. Accordingly, the requirements for the echocardiographer performing a study in these patient groups differ in many respects from those outlined for the echocardiographer who uses TEE in the adult population [16]. In recognition of the unique aspects of TEE in children and ACHD, various cognitive and technical skills have been suggested with respect to TEE competence that specifically apply to pediatric cardiologists and adult congenital heart specialists and extend beyond the core basic TEE competencies listed above for pediatric cardiology fellowship training [14–16]. These are listed in Table 3.7.

Training Guidelines

For Physicians Who Practice Pediatric Cardiology and Adult Congenital Heart Disease

Guidelines for training and maintenance of competence in the performance of TEE in children and all patients with CHD have been outlined as displayed in Table 3.8. The recommendations are primarily aimed for physicians trained in pediatric cardiology/ACHD and include: (1) prior TTE experience, (2) a minimum number of supervised esophageal intubations, if part of practice (25 cases, 50% under 2 years of age), and (3) performance and interpretation of at least 50 TEE examinations in pediatric and ACHD patients prior to independent TEE practice. Ongoing TEE experience is required to maintain competency [16]. Physicians involved in ACHD TEE imaging should have training and/or experience in ACHD.

For Physicians Not Formally Trained in Pediatric Cardiology or Adult Congenital Heart Disease

In the absence of formal pediatric cardiology or ACHD fellowship, intensive training in an accredited congenital/pediatric laboratory with emphasis on TEE imaging has been recommended for those interested in TEE practice in this population [16]. The most recent guidelines stated that their aim was “to promote safety and quality by clarifying the necessary skills and the extent of supervised training and experience needed to perform TEE”. It was noted that there was “no intent to exclude physicians from performing TEE, but rather to promote a standard of safety and effective performance of the exam in complex and often frail pediatric and ACHD populations”.

An editorial about the early intraoperative TEE experience, addressing training in general and not specific to the use of the technology in pediatric patients nor in adults with CHD, noted that training in the echocardiography laboratory may be impractical for anesthesiologists [124]. An alternate approach was suggested as follows: a program with appropriate mentoring that includes supervision and interpretation initially, followed by gradually expanded clinical practice with appropriate consultation. The 2013 *ASE/SCA Comprehensive TEE Guidelines* in fact noted that whereas TTE experience is a requirement for cardiology-based TEE training, it is not a prerequisite for anesthesiology-based

Table 3.7 Cognitive and technical skills required for competence in TEE for congenital and pediatric acquired heart disease

Cognitive Skills Related to Competence in Echocardiography
• Understanding of principles of cardiovascular ultrasound
• Knowledge of basic principles of ultrasound transducer design and function
• Recognition of key components of echocardiography machine
• Understanding of important principles of echocardiographic image generation and blood velocity measurements
• Understanding of fundamental principles of Doppler echocardiography and applications of the different forms of Doppler evaluation
• Knowledge of quantitative methods in echocardiography that include structural measurements, hemodynamic assessment, and functional evaluation (systolic and diastolic)
• Knowledge and recognition of the various types of echocardiographic artifacts that might be encountered
• Knowledge of normal and abnormal cardiovascular anatomy and physiology

(continued)

Table 3.7 (continued)

