COMPREHENSIVE REVIEW

Safety of Transesophageal Echocardiography

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Since its introduction into the operating room in the early 1980s, transesophageal echocardiography (TEE) has gained widespread use during cardiac, major vascular, and transplantation surgery, as well as in emergency and intensive care medicine. Moreover, TEE has become an invaluable diagnostic tool for the management of patients with cardiovascular disease in a nonoperative setting. In comparison with other diagnostic modalities, TEE is relatively safe and noninvasive. However, the insertion and manipulation of the ultrasound probe can cause oropharyngeal, esophageal, or gastric trauma. Here, the authors review the safety profile of TEE by identifying complications and propose a set of relative and absolute contraindications to probe placement. In addition, alternative echocardiographic modalities (e.g., epicardial echocardiography) that may be considered when TEE probe placement is contraindicated or not feasible are discussed. (J Am Soc Echocardiogr 2010;23:1115-27.)

Keywords: Safety, Transesophageal, Echocardiography, Perioperative, Nonoperative, Complications, Contraindications

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Target Audience:
This activity is designed for all cardiovascular physicians and cardiac sonographers with a primary interest and knowledge base in the field of echocardiography; in addition, residents, researchers, clinicians, intensivists, and other medical professionals with a specific interest in cardiac ultrasound will find this activity beneficial.

Objectives:
Upon completing the reading of this article, the participants will better be able to:

1. Recognize the different risk profile for TEE in the operative and non-operative setting.
2. List the absolute and relative contraindications of TEE.
3. Recognize the common sites and mechanisms of potential injury related to TEE in both the adult and pediatric populations.
4. Appreciate the most common major and minor TEE-related injuries, including oropharyngeal, esophageal, and gastrointestinal injury.
5. Apply recommendations for the prevention of TEE-related orogastric, cardiovascular, and respiratory complications, and appreciate the echocardiographic alternatives to TEE.
6. Identify a subset of procedural risks more specific to the pediatric/infant population.

Disclosures:
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Transesophageal echocardiography (TEE) has become a standard intraoperative diagnostic technique for the management of patients undergoing cardiac surgery[1-4] as well as other major surgical procedures (i.e., lung transplantation[5,6] liver transplantation,[7] and aortic surgery[8]). High-risk patients may also benefit from transesophageal echocardiographic monitoring in a variety of surgical settings (e.g., lung, renal, abdominal, and head, neck, and chest wall surgeries).[9] In addition, patients in intensive care units (ICUs)[10-13] or emergency rooms may profit from the diagnostic information on TEE that cannot be obtained by other modalities in a timely manner.[14-17] Recently, the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography updated the practice guidelines for perioperative TEE to assist physicians in the appropriate application of TEE and to improve the outcomes of surgical patients.[9] These comprehensive guidelines focus on highlighting patient populations likely to benefit from TEE and also list relative and absolute contraindications to TEE probe insertion.

The American College of Cardiology Foundation and the American Society of Echocardiography, together with key specialty and subspecialty societies, published appropriateness criteria for TEE in a nonoperative setting in an effort to respond to the need

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Abbreviations
EGD = Esophagogastroduodenoscopy
GI = Gastrointestinal
ICU = Intensive care unit
TEE = Transesophageal echocardiography
TTE = Transthoracic echocardiography

for the rational use of imaging services.[18] In general, it is assumed that TEE is appropriately used as an adjunct or subsequent test to transthoracic echocardiography (TTE) when suboptimal images on TTE preclude obtaining a diagnostic study. The indications for which TEE may reasonably be the test of first choice include, but are not limited to, aortic pathology, cardiac valve dysfunction, percutaneous noncoronary cardiac interventions, infective endocarditis, atrial fibrillation or flutter, and embolic events.[18,19]

Although TEE is considered a safe and relatively noninvasive diagnostic technique, severe, even life-threatening complications have been reported (Table 1, Figure 1). The infrequency of serious complications and difficulties in evaluating rare events limit the identification of TEE-associated predictors of increased morbidity or mortality. Several retrospective studies involving larger patient populations have identified inherent risk factors associated with TEE. A literature search was conducted via Medline and PubMed (1966 to June 1, 2010), and the bibliographies of retrieved articles were also reviewed.

For practicing echocardiographers, it is important to be familiar with potential complications of TEE to allow a thorough risk-benefit analysis on an individual basis. This holds especially true for patients with preexisting gastroesophageal disease, for whom the decision about the benefit versus potential harm of TEE can be difficult.

In this review, we summarize the available literature pertaining to the risks, complication rates, and overall safety of TEE, with the goal of facilitating the identification of patients in whom alternative echocardiographic modalities or other invasive or noninvasive diagnostic strategies should be considered.

GENERAL CLINICAL EXPERIENCE OF TRANSESOPHAGEAL ECHOCARDIOGRAPHIC SAFETY

Reported rates of major TEE-related complications in ambulatory, nonoperative settings range from 0.2% to 0.5%. TEE-associated mortality has been estimated to be <0.01% (Tables 2 and 3).[20-23] These rates of adverse outcomes are comparable with those associated with gastroscopy or esophagogastroduodenoscopy (EGD), for which the overall risk for nonfatal complications is between 0.08% and 0.13%, and the reported mortality rate is approximately 0.004%.[24,25] In comparison with the use of TEE in a nonoperative setting, intraoperative TEE poses a slightly different risk profile, because it involves probe placement and manipulation in intubated patients under general anesthesia who have frequently received neuromuscular blocking drugs. These patients are unable to swallow to facilitate probe insertion and cannot respond to possibly injurious probe manipulations. Furthermore, several consecutive transesophageal echocardiographic examinations or continuous intraoperative monitoring might be required for a subset of surgical patients. Overall rates of TEE-related morbidity with intraoperative TEE, however, have been estimated to be similar to nonoperative patients and range from 0.2% to 1.2%.[26-29] In the largest study of intraoperative TEE–related complications to date, a single-center case series of 7,200 patients, Kallmeyer *et al.*[28] reported TEE-associated morbidity and mortality of 0.2% and 0%, respectively. In contrast, Lennon *et al.*[30] surveyed patients for later complications and suggested that rates of major gastrointestinal (GI) injuries (e.g., gastric laceration, hemorrhage, or perforation) could be as high as 1.2%. More than half of the complications presented >24 hours postoperatively, with one patient not presenting until day 11. The authors therefore suggested that the accurate assessment of overall risk for TEE may have previously been underestimated given a possible delay in the clinical manifestation of TEE-related GI injury.[30]

