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Section 1 Fundamentals of transesophageal echocardiography

Section 1 Chapter 1

Fundamentals of transesophageal echocardiography

Introduction: indications, training, and accreditation in transesophageal echocardiography

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History and development of TEE

Transesophageal echocardiography (TEE) is a relatively recent development in imaging. The major innovations in TEE have all occurred since 1970. Early workers had both Doppler [1,2] and M-mode technology [3] available for use via the esophageal route, but the most significant development was the rigid, mechanical, two-dimensional, echocardiographic transesophageal endoscope in 1977 [4]. The initial device was a mechanical rotating transducer mounted on a rigid endoscope. This was replaced by a flexible endoscope, and linear and sector phased array technology was further incorporated.

Initially, transducers ranging from 10 MHz to 2.25 MHz were used, although the highest-frequency transducers were developed for gastrointestinal rather than cardiac imaging. In the early 1980s, following further technological developments, the value of TEE was established both as an outpatient diagnostic tool and for intraoperative monitoring of left ventricular function and air embolism. Further development was accelerated in the later 1980s by two separate events: the reporting of the value of TEE in establishing the diagnosis of aortic dissection [5,6], and the development of a high-resolution transesophageal probe with pulsed and color-flow Doppler technology.

This specification has formed the basis for the current standardized TEE probe, i.e. a flexible endoscope without optics or suction, 5 MHz transducer, 8–11 mm diameter adult endoscope with a 100 cm shaft length, four-way movable tip, and pulsed-wave and color-flow Doppler technology. Other more recent developments include a smaller endoscopic shaft with a diameter as small as 4 mm, variable-frequency transducers ranging from 3.5 to 7 MHz, omniplane transducers capable of viewing the heart from a wide variety of angles, and continuous-wave Doppler technology. Most recently, tissue Doppler imaging has become standard on most TEE systems, and three-dimensional (3D) imaging. ‘Live’ 3D and further 3D technologies are becoming routinely incorporated [7].

Despite its relatively short history, TEE has become a well-established imaging modality. It has enabled the more accurate diagnosis of complex lesions in cardiology, and its use in the perioperative setting has had a marked impact on the development of cardiac anesthesia and surgery.

Indications for TEE examination

The indications for TEE examination in Europe were first published on behalf of the Working Group of the European Society of Cardiology in 2001 [8].

The authors’ intention was to briefly describe the minimal requirements for a complete TEE examination. The primary indications for TEE stated by the authors were to identify sources of embolism, and to evaluate infective endocarditis, aortic aneurysm and aortic dissection, mitral regurgitation, and prosthetic valves (Table 1.1). However, the authors also noted that the indications for TEE were constantly increasing, and that frequently TEE was undertaken in circumstances where transthoracic echo had failed to provide sufficient information in an individual patient.

In contrast, perioperative TEE is undertaken as a stand-alone procedure, although there is a high likelihood that many patients will have received a preoperative transthoracic (TTE) examination at some point.

The first report on the indications for perioperative TEE was published in 1996 by the American Society of Anesthesiologists (ASA) and the Society of Cardiovascular Anesthesiologists (SCA) [9]. In these guidelines, the authors addressed the indications for TEE based on the level of evidence supporting their use, and also the proficiency of those carrying out the examination. Category I indications were supported by the strongest level of evidence or expert opinion, Category II indications were supported by lesser

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Table 1.1. Principal TEE indications: essential views and structures in specific clinical conditions [8]

1. Source of embolism
• Left ventricular apex or aneurysm (transgastric and low transesophageal two-chamber views)
• Aortic and mitral valve
• Ascending and descending aorta, aortic arch
• Left atrial appendage (including pulsed-wave Doppler exam); note spontaneous contrast
• Left atrial body including interatrial septum; note spontaneous contrast
• Fossa ovalis/foramen ovale/atrial septal defect/atrial septal aneurysm; contrast + Valsalva
2. Infective endocarditis
• Mitral valve in multiple cross-sections
• Aortic valve in long- and short-axis views; para-aortic tissue (in particular, short-axis views of aortic valve and aortic root) to rule out abscess
• Tricuspid valve in transgastric views, low esophageal view, and right ventricular inflow–outflow view
• Pacemaker, central intravenous lines, aortic grafts, Eustachian valve, pulmonary valve in longitudinal right atrial views and high basal short-axis view of the right heart (inflow–outflow view of the right ventricle)
3. Aortic dissection, aortic aneurysm
• Ascending aorta in long-axis and short-axis views, maximal diameter; note flap or intramural hematoma, para-aortic fluid
• Descending aorta in long- and short-axis views; note maximal diameter, flap, intramural hematoma, para-aortic fluid
• Aortic arch; note maximal diameter, flap, intramural hematoma, para-aortic fluid
• Aortic valve (regurgitation, annular diameter, number of cusps)
• Relation of dissection membrane to coronary ostia
• Pericardial effusion, pleural effusion
• Entry/re-entry sites of dissection (use color Doppler)
• Spontaneous contrast or thrombus formation in false lumen (use color Doppler to characterize flow/absence of flow in false lumen)
4. Mitral regurgitation
• Mitral anatomy (transgastric basal short-axis view, multiple lower transesophageal views); emphasis on detection of mechanism and origin of regurgitation (detection and mapping of prolapse/flail to leaflets and scallops, papillary muscle and chordal integrity, vegetations, paraprosthetic leaks)
• Left atrial color Doppler mapping with emphasis on jet width and proximal convergence zone
• Left upper pulmonary, and, if eccentric jet present, also right upper pulmonary venous pulsed Doppler
• Note systolic or mean blood pressure!
5. Prosthetic valve evaluation
• Morphological and/or Doppler evidence of obstruction (reduced opening/mobility of cusps/disks/leaflets and elevated velocities by CWD)
• Morphological and Doppler evidence of regurgitation, with mapping of the origin of regurgitation to specific sites (transprosthetic, paraprosthetic); presence of dehiscence
• Presence of morphological changes in the prosthetic structure: calcification, perforation of bioprostheses, absence of occluder
• Presence of additional paraprosthetic structures (vegetation/thrombus/pannus, suture material, strand, abscess, pseudoaneurysm, fistula