Cognitive Skills Related to Competence in Congenital and Pediatric Acquired Heart Disease
• Understanding of the segmental approach to CHD and application of nomenclature
• Thorough knowledge of the spectrum of congenital heart defects and their natural/unnatural histories
• Knowledge of appropriate medical and surgical therapies, as well as transcatheter-based interventions in CHD
• Knowledge of acquired diseases that affect the cardiovascular system in children
Cognitive and Technical Skills Related to Competence in TTE for Congenital and Pediatric Acquired Heart Disease
• Basic knowledge for competence in echocardiography
• Knowledge of appropriate use criteria for TTE
• Thorough knowledge and understanding of the clinical applications of TTE
• Knowledge of the normal pediatric echocardiogram
• Knowledge of the echocardiographic manifestations of CHD and of acquired conditions that affect the cardiovascular system in children
• Proficiency in performing a TTE study and rendering an interpretation of echocardiographic images, including the recognition of normal and abnormal anatomic findings of the cardiovascular system and peripheral structures that might be relevant during the assessment (e.g. liver, diaphragm, pleural space)
• Proficiency in the interpretation of hemodynamics, including the ability to define both normal intracardiac flow velocities and patterns, as well as correctly interpret flow disturbances
• Ability to write a detailed report of the findings and render an interpretation of the echocardiographic information
Cognitive Skills Related to TEE in Congenital and Pediatric Acquired Heart Disease
• Knowledge of echocardiography and transthoracic imaging
• Knowledge of available TEE technology (including systems, hardware, and probe design)
• Understanding of oropharyngeal anatomy and knowledge of endoscopic techniques (if probe placement within scope of practice)
• Understanding of aspects relevant to conscious sedation, including potential complications and their management (as applicable depending upon setting, patient type)
• Knowledge of normal and abnormal cardiovascular anatomy as depicted tomographically by TEE
• Detailed knowledge of anatomic, hemodynamic, and myocardial functional assessment (includes determination of qualitative and quantitative parameters by TEE)
• Knowledge of TEE indications, particularly in the pediatric and ACHD settings
• Understanding limitations of TEE and use of alternate/complementary imaging modalities
• Knowledge of the strengths of the TEE imaging approach, specifically as compared to TTE
• Understanding of the use of TEE in a variety of clinical settings (operating room, cardiac catheterization laboratory, critical care unit, and outpatient setting)
• Through understanding of requirements in preparation for a study, such as review of clinical and available imaging information for each patient (includes knowledge of data obtained from other cardiovascular diagnostic methods that may allow for correlation with TEE findings)
• Understanding of the TEE information to be obtained, the planned surgical procedure/intervention, and questions to be addressed
• Knowledge of tomographic views used in the comprehensive TEE imaging examination of CHD and acquired pediatric heart disease
• Knowledge of criteria utilized for TEE probe selection and unique aspects in children
• Knowledge of clinical settings where 3D TEE is recommended or may be potentially useful
• Knowledge of safety issues related to TEE including contraindications, risks, and complications, particularly as applicable to neonates and young infants
• Knowledge of the steps involved in TEE probe care, infection control measures, and electrical safety issues
• Ability to communicate and discuss relevant TEE findings and other important information to health care providers (may also include patient, family member or responsible party as appropriate) sometimes under the most challenging situations. Communication of preoperative and postoperative TEE findings is of importance in the intraoperative setting.
Technical Skills for Competence in TEE in Congenital and Pediatric Acquired Heart Disease
• Rich practical experience in echocardiography and specifically, in the TTE assessment of congenital and pediatric acquired heart disease (acquired by performing and interpreting these studies)
• Proficiency in the safe and effective use of conscious sedation for TEE (if within the scope of practice)
• Proficiency at probe insertion techniques (if within scope of practice)
• Proficiency in the operation of probe controls and instrument manipulations for acquisition of standard and modified views, Doppler information, and relevant data
• Proficiency in the optimization of 2D/3D images and Doppler settings by instrument control adjustments. Note that 3D TEE imaging represents an advanced application of TEE and the required competencies for 3D imaging may be limited to only certain individuals that consider this part of their practice.
• Proficiency in the anatomic interpretation of TEE images including the recognition of normal and abnormal anatomic findings
• Proficiency in imaging specific structures and characterizing congenital anomalies by TEE
• Proficiency in the intraoperative use of TEE and the postoperative assessment of the surgical intervention
• Proficiency in the use of TEE to guide catheter-based interventions, assess post-procedural results, and recognize complications
• Proficiency in TEE probe care and equipment handling (varies by institution)
• Proficiency in generating a TEE report to be included in the medical record

Table 3.8 Guidelines for training and maintenance of competence in TEE in children and all patients with CHD

Component	Objective	Duration	Number of cases
Echocardiography	Prior experience in performing/ interpreting TTE	6 months or equivalent	Minimum of 450 cases across all age groups
Esophageal intubation (if part of practice)	TEE probe insertion	Variable	25 cases (50% under 2 years of age)
TEE exam	Perform and interpret with supervision	Variable	50 cases
Ongoing TEE experience	Maintenance and competency	Annual	25–50 cases per year or achievement of laboratory-established outcomes variables

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training [13]. It should be mentioned that various centers that specialize in the care of adults with cardiovascular disease, including CHD, have successfully integrated non-cardiologists into intraoperative TEE assessment.