Table 1 TEE-related injuries

Site	Injury
Oropharyngeal	Lip bruising/laceration, loose/chipped tooth, displaced dentures, pharyngeal laceration, perforation of the hypopharynx, accidental tracheal intubation
Esophageal	Odynophagia, dysphagia, laceration/perforation, Mallory-Weiss tear
Gastric	Laceration/perforation, hemorrhage
Miscellaneous	Splenic laceration, compression of mediastinal structures, airway compromise, thermal injury/burn, tongue necrosis

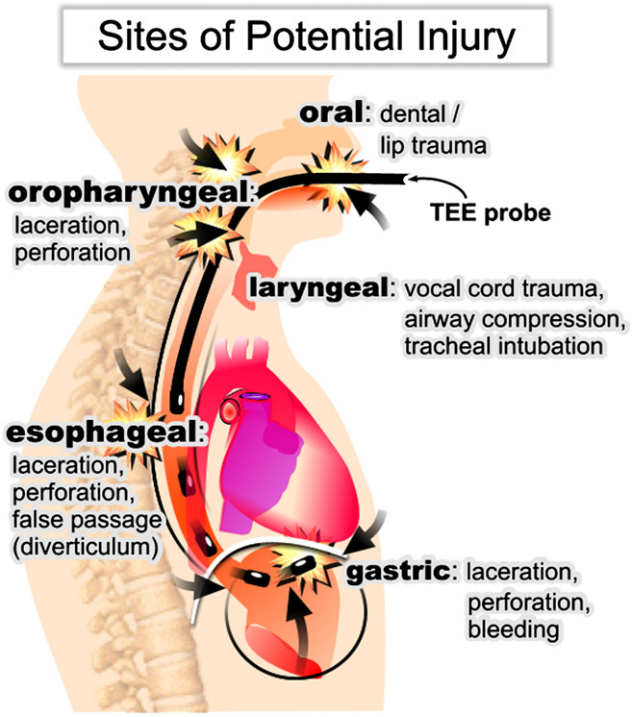

Figure 1 Sites of potential injury related to TEE include oral injury (e.g., lip or dental trauma), oropharyngeal injury (e.g., laceration, perforation), laryngeal injury (e.g., vocal cord trauma, compression of airway structures, inadvertent tracheal intubation), esophageal injury (e.g., laceration, perforation, false passage into diverticulum), gastric injury (e.g., lacerations or perforation particularly of fundus or gastroesophageal junction), and gastric bleeding.

Table 2 Incidence of TEE-related morbidity by complication and setting

Complication	Ambulatory	Intraoperative	Pediatric	ICU
Dental injury	ASA/SCA[31] 0.1%	Kallmeyer *et al.*[28] 0.03%		
Lip injuries	ASA/SCA[31] 13%			
Hoarseness	ASA/SCA[31] 12%			
Pharyngeal discomfort			Cyran *et al.*[126] 5%	
Severe odynophagia		Kallmeyer *et al.*[28] 0.1%		
Minor pharyngeal bleeding	Khandheria *et al.*[20] 0.14%; Daniel *et al.*[23] >0.01%; Seward *et al.*[22] 0.2%	Kallmeyer *et al.*[28] 0.01%		
Dysphagia	ASA/SCA[31] 1.8%	Hogue *et al.*[33] (OR, 4.68); Rousou *et al.*[32] (AO, 7.80); Owall *et al.*[35*]		
Bronchospasm	Daniel *et al.*[23] 0.07%; Chan *et al.*[69] 0.06%			
Laryngospasm	Seward *et al.*[22] 0.14%			
Endotracheal tube malposition		Kallmeyer *et al.*[28] 0.03%	Stevenson[70] 0.2%	
Inadvertent tracheal extubation			Stevenson[70] 0.5%	
Tracheal intubation with probe	Chan *et al.*[69] 0.02%			
Airway obstruction			Stevenson[70] 1%–5.5%	
Compression-related complications			Greene *et al.*[98] 0:50; Stevenson[70] 0.6%	
Dysrhythmias (AF, VF, VT, NSVT, AVB)	Daniel *et al.*[23] 0.06%; Chan *et al.*[69] 0.1%; Seward *et al.*[22] 0.3%		Stevenson[70] 0:1,650	Slama *et al.*[92] 1.6%
CHF	Seward *et al.*[22] 0.05%			
Perforation	Daniel *et al.*[23] <0.01%	Kallmeyer *et al.*[28] 0.01%; Chan *et al.*[69] 0:1,500; Lennon *et al.*[30] 0.3%		
Major bleeding	Daniel *et al.*[23] <0.01%	Kallmeyer *et al.*[28] 0.03%; Lennon *et al.*[30] 0.8%	Stevenson[70] 0:1,650	
Mortality	Daniel *et al.*[23] <0.01%; Khandheria *et al.*[20] 0.02%; Seward *et al.*[22] 0.01%	Kallmeyer *et al.*[28] 0:7,600	Stevenson[70] 0:1,650	Stoddard and Longaker[127] 0:283
Major morbidity	Seward *et al.*[22] 0.2%	Kallmeyer *et al.*[28] 0.2%; Lennon *et al.*[30] 1.2%; Owall *et al.*[35] 0:24		Stoddard and Longaker[127] <0.01%
Overall complication rate	Daniel *et al.*[23] 0.18%; Khandheria *et al.*[20] 2.8%	Kallmeyer *et al.*[28] 0.2%	Stevenson[70] 2.4%	Khoury *et al.*[94] 2.6%; Oh *et al.*[95] 4%; Poelaert *et al.*[93] 0:108

AF, Atrial fibrillation; *AO*, adjusted odds; *ASA*, American Society of Anesthesiologists; *AVB*, atrioventricular block; *CHF*, congestive heart failure; *NSVT*, nonsustained ventricular tachycardia; *OR*, odds ratio; *SCA*, Society of Cardiovascular Anesthesiologists; *VF*, ventricular fibrillation; *VT*, ventricular tachycardia.
*No significant difference in the incidence of dysphagia between TEE and no TEE.

RISK OF TRANSESOPHAGEAL ECHOCARDIOGRAPHY TO THE ORAL CAVITY, PHARYNX, ESOPHAGUS, AND GASTROINTESTINAL TRACT

Risk for Minor Oropharyngeal and Esophageal Injury

The overall incidence of TEE-related minor oropharyngeal injury, including lip trauma, dental injury, hoarseness, sore throat, dysphagia, or odynophagia, has been reported as 0.1% to 13%.[28,31] In Kallmeyer *et al.*'s[28] series, dental injury occurred at a rate of 0.03%. Odynophagia severe enough to be investigated by EGD was reported in seven patients (0.1%). Endoscopic evaluation of these individuals revealed linear abrasions in the upper (one patient), middle (one patient), and lower esophagus (two patients). In a case series of 838 consecutive cardiac surgical patients by Rousou *et al.*,[32] TEE was associated with an odds ratio for dysphagia 7.8 times greater than in patients in whom TEE was not performed. Although many of these events are frequently minor and self-limited, significant morbidity can result. In one study, dysphagia was associated with an increased incidence of aspiration, pneumonia, need for tracheostomy, and increased length of ICU stay.[33] Hogue *et al.*[33] reviewed the charts

Table 3 Complications of TEE in adult patients

Study	Population	Complications
Chan *et al.*[69]	1,700 ambulatory patients	Complication rate 0.47% (accidental tracheal intubation, bronchospasm, atrial fibrillation); placement failure 0.73%
Colreavy *et al.*[89]	255 critically ill patients	Complication rate 1.6%; transient hypotension, oropharyngeal bleeding, pulmonary aspiration
Daniel *et al.*[23]	10,419 conscious/sedated patients	Complication rate 0.18%; one mortality; placement failure 1.9%
Hogue *et al.*[33]	869 cardiac surgical patients	Risk for dysphagia independently correlated with intraoperative TEE, age, prolonged postoperative intubation
Hulyalkar and Ayd[27]	Cardiac surgical patients	No increase in incidence of 41 prospectively studied postoperative frank or occult patients, 40 controls; 200 bleeding or gastroesophageal retrospectively studied complaints from controls
Kallmeyer *et al.*[28]	7,200 cardiac surgical patients	Morbidity 0.2%, no deaths
Khandheria *et al.*[20]	7,134 conscious/sedated patients	Complication rate 2.8%; major complications (laryngospasm, sustained ventricular tachycardia, congestive heart failure, death) 0.26%; one death
Lennon *et al.*[30]	516 cardiac surgical patients	Major gastroesophageal complications 1.2%, four gastroesophageal tears/ulcers, two gastric perforations, time of presentation < 11 days
Min *et al.*[21]	10,000 conscious/sedated patients	Mortality 0%; orogastric perforation 0.03% (one hypopharyngeal, two cervical esophageal, no gastric)
Owall *et al.*[35]	57 cardiac surgical patients	No increased rate of odynophagia, sore throat
Poelaert *et al.*[93]	108 critically ill patients	One transient ventricular tachycardia
Rousou *et al.*[32]	838 cardiac surgical patients	Odds ratio 7.8 dysphagia

of 869 patients undergoing cardiac surgery (with and without TEE) and found that 4% subsequently had evaluation by barium swallow for swallowing dysfunction. Older age was the strongest independent predictor of swallowing dysfunction ($P < .001$), followed by the duration of postoperative intubation ($P = .001$), but the use of intraoperative TEE itself also appeared to be an independent risk factor for dysphagia (odds ratio, 4.68; 95% confidence interval, 1.76–12.43; $P = .003$).

Although an association between intraoperative TEE and postoperative dysphagia or odynophagia has been suggested,[28,32,33] an independent correlation has not been consistently demonstrated.[27,34,35] A prospective study by Owall *et al.*[35] randomized 57 patients undergoing cardiac surgery to either have or not have transesophageal echocardiographic monitoring and reported no significant differences in the rates of sore throat or odynophagia. Another nonrandomized study prospectively examined 41 patients undergoing cardiac surgery with and 40 patients without TEE, as well as retrospective analysis of another 200 cases, and found no difference in anorexia, dysphagia, and sore throat.[27] These studies are limited by size and/or lack of randomization. Given the morbidity that may be associated with severe dysphagia, further study of this area is warranted.

The incidence of dental injury ranges from 0.03% to 0.1%[28,31] and correlates with a patient's overall dental health. Dentures can also be dislodged by a TEE probe, highlighting a thorough preprocedural assessment of the oral cavity.[36] Sriram *et al.*[37] reported a case of tongue necrosis and formation of a permanent cleft associated with TEE probe position in a prolonged cardiac operation. Intraoperative tongue swelling in the setting of TEE has been described in the past,[38] but the majority of tongue pathology in the perioperative period is attributed to endotracheal tube position, the duration of endotracheal intubation,[39] or the surgical procedure itself (i.e., head and neck surgery, prone positioning, and risk for venous congestion).[40]

TEE and Orogastric Tract Perforation

Upper GI perforations after TEE have been reported in both pediatric and adult surgical patients,[29,30,41-49] with an estimated incidence between 0.01% and 0.04%.[28,30] This incidence is consistent with the approximate rate of one to three per 10,000 TEE-related perforations in ambulatory, conscious, or semiconscious patients.[21,23] GI perforation is associated with severe morbidity, and depending on mode of management (surgical vs medical) and time to diagnosis, mortality can range from 10% to 56%.[25,50] Delayed recognition of serious orogastric canal injury or perforation can be a problem in heavily sedated patients and in the setting of intraoperative TEE in anesthetized patients. Although evidence of rupture may be dramatic with the sudden appearance of the probe in the surgical field,[41] excessive orogastric hemorrhage, or subcutaneous emphysema, the signs of perforation are frequently subtle and likely to be masked by sedation or general anesthesia and postoperative intubation and sedation. Patients may present much later with nonspecific signs such as dyspnea, agitation, fever, or bloody nasogastric aspirates. Symptoms relating to spontaneous esophageal perforation such as Meckler's triad of vomiting, pain, and subcutaneous emphysema are rarely present, and according to one study of esophageal