In contrast to the well-recognized role and contributions of adult cardiac anesthesiologists to TEE practice, the role of pediatric cardiac anesthesiologists has been less clear. It has been suggested that when cardiac anesthesiologists with appropriate training and expertise in pediatric TEE provide interpretation of the examination, a second provider trained in TEE or congenital cardiovascular anesthesiology should be available, in order to ensure undivided attention to peri-procedural TEE and limit any distractions from patient care [15]. It has also been debated whether TEE for pediatric cardiac surgery should be routinely performed and interpreted by pediatric cardiac anesthesia providers, and questions remain regarding what the exact role of a pediatric cardiac anesthesiologist should be with respect to perioperative imaging [125–127]. Unlike cardiac disease in adult patients, most abnormalities in children are structural in nature and their comprehensive assessment requires extensive knowledge of CHD. An in-depth and wide-ranging skill set is needed: familiarity with the 3D appearance of normal and abnormal cardiovascular anatomy and pathology for the vast array of CHD (as well as their structural variants); the physiologic impact and hemodynamic consequences of CHD, as well as its natural and unnatural history; and multiple medical, surgical, and catheter-based treatment options for the various types of pediatric heart disease. In the practice of pediatric TEE, it is also important to be familiar with disorders such as cardiomyopathies, inflammatory diseases of the myocardium, infections that can affect the heart, cardiac tumors, and many other acquired conditions of the cardiovascular system in children. Furthermore, an understanding of TEE technology is essential, including indications, contraindications, optimization of system settings, benefits and limitations of the modality, and the recognition of artifacts. Finally, a thorough knowledge of TEE techniques, probe insertion and manipulation, and the standard views and modifications required to evaluate CHD are essential, along with a comprehensive understanding of the TEE appearance of the many different forms of unoperated and operated CHD.

Whereas most pediatric and congenital cardiac anesthesia providers are familiar with the many applications of TEE and proficient in the assessment of intravascular volume status, global cardiac function, and intraoperative monitoring, the comprehensive anatomic evaluation and appraisal of surgical results in CHD (particularly in the case of more than simple lesions) is usually considered beyond their scope of practice in North America. A survey of the utilization of TEE during repair of congenital cardiac defects in North American Centers published in 2003 addressed, among several issues, performance practices among various centers [128]. The following was reported: (1) the TEE study was performed by a pediatric cardiologist in 85% of centers, with sonographer assistance in 38%; (2) in 26% of centers, TEE was performed by fellows in the presence of attending cardiologists; (3) anesthesiologists alone performed TEE in 3% of centers, while in an additional 3% of centers they were assisted by sonographers; (4) no center reported that TEEs were performed by sonographers without physician presence, and no center reported the use of telemetry. With respect to this data, it was noted that the numbers did not add up to 100% due to the fact that some centers provided more than one response.

In this regard, the practice of perioperative pediatric/congenital TEE varies between the United States, where in most cases a pediatric cardiologist or ACHD specialist is the primary echocardiographer, versus Europe and other regions of the world, where intraoperative imaging is mostly performed by the surgeon and anesthesiologist, with consultation from a cardiologist only as needed. Regardless of who renders the diagnostic assessment, there is an important role for all members of the perioperative team—surgeon, cardiologist, and anesthesiologist—with regard to perioperative imaging.

In his review of clinical outcomes in children, Stevenson highlighted the importance of physician skills for competent performance of intraoperative echocardiography during congenital heart surgery [129]. Clinical outcomes were better when TEE examinations were performed by physicians who met the criteria listed in the published guidelines. This article, accompanied by a thought-provoking editorial entitled

"*Transesophageal Echocardiography Guidelines: Return to Bypass or to Bypass the Guidelines?*", as well as several subsequent letters to the editor, highlighted the critical importance of sufficient training and expertise for intraoperative echocardiographers, regardless of specialty [130–132].

Certification in Transesophageal Echocardiography

There is currently no certification pathway specifically designed for the physician performing TEE in children, nor in the ACHD patient. The National Board of Echocardiography provides both basic and advanced certification in perioperative TEE. The goal of a basic certification is to recognize competence in the non-diagnostic use of the imaging modality within the customary practice of anesthesiology. The advanced certification, in contrast to the focus on intraoperative monitoring of the basic competency, recognizes the diagnostic skills required for intraoperative cardiac surgical intervention or postoperative medical/surgical management. The process of advanced certification involves fellowship training, passing an advanced exam, and performing a specified number of studies. The credentialing exam for advanced certification is oriented primarily toward the practice of adult echocardiography, and the content regarding CHD is relatively limited. The case requirements do not specify CHD. This certification expires after ten years, and to be recertified the individual must pass a recertification exam and complete recertification requirements. The details of this process can be found at www.echoboards.org.

Safety Considerations and Complications

Data Regarding Safety

Various reports have addressed the safety of TEE as the applications of this modality have expanded over time. The extensive TEE clinical experience in the adult population, including relatively high-risk patient groups, has shown an overall extremely favorable safety profile [133–141]. Although rarely observed, the most frequently encountered TEE complications in the adult relate to trauma to the oropharynx and/or esophagus, resulting in symptomatology such as pharyngeal discomfort, odynophagia, and dysphagia. The use of direct laryngoscopic guidance during TEE probe placement has been examined in adult patients in an effort to minimize potential oropharyngeal mucosal injury [142]. Whether this may benefit children remains to be determined but may be considered if difficulty is encountered during probe insertion.

Data regarding safety in the pediatric age group have likewise shown a low incidence of complications, in the range of 1% to 3% [143–146]. The use of TEE has been successfully reported in tiny infants well under 3.0 kg in weight [147]; however, caution must be exercised in this patient group and the expected benefits of the imaging approach should exceed the potential risks.

Stevenson prospectively examined the incidence and severity of complications during TEE imaging in 1650 pediatric cases (mean age of 3.6 years, mean weight of 17.2 kg) [143]. The complication rate was reported to be low, occurring in 2.4% of cases (failure of probe placement excluded). When encountered, problems were mostly related to the respiratory system or vascular compression. No significant bleeding, arrhythmias, esophageal injuries, or deaths were identified. Randolph and associates did not identify major complications among 1002 patients that comprised both children and adults with CHD [145]. Minor complications were identified in 1% of the cases, most often observed in infants less than 4 kg in weight. A report on a ten-year experience that examined 580 TEE studies during pediatric cardiac surgery observed an incidence of complications of 2.7% and no prolonged problems or morbidity related to TEE [146]. Others have reported similar findings [144].

Probe Insertion Failure

A retrospective study in neonates ≤4 kg examined risk factors for TEE probe insertion failure—defined by inability to pass the probe into the mid-esophagus or change in ventilatory or hemodynamic status in these infants [148]. Devices utilized included the biplane and mini-multiplane pediatric probes. Although TEE could be performed successfully in most of these neonates undergoing cardiac surgery, there were identifiable factors associated with probe insertion failure which included lower patient weight, abnormal craniofacial anatomy, prematurity, and 22q11 deletion. The current availability of the micro-multiplane pediatric TEE probe (Chap. 2) may overcome the challenge of device insertion in these small infants. Nevertheless, recognition of potential risk factors for probe insertion in general and a high-level of vigilance during esophageal intubation is warranted in neonates and very small infants.

The presence of Down syndrome has been associated with difficult TEE probe placement [33]. This may be related to the relatively large tongue or potential intrinsic narrowing of hypopharyngeal structures in this cohort. Individuals with Down syndrome are known to be at risk for upper cervical spine instability that may threaten spinal cord integrity. It may be prudent to exert gentle care during probe placement in these patients [149, 150]. The potential for sinus bradycardia and in very rare cases sinus arrest, presumably related to vagal stimulation during probe placement, has also been anecdotally observed in this subset of patients.