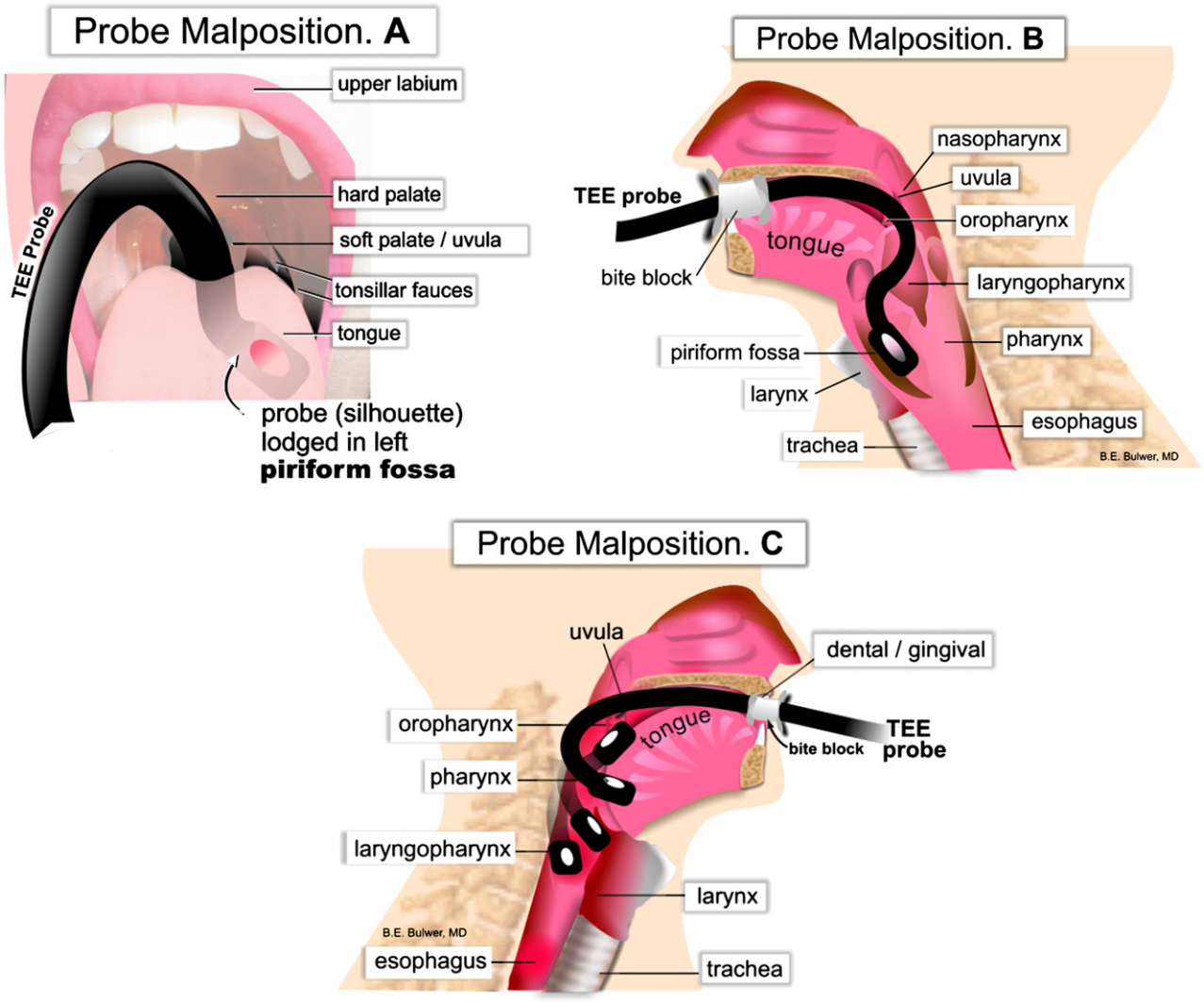

Figure 2 Probe malposition. **(A,B)** Difficulty during probe insertion can be encountered if the TEE probe is lodged into one of the pyriform sinuses. **(C)** In addition to causing mucosal injury to the oropharynx, the TEE probe can occasionally become distorted in extreme flexion. Attempts to withdraw a TEE probe in this configuration before advancing into the stomach and unfolding the kink can lead to severe esophageal injury.

perforation from all causes, up to 33% of initial chest radiographs are within normal limits.[51] A high level of vigilance for the potential for esophageal rupture must be maintained when considering the etiology of immediate postoperative findings such as pneumothorax, pleural effusions, or postprocedural shortness of breath.

Certain areas of the orogastric tract appear to be more susceptible to perforation than others. One review of EGD reported that ruptures occurred in the hypopharynx 20% of the time, the esophagus 40%, the stomach 5%, and the duodenum 35%.[25] During TEE probe placement, the parapharyngeal area may be vulnerable to injury if the probe gets lodged in one of the pyriform sinuses (Figures 2A and 2B). The upper esophagus at the level of the cricopharynx may also be particularly prone to injury, because the posterior aspect of the esophagus at the Lannier triangle, is covered only by fascia. Spasm or hypertrophy of the cricopharyngeal muscle[49] or narrowing of the space by osteophytic disease of the cervical spinal column may further increase risk for tissue disruption or perforation (Figure 1). In a recent, large single-center series of 10,000 consecutive transesophageal echocardiographic exams in ambulatory patients, Min *et al.*[21] reported three cases (0.03%) of TEE-associated perforation: one hypopharyngeal and two cervical esophageal. The authors noted that each case was associated with difficult probe placement and advanced patient age (>75 years).

An increased risk for perforation is associated with TEE in patients with gastroesophageal pathology (e.g., Zenker's diverticulum, esophageal stricture or obstructing mass, fibrosis secondary to prior chest radiation), distorted anatomy (e.g., massive cardiomegaly,[42] tracheoesophageal fistula or atresia), and resistance to probe insertion[41] (Table 4). However, perforations have also been documented in patients with no previous GI disease. One case report of a gastroesophageal junction perforation in an elderly patient with severe peripheral vascular disease undergoing revascularization of the lower extremity suggests that rupture could occur secondary to compression of ischemia prone tissues.[43] Some authors have speculated that factors such as

Table 4 Suggested contraindications to TEE

Absolute Contraindications	Relative Contraindications
Perforated viscous	Atlantoaxial joint disease*
Esophageal pathology (stricture, trauma, tumor, scleroderma, Mallory-Weiss tear, diverticulum)†	Severe cervical arthritis*
Active upper GI bleeding	Prior radiation to the chest
Recent upper GI surgery	Symptomatic hiatal hernia
Esophagectomy, esophagogastrectomy	History of GI surgery
	Recent upper GI bleed
	Esophagitis, peptic ulcer disease
	Thoracoabdominal aneurysm
	Barrett's esophagus
	History of dysphagia
	Coagulopathy, thrombocytopenia

*Causing restricted cervical mobility.