An investigation in children under 10 kg in weight demonstrated that head positioning to the side rather than to the midline facilitated TEE probe placement [151]. The study proposed that anatomic changes in the hypopharynx associated with head turning favored probe passage, which was confirmed by turning the head to the left.

Trauma to the Gastrointestinal Tract

Trauma to the esophagus during TEE imaging can be due to probe insertion, manipulation, or direct ultrasound energy transmission resulting in thermal injury. A few publications have addressed the subject of esophageal morbidity related to TEE in pediatric patients. A study by Greene and associates described findings upon flexible endoscopic examination in 50 children following cardiac surgery where TEE imaging was performed [152]. Children ranged from 4 days to 10 years of age, with a mean weight of 12.6 kg. Thirty-two of 50 patients (64%) were found to have abnormal findings on the endoscopic examination. These occurred more frequently in those under 9 kg of weight. Abnormalities included erythema, edema, and hematoma. Less frequently, mucosal erosion and petechiae were seen. No long-term feeding or swallowing difficulties were identified among the 48 patients who survived the operation. In view of the mild mucosal injury detected, it was suggested that meticulous care must be exercised in the insertion and manipulation of TEE probes in all patients, but particularly in the smallest of infants. To reduce the potential risk of pressure-related and thermal energy damage, the tip of the TEE probe should be advanced into the stomach and remain in an unlocked neutral position, non-imaging (frozen) mode, when not actively imaging. Some imagers prefer to disconnect the probe from the machine between pre and postoperative studies.

The potential contribution of TEE to oropharyngeal dysphagia after cardiac surgery has been of concern [153, 154]. A study in children undergoing open heart procedures with TEE reported an 18% incidence of dysphagia [155]. Risks factors included age under 3 years, preoperative tracheal intubation, long duration of tracheal intubation, and interventions for left-sided obstructive pathologies. Dysphagia affected postoperative recovery and contributed to major morbidity. Although the role that TEE imaging may play in postoperative swallowing dysfunction remains unclear, its potential impact as a risk factor should not be overlooked.

Airway and Hemodynamic Concerns

Another clinical concern in children has been that of upper airway obstruction requiring the need for tracheal reintubation in certain high-risk patients after TEE [156]. The effects of TEE probe placement on endotracheal tube cuff pressure have been examined, given the potential for related airway morbidity. A significant increase in endotracheal tube cuff pressure has been reported during TEE probe insertion, however this increase is transient and returns to baseline values upon probe advancement into the stomach [157, 158].

Less likely problems related to TEE include ventilatory or hemodynamic impairment. Reported complications include accidental tracheal extubation, ventilatory compromise due to impingement of the esophageal probe on the tracheobronchial tree, and alterations of cardiac rhythm [159–162]. Compression of adjacent cardiovascular structures by the probe has been reported, resulting in circulatory derangement [163]. Compression of an aberrant subclavian artery can lead to a dampened radial artery blood pressure tracing [164]. Descending aortic compression can manifest as a change in the contour of a lower extremity arterial pressure tracing or pulse oximeter signal. Serious complications such as esophageal perforation, unintended gastric incision during sternotomy, and subglottic stenosis have been described in the pediatric age group although, fortunately, these have been extremely rare [143, 165, 166]. Evidence linking anticoagulation with a significant risk for bleeding during a TEE examination is lacking. However, since minor trauma to oropharyngeal structures can occur at the time of probe placement and/or removal, judicious use of this modality is warranted in patients who are receiving anticoagulation therapy.

Andropoulos and colleagues evaluated the impact of TEE on ventilation and hemodynamic variables in small infants undergoing cardiac surgery [167, 168]. No significant changes in measured parameters of gas exchange and pulmonary mechanics were observed in relation to probe insertion. The investigation noted that hemodynamic complications from TEE, although possible, were rare. These data provided reassurance to those involved in intraoperative TEE imaging of very young infants.

One particular circumstance deserves further discussion. A cause for concern in infants with total anomalous pulmonary venous drainage is the potential for hemodynamic compromise resulting from compression of the pulmonary venous confluence by the TEE probe [169]. The issue was evaluated in a case series that included 28 infants (ages 1 day to 7 months) with various types of anomalous pulmonary venous connections [170]. Nearly a third of the cohort developed acute hypotension and hypoxemia following probe insertion. To reduce the potential risk of compression of the pulmonary venous confluence resulting in hemodynamic instability, it was suggested that TEE probe placement in these patients should be performed after sternotomy. Therefore, if TEE imaging is contemplated in these infants, close observation for possible hemodynamic compromise is warranted. Epicardial imaging offers a potentially less risky alternative in this setting.

Despite the rare potential for morbidity and higher likelihood of complications in small infants, the overall experience supports the impression that the benefit versus risk assessment significantly favors the use TEE in the pediatric age group. The micro-multiplane TEE is considered a safe device and in the current era that can be applied to more at-risk neonates. Further miniaturization of TEE imaging hardware in the future, if technologically feasible, may provide for even safer applications of this modality in the smallest of neonates.

Risk of Bacteremia and Endocarditis Prophylaxis

It has been reported that endoscopic procedures of the gastrointestinal tract can be associated with bacteremia [171]. The frequency of bacteremia has been linked to specific interventions performed. However, in general the overall incidence of bacteremia as a result of upper gastrointestinal endoscopy is considered small [172]. Although endocarditis temporally related to the TEE examination has been reported, the incidence of bacteremia associated with TEE is extremely low [173–177].

Current AHA guidelines do not recommend the administration of antibiotics solely to prevent endocarditis for patients who undergo gastrointestinal tract procedures [178]. The implication is that this also applies to esophageal instrumentation related to TEE.

Contraindications

Prior to the use of TEE in any patient, it is essential to consider potential contraindications, given the semi-invasive nature of the procedure and associated potential morbidity. Absolute and relative contraindications have been outlined in both the pediatric and adult TEE guidelines [13, 16]. Those noted in the recently published pediatric and congenital guidelines are listed in Table 3.9.

Patients with intrinsic esophageal abnormalities should be considered at potential risk for injuries related to TEE probe insertion and/or manipulation. High-risk esophageal conditions include unrepaired tracheoesophageal fistula, esophageal obstruction or stricture, and perforated hollow viscus. A history of prior esophageal or gastric surgery, severe coagulopathy, and significant thrombocytopenia all are relative contraindications. Although the presence of esophageal varices has been regarded a relative contraindication, recent reports in affected patients have indicated that the incidence of TEE-related variceal bleeding risk is low and the procedure appears to be safe in most individuals [179–181].

Surgical interventions addressing isolated aortic arch anomalies, such as vascular rings, generally do not benefit significantly from TEE. In fact, TEE probe insertion in these cases can lead to respiratory compromise, since the trachea and esophagus pass through a space surrounded by relatively rigid vascular structures, and when the TEE probe is inserted into the esophagus, compression can occur of the adjacent trachea.

The safety of TEE has not been formally examined following gastrostomy tube/button placement with or without Nissen fundoplication. It is unknown how long after these procedures TEE imaging can be safely undertaken, or whether the risk varies according to the exact nature of the procedure (percutaneous versus open gastrostomy tube placement). If a TEE examination is indicated in these patients, it might be reasonable to restrict imaging to the upper and mid esophagus and exclude interrogation from the transgastric and deep transgastric windows.

Whenever there are concerns regarding risks, if after careful assessment the use of TEE is favored, the following approaches might mitigate potential problems: a focused

Table 3.9 Contraindications to TEE

Absolute	Relative
Unrepaired tracheoesophageal fistula	History of prior esophageal or gastric surgery
Esophageal obstruction or stricture	History of esophageal cancer
Perforated hollow viscus	Esophageal varices or diverticulum
Active gastric or esophageal bleeding	Recent gastrointestinal bleed
Poor airway control	Active esophagitis or peptic ulcer disease
Severe respiratory depression	Vascular ring, aortic arch anomaly with or without airway compromise
Uncooperative, unsedated patient	Oropharyngeal pathology
	Severe coagulopathy
	Significant thrombocytopenia
	Cervical spine injury or anomaly
	Post-gastrostomy or fundoplication limit imaging to esophageal windows

Reprinted from Puchalski et al. [16]; with permission from Elsevier examination to address specific important questions, limiting unnecessary probe handling/manipulation, and restricting the performance of the TEE examination to individuals with the highest level of expertise. In the intraoperative setting, consideration should also be given to the use of alternate intraoperative imaging modalities, such as epicardial echocardiography, in high-risk patients.