†TEE may be used for patients with oral, esophageal, or gastric disease, if the expected benefit outweighs the potential risk, provided the appropriate precautions are applied. These precautions may include the following: considering other imaging modalities (e.g., epicardial echocardiography), obtaining a gastroenterology consultation, limiting the examination, avoiding unnecessary probe manipulation, and using the most experienced operator.[9]

small stature, older age, chronic steroid use, prolonged procedure time, history of radiation therapy involving the thorax, presence of congestive heart failure, and low cardiac output before and after cardiopulmonary bypass may be correlated with increased risk for perforation or serious GI injury.[21,44,48]

TEE-Related GI Bleeding

GI trauma associated with TEE can, in rare instances, lead to serious bleeding. At least 13 cases of major upper GI hemorrhage have been reported in the literature to date.[23,29,30,52-56] Such episodes have involved large-volume hematemesis or orogastric aspirates of copious bright red blood or "coffee grounds" from 500 mL to as much as 9 L throughout the postoperative period. The overall incidence of major bleeding complications after TEE has been estimated to be between 0.02% and 1.0%.[23,28,30]

GI bleeding is often secondary to direct trauma to the mucosa or mechanical disruption of friable tissues (e.g., esophageal varices, esophageal tumor). Other non-GI bleeding, such as cardiac tamponade from rupture of an aortic aneurysm,[57] rupture of an aortic dissection,[58] and splenic laceration during intraoperative TEE,[59] have also been described. In a large case series of ambulatory (nonoperative), conscious transesophageal echocardiographic exams by Daniel *et al.*,[23] fatal hemorrhage occurred in one patient in whom TEE probe insertion disrupted esophageal tissue infiltrated by a lung tumor. Minor pharyngeal bleeding occurred in 0.01% (one of 10,218) of the examinations and can lead to aspiration in patients unable to protect their airways.

Given the potential for TEE to cause injury to the orogastric mucosa, there is a recognized risk for GI bleeding after intraoperative TEE during cardiac surgery, particularly given anticoagulation and post cardiopulmonary bypass coagulopathies. St-Pierre *et al.*[56] reported a case of massive hemorrhage after TEE in a patient undergoing coronary bypass grafting following an acute myocardial infarction. The patient was fully heparinized for cardiopulmonary bypass when the TEE probe was inserted and the echocardiographic exam was performed. Immediately after removal of the probe, 1.2 L of bright red blood drained from the orogastric tube. Subsequent EGD showed evidence of a mucosal tear near the gastroesophageal junction, as well as multiple erosions noted within the esophagus. In another case report, an 81-year-old woman undergoing aortic and mitral valve repair and coronary artery bypass surgery developed upper GI bleeding with almost 1 L of bright red blood aspirated by the orogastric tube. EGD showed several linear abrasions in the esophagus and a large contusion and mucosal tear at the gastroesophageal junction.[29]

Despite these and other reports, multiple studies have failed to show an increased risk for GI bleeding after TEE, even in the setting of anticoagulation. In fact, cardiac surgery itself is associated with upper GI bleeding, often secondary to bleeding duodenal ulcers or gastric erosions. In a case series of 8,559 patients undergoing cardiac surgery with cardiopulmonary bypass and no TEE, Egleston *et al.*[60] reported gastric complications in 0.41% of patients and an associated mortality rate of 25.7%. Thus, many GI injuries may not be due to TEE. Hulyalkar and Ayd[27] evaluated 41 patients undergoing cardiac surgery with TEE matched with 40 cardiac surgical patient controls in whom TEE was not performed. A retrospective analysis of additional 200 randomly selected patients was also performed. The investigators reported no difference between the control and TEE (prospective and retrospective) groups in the incidence of occult blood in nasogastric tube aspirates. Similarly, McSweeney *et al.*[61] examined risk factors for GI complications in patients undergoing cardiac surgery and reported that although the overall incidence of complications in patients undergoing intraoperative TEE was increased, TEE was not an independent predictor of major GI morbidity.

Although anticoagulation does not appear to greatly increase the risk for TEE-associated bleeding complications, procedures such as thrombolysis may increase the potential for subsequent bleeding after TEE. One large study reported severe hemorrhage with a hemothorax and shock after rupture of a large intramural hematoma of the esophagus in a patient who underwent thrombolysis for a partially thrombosed prosthetic mitral valve 4 hours after diagnostic TEE.[23] Given the potential for bleeding complications, placing TEE probes before full anticoagulation is generally advised.

Another presumed relative contraindication to TEE is the presence of esophageal varices (e.g., in liver transplantation patients). The concern for injury related to esophageal manipulation stems largely from case reports depicting complications from nasogastric tube or esophageal stethoscope placement in this patient population.[62] The guidelines on the prevention and management of gastroesophageal varices and variceal hemorrhage in cirrhosis by the American College of Gastroenterology[63] recommend endoscopic surveillance for gastroesophageal varices in patients with established diagnoses of cirrhosis. In a recently published retrospective case series in patients with known varices, Spier *et al.*[64] highlighted the relative safety of TEE. The authors concluded that adherence to the published American College of Gastroenterology surveillance guidelines seems safe practice in cirrhotic patients but recommend a preprocedural endoscopy for patients who have not previously been evaluated. To date, there are no reports of procedure-related complications of TEE in a patient with varices, suggesting that TEE can be performed without excessive risk in this patient population.

MISCELLANEOUS RISKS OF TRANSESOPHAGEAL ECHOCARDIOGRAPHY

Cardiovascular and Respiratory Complications

Reports of cardiovascular complications following TEE (e.g., associated arrhythmias) are rare. In a series of 341 obese patients and 323 control patients undergoing TEE, there was one case of atrial fibrillation in the obese group and one case of supraventricular tachycardia in the control group associated with the procedure.[65] Another study of 10,419 patients, of whom 88.7% were conscious and the vast majority without sedation, found three cases of nonsustained ventricular tachycardia, three cases of transient atrial fibrillation, and one case of third-degree atrioventricular block.[23] More literature exists on cardiovascular complications of upper GI endoscopy. In 21,946 endoscopic procedures performed over a 4-year period, there were four cases of supraventricular tachycardia, two cases of myocardial infarction, and one case of congestive heart failure.[66] Tseng *et al.*[67] found ventricular arrhythmias and myocardial ischemia, although mostly subclinical, to be common in patients with stable coronary artery disease undergoing emergent endoscopy for upper GI bleeds, especially in those with concomitant congestive heart failure. The growing use of TEE has led to a larger number of examinations in increasingly ill patients. Patients with cardiomyopathies potentially have a higher propensity for arrhythmias.[68] It is therefore conceivable that the release of adrenergic hormones and possible hypoxemia and hypercarbia from procedural sedation could act as triggers for arrhythmias.

Respiratory complications associated with TEE have also been described. Intraoperative TEE–related endotracheal tube malpositioning was noted in 0.03% of cases in Kallmeyer *et al.*'s[28] study and can potentially lead to catastrophic outcomes. However, respiratory compromise primarily occurs in the nonoperative setting and includes hypoxia, unplanned need for endotracheal intubation (secondary to oversedation or aspiration), accidental tracheal intubation with the probe, bronchospasm, and laryngospasm.[20,23,69,70] Methemoglobinemia and ensuing hypoxemia from topicalization of the oropharynx with benzocaine in preparation for TEE probe insertion has also been reported.[71] Airway compression is more common in the pediatric population, but has been found in adults as well.[72] Arima *et al.*[73] reported airway obstruction during TEE probe placement in a patient with tracheal distortion from an ascending aortic pseudoaneurysm. Recurrent laryngeal nerve injury has been encountered, particularly in the setting of transesophageal echocardiographic monitoring during neurosurgical procedures with patients in the sitting position.[31] In cardiac surgery, however, Kawahito *et al.*[74] followed 116 patients (64 patients with TEE and 52 patients with no TEE) and did not find a statistically significant difference in the incidence of recurrent laryngeal nerve injury.

Thermal Injury, Infectious, and Chemical Complications

Thermal tissue injury created by the piezoelectric crystal vibration within the probe tip or by direct absorption of ultrasound energy has also been proposed as a potential mechanism of injury.[75] Although animal studies have not demonstrated any histopathologic changes attributable to ultrasound energy in this setting,[75,76] thermal injury has been suspected in the setting of patients with severe atherosclerosis and possibly poorly vascularized and friable esophageal tissue.[43] Although the risk for thermal injury seems to be minimal, measures can be taken to limit the risk for thermal or necrotic damage to the esophageal mucosa. The probe may be set at the minimal gain and acoustic power necessary to obtain adequate images. In addition, the power can be turned off during cardiopulmonary bypass, while the probe tip should be kept in an unlocked, unflexed position when not being used. To address the issue of inadvertent heating of the probe, most probes are fitted with a thermistor to sense increases in temperature and are designed to automatically shut down if a preset threshold temperature (42°C–44°C) is reached.

The Association for Professionals in Infection Control and Epidemiology has published guidelines for infection prevention and control in flexible endoscopy.[77] Current standard high-level disinfection practices use a multistep process that relies on liquid chemical sterilants followed by a rinsing step with water. The use of aldehyde and nonaldehyde sterilization solutions has decreased endoscopy-related infection rates but carries the risk for chemical burns in case of insufficient water rinse.[78] Moreover, infectious complications (i.e., *Legionella pneumophila*) have been linked to contaminated rinse water.[79]

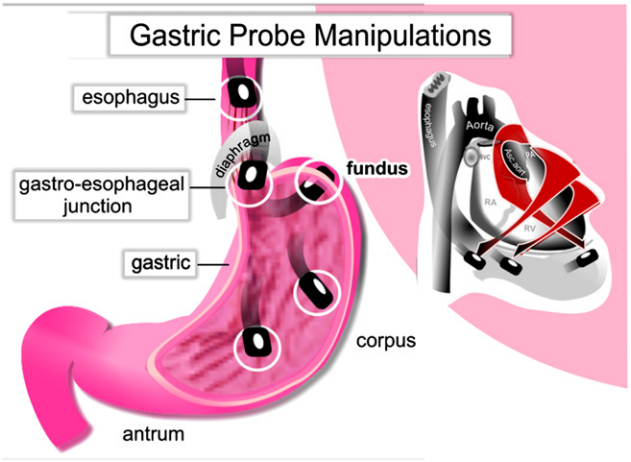

Figure 3 Gastric probe manipulations. Gastric injury typically occurs in the gastric fundus during deep transgastric probe manipulation, especially when requiring extreme anteflexion to bring the probe inline and in contact with the apex of the heart (e.g., deep transgastric aortic outflow view). The gastroesophageal junction is a vulnerable zone because probe manipulation at this level may place the relatively fixed tissues under considerable tension.

MECHANISMS OF TRANSESOPHAGEAL ECHOCARDIOGRAPHY–ASSOCIATED INJURY

TEE Probe Placement

Esophageal and gastric injury has long been a recognized risk associated with diagnostic interventions of the upper GI tract.[24,25,80-85] One proposed source of pharyngeal and esophageal injury during TEE involves improper probe placement. If the tip of the probe is not centered in the posterior pharynx and instead is placed laterally into the pyriform fossa, the probe may bend or "buckle" (Figures 2A–2C). Advancement of the probe in this situation may cause the tip to be oriented in an extreme retrograde position. Manipulation or rapid removal of the probe oriented in this manner could cause serious gastroesophageal laceration.[86] Similarly, manipulation of the probe while locked in extreme anteflexion could significantly distort the esophagus leading to serious mucosal tears or perforation.

TEE Probe Manipulation

Manipulation of even well-placed probes within the esophagus and gastrum has the potential to cause injury (Figure 3). An analysis of probe position during short-axis views of the left ventricle demonstrated the probe to be within the esophagus 13.6% of cases, the gastric cardia 13.6%, and the midgastrum 72.7%.[87] Significant anteflexion of the TEE probe tip at the gastroesophageal junction may put considerable tension on the tissues, causing mucosal disruption or Mallory-Weiss tears.[54,75] In two case reports, manipulation of the probe within the gastrum resulted in splenic laceration and injury, possibly secondary to torsion of the splenic hilum indirectly through the gastrosplenic ligament.[59,88] Laceration and even perforation of the gastric cardia and lesser curvature presumably from transgastric or deep transgastric probe manipulation has also been reported.[30]

Pressure-Related Injury

An often postulated mechanism of GI morbidity, though not clearly supported by the literature, involves tissue injury or necrosis secondary to pressure at the mucosal-probe interface, especially if the probe is retained for long periods in a flexed or locked position. Animal models, however, have failed to identify significant esophageal wall pressures (>17 mmHg) or evidence of mucosal injury even when the probe was maintained in maximal flexion for prolonged periods. Similarly, mucosal-probe contact pressures of up to 60 mmHg in humans have not been associated with identifiable injury.[75] O'Shea *et al.*[76] examined the excised esophagus of monkeys and dogs who had undergone prolonged (up to 8.5 hours) transesophageal echocardiographic examinations and found no evidence of erosion or necrosis, even in fully anticoagulated animals.