Summary

High-resolution TEE imaging allows for comprehensive anatomic, hemodynamic, and functional evaluation in patients with CHD and in pediatric acquired heart disease. The extensive benefits of TEE in the perioperative period and other nonsurgical settings has led to its recognition as a critical tool, as well as its incorporation into the standard of care for children with cardiovascular disease (both congenital and acquired) and adults with CHD. It is anticipated that further refinements in ultrasound technology in the future will continue to expand the applications of TEE and add to the already significant contributions of this imaging modality for the management of these patients.

Questions and Answers

1. The following should be considered in all adults with a history of CHD scheduled to undergo TEE imaging *EXCEPT* for:
   a. Risk assessment
   b. Review of all available diagnostic studies
   c. Contraindications of the procedure
   d. Routine need for general anesthesia
   e. Study indications

   Answer: d

   Explanation: Transesophageal echocardiography is frequently used in the ambulatory setting in adult patients, where the study is undertaken after topical anesthesia is applied to the oropharynx and intravenous sedation is administered. This is unlike the TEE practice in children, who in most cases require endotracheal intubation and general anesthesia.

2. Relative contraindications to TEE in children include all *EXCEPT* for:
   a. Oropharyngeal pathology
   b. Vascular ring with airway compromise
   c. Esophageal stricture
   d. Severe coagulopathy
   e. History of gastric surgery

   Answer: c

   Explanation: Among the answers listed, all represent *relative* contraindications to TEE, except the presence of an esophageal stricture which is regarded an *absolute* contraindication.

3. The following factors are considered to increase risk during noncardiac surgery in ACHD and may be considered potential indications for perioperative TEE monitoring, *EXCEPT* for:
   a. Eisenmenger physiology
   b. Unrepaired tetralogy of Fallot
   c. Poor overall health
   d. Transposition of the great arteries, post arterial switch operation without residua
   e. Need for an emergent exploratory laparotomy in a patient who has previously undergone Fontan palliation

   Answer: d

   Explanation: Conditions among the patients listed such as cyanosis, pulmonary hypertension, poor health, and emergent interventions, all present increased perioperative risks (refer to Table 3.5) [62]. An adult with uncomplicated, repaired transposition should be considered normal anatomically and physiologically, and, TEE during noncardiac surgery would not be indicated in this patient based solely on the history of CHD.

4. The minimum number of TEE examinations to be performed and interpreted with supervision prior to independent practice as outlined in training guidelines for the performance of TEE in children and all patients with CHD is
   a. 25 cases
   b. 50 cases
   c. 75 cases
   d. 100 cases
   e. 150 cases

   Answer: b

   Explanation: The guidelines for training and maintenance of competence of TEE in children and all patients with CHD recommend that at least 50 TEE examinations should be performed and interpreted with supervision prior to independent TEE practice [16].

5. The following represents best TEE practice in all CHD patients undergoing imaging:
   a. Administration of endocarditis prophylaxis
   b. A comprehensive TTE examination prior to TEE
   c. Routine use of TEE probes with 3D capabilities
   d. Maintainance of the probe in an active imaging mode throughout the bypass period
   e. Uniform use of epicardial imaging

   Answer: b

Explanation: A complete TTE should be performed, or at least attempted in all patients prior to TEE imaging. Endocarditis prophylaxis is not routinely recommended by the AHA for gastrointestinal instrumentation, including TEE. Three-dimensional TEE imaging is currently only available for a subset of patients with CHD (older children, adolescents and adults) due to lack of hardware for this application in small children. During cardiopulmonary bypass, the probe should remain in a neutral position in the stomach in a non-imaging mode (frozen image or detached probe from imaging system). Epicardial imaging complements TEE assessment, and at times represents a safer or the only suitable intraoperative imaging modality, but in most cases TEE imaging is the preferred approach.

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