TRANSESOPHAGEAL ECHOCARDIOGRAPHY IN SPECIFIC PATIENT POPULATIONS

ICU Patients

TEE has an evolving role in critical care medicine,[89] particularly in circumstances in which TTE has been inadequate (e.g., small endocarditic lesions on the aortic valve). A growing body of literature describes the successful use of continuous transesophageal monitoring devices in critically ill patients.[90,91] The ICU population presents issues not encountered in the ambulatory setting. Critically ill patients are often ventilator dependent and frequently suffer from major cardiopulmonary dysfunction as well as coagulopathies, infections, and malnutrition. Frequently, patients' altered mental status and the sedation requirements limit their cooperation during TEE. Nevertheless, studies that have sought to evaluate the safety and utility of TEE in the critically ill have confirmed its relative safety in this patient group.[89,92-95] One case series of 108 consecutive transesophageal echocardiographic exams performed in a medical and surgical ICU within a 7-month period reported no serious complications except for a single incident of transient ventricular tachycardia.[93] The investigators reported that even patients with relative contraindications to TEE, such as esophagitis, esophageal varices, and oozing from the mouth or upper GI tract, underwent TEE without apparent complications.[93] Another case series of 255 consecutive transesophageal echocardiographic examinations in ICU patients was associated with a complication rate of 1.6%.[89] In that study, the most common complication was transient hypotension related to sedation used for probe insertion. Oropharyngeal bleeding was reported in one patient who had both uremia and thrombocytopenia. Pulmonary aspiration occurred in one patient in the setting of tracheal intubation in preparation for TEE. Although these reports reflect the overall low complication rate associated with TEE in ICU patients, they are admittedly based on relatively small populations and may not fully reflect the degree of inherent risk. Until more experience with TEE in the ICU is available, a degree of caution may be warranted. Therefore, it may be advisable to initially perform TTE in critically ill patients if feasible and perform TEE if TTE does not yield the required information.

Pediatric Patients

Until about 1989, the use of TEE in the pediatric population was limited to older children (aged > 7 years), because available probes were too large for use in infants or neonates.[1] Today, probes as small as 5.9 mm in diameter are available, and TEE has been performed in infants.[31,96] With the development of miniaturized, pediatric TEE probes, TEE has been increasingly used in pediatric cardiac surgery to monitor ventricular function, valvular or structural cardiac abnormalities, and hemodynamic status as well as a guide for medical and surgical intervention in the perioperative period. Advancement in probe technology such as the development of biplane pediatric probes and continuous-wave Doppler have further enhanced the utility and use of TEE in pediatric patients.

Although few studies have evaluated the safety of TEE in the pediatric population (Table 5), its use, particularly in very small infants and neonates, presents some risks and considerations not evident in other settings. First, because this population is unable to cooperate with awake TEE, the procedure is usually performed under general anesthesia with endotracheal intubation and ventilation.[70,97] Given the smaller size of these patients, TEE may be complicated by compression or obstruction of the airway or mediastinal structures associated with probe insertion.[98-100] Abnormalities of the central vasculature such as double aortic arch, interrupted aortic arch, or total anomalous pulmonary venous connection in this population may increase the risk for complications secondary to compression by the TEE probe. Hemodynamic compromise during TEE has been reported anecdotally,[98] and one series of 272 pediatric patients noted an incidence of 0.07%.[96,98] This complication, however, seems to occur only in very small patients, particularly those with abnormal vascular anatomy. Andropoulos *et al.*,[101] in a careful prospective evaluation of TEE for cardiac surgery in 25 patients weighing 2 to 5 kg, were unable to detect any hemodynamic perturbations attributable to TEE. The authors suggested that TEE-related hemodynamic complications are rare and should not prevent the use of TEE in small infants when otherwise indicated.

More common complications include inadvertent dislodgment of the endotracheal tube or advancement of the tube into the mainstem bronchus during TEE probe placement or advancement.[70,99] Certain probe manipulations have been particularly problematic. For example, hypotension and increased peak inspiratory pressures have been noted with transgastric views, likely because of anteflexion of the probe against the diaphragm[99] (Figure 3). Inadvertent gastric incision has occurred when the transgastric images were being obtained during sternotomy (related to the tenting of the stomach against the anterior abdominal wall).[70] These complications are clearly correlated with, though not limited to, patients of smaller size and weight.[70,96,101]

Nevertheless, available evidence suggests that TEE with properly sized probes appears to be relatively safe. Patients as small as 2.4 to 6.5 kg have undergone TEE with pediatric probes safely.[31,96,102-105]

Table 5 Complications of TEE in pediatric patients

Study	Number of patients	Complications
Bezold *et al.*[128]	341	Five ventilatory problems, five failed placements
Cyran *et al.*[126]	18	One transient pharyngeal pain; two <1-cm areas erythematic at gastroesophageal junction on EGD
Lam *et al.*[129]	59	Four complications (6.7%): desaturation, elevated left atrial pressures, pulmonary vein narrowing
Muhiudeen *et al.*[102]	90	Four complications (4.4%): severe bronchospasm, arrhythmias
Muhiudeen *et al.*[106]	127	26 complications (20.5%): 12 mainstem advancements of endotracheal tube
O'Leary *et al.*[130]	104	Two complications (1.9%): one dampening of femoral arterial wave form with probe flexion, one increased ventilatory pressure
Rice[132]	399	18 complications (4.5%): nine airway complications (50% of these patients had trisomy 21)
Ritter[103]	157	No failed placements, no complications
Rosenfeld[133]	86	Six complications: two failed placements, four elevated left atrial pressure
Stevenson and Sorensen[96]	348	17 complications (in 16 patients) (4.6%): airway obstruction, one gastric incision, failed placement
Stevenson[131]	667	24 complications (3.5%)
Stevenson[70]	1,650	3.2% complication rate
Stumper *et al.*[104]	25	No complications
Stumper[134]	261	Six complications (2.3%): one bleeding, two arrhythmias, one unspecified; two failed placements

Although adult TEE probes have been used successfully in patients as small as 14.7 kg,[96] some authors recommend using a pediatric TEE probe for all patients weighing < 20 kg.[96,102] A large case series of 1,650 pediatric patients (mean age, 3.6 years; mean weight, 17.2 kg) reported an overall complication rate of 3.2%, with no fatal events reported. Other studies have reported complication rates ranging from 1.8% to 8.7%.[70] One study, however, reported a complication rate as high as 20.4%, which was mostly related to right mainstem endotracheal tube advancement.[106] Greene *et al.*[98] evaluated 50 infants endoscopically immediately following intraoperative TEE (mean weight, 12.6 kg) and found mild mucosal injury including areas of erythema (54%), edema (24%), erosion (14.1%), hematoma (22%), and petechiae (4.1%) in up to 64% of study patients. Injury most often occurred at the level of the cricopharyngeal muscle and more commonly in smaller patients. Esophageal injury was not identified in another study that involved postmortem examination of infants after TEE for congenital heart disease surgery.[107] In addition, O'Shea *et al.*[76] evaluated the effect of prolonged manipulation of a 10-mm-diameter TEE probe on esophageal trauma in fully heparinized monkeys weighing 3 to 5 kg and could not identify a significant risk for gastroesophageal injury. In general, if an appropriately sized probe is carefully inserted and manipulated, TEE in pediatric patients appears to be relatively safe.

RECOMMENDATIONS

Prevention of Orogastric Tract Injury

Given the concerns for significant orogastric tract injury, forceful placement or removal of the TEE probe ought to be avoided under all circumstances. Probe insertion should never be attempted in the locked position. Generous lubrication might decrease friction along the mucosa and mucosal folds, while a bite block can help keep the probe midline and prevent dental injury as well as damage to the probe itself. If significant resistance is met during initial oropharyngeal insertion of the probe, placement under direct visualization may be attempted. A rigid laryngoscope–assisted insertion technique in anesthetized patients has been successfully used to prevent mucosal injury.[108] Nonoperative patients under conscious sedation can be asked to swallow to facilitate probe insertion. In pediatric patients weighing <10 kg, Mart and Rosen[109] found that TEE probe insertion was easier with the patient's head turned sideways. Unfortunately, no equivalent positioning studies are available in the adult population. Depending on patient anatomy, either head flexion or head extension with chin lift can potentially alleviate probe placement into the esophagus. Various devices to assist guidance of the probe have been described in the literature, and their use depends largely on individual experience and expertise or institutional availability.[110,111] Reuss *et al.*[112] reported the successful use of an esophageal overtube in four patients with previously difficult esophageal intubation. In practice, an anesthesiologist could place the TEE probe using direct laryngoscopy if the patient is deeply sedated. In case of continued resistance to placement or advancement of the probe, alternative imaging approaches, such as TTE or epicardial echocardiography, should be considered. If, however, the potential diagnostic information of TEE is deemed crucial, consideration may be given to an urgent gastroenterology consult. In some instances, the TEE probe can still be placed under direct visualization[113] or a formal upper GI examination can precede the study. The case of a high-risk patient with an esophageal stricture has been published in which the stricture was dilated, and a TEE probe subsequently placed.[114] However, esophageal injury has been reported despite preprocedural esophagoscopy.[115] Risk and benefit for each individual patient must be very carefully weighed in such situations. Contraindications (Table 4) to TEE probe placement very frequently include a history of dysphagia. Careful patient assessment for significant swallowing

difficulties and a thorough exam may therefore help identify potential abnormalities of the orogastric tract and alert the echocardiographer to an increased risk for severe injury.

Prevention of Cardiovascular and Respiratory Complications

Given the potential for airway and cardiovascular compromise during TEE examination, particularly in nonintubated patients, airway and additional emergency equipment (i.e., code cart) should be readily available. Patients need to be closely monitored during and after the procedure if sedation is administered. Moreover, echocardiographers are to be familiar with the local anesthetics used for airway topicalization and their recommended maximum doses to prevent drug-related toxicity. It seems prudent that TEE providers undergo formal training before the administration of intravenous conscious sedation to prevent inadvertent overdosing and potential for hypoxemia and/or hypercarbia. The American Society of Anesthesiologists has published practice guidelines for sedation and analgesia by nonanesthesiologists.[116] If significant amounts of sedation are to be used or a patient has little physiologic reserve (e.g., low ejection fraction, significant valvular stenotic disease, severe pulmonary hypertension, obstructive sleep apnea, significant pulmonary disease), experts with particular skills in airway management should be consulted.

ECHOCARDIOGRAPHIC ALTERNATIVES TO TRANSESOPHAGEAL ECHOCARDIOGRAPHY

In patients with relative or absolute contraindications to TEE (Table 4) or in situations in which attempted TEE probe placement is unsuccessful, TTE or epicardial echocardiography can be a useful alternative. During open-heart surgery, epicardial echocardiography represents a noninvasive and quite accessible alternative to TEE. Epicardial echocardiography was first introduced in the 1970s for the evaluation of open mitral commissurotomy.[117] Further development of TEE and its advantages of continuous imaging without interruption of the operation have contributed to the decreased use of epicardial echocardiography.

More recently, epiaortic echocardiography has been used intraoperatively to assess the aortic cannulation and cross-clamp sites to minimize embolic complications of cardiopulmonary bypass. This approach has been shown to significantly influence intraoperative surgical decision making.[118] Several authors have suggested that epiaortic echocardiography may occasionally offer superior imaging and evaluation of aortic valve pathology.[119,120] In some circumstances, epicardial imaging may allow for better Doppler beam alignment and thus permit more accurate measurement of valve gradients and valve areas compared with TEE. Epicardial echocardiographic measurement of aortic valve area has recently been validated compared with TEE, TTE, and cardiac catheterization.[121] The epicardial approach has also been used in pediatric cardiac surgery both as an alternative and as a complementary approach to TEE.[104] A comprehensive epicardial and epiaortic exam, with correlations to the image planes identified with TEE, has been described.[122] Alternative approaches such as substernal echocardiography or intracardiac echocardiography may also prove to be useful in the intraoperative and perioperative settings.[123,124] These innovations are currently limited by considerations of increased cost, limited windows, time required for examinations, and additional expertise necessary[125] but may be useful options in selected patient populations.

CONCLUSIONS

TEE represents a valuable and generally safe diagnostic and monitoring tool for the evaluation of cardiac performance and structural heart disease and can favorably influence clinical decision making. Although complications associated with TEE probe placement and manipulation can occur, these events are rare. Awareness of the possible complications, proper identification, and careful assessment of patients who are at increased risk for adverse events related to TEE are very important. In those patients, the use of alternative imaging techniques should be considered to further minimize TEE-associated injury.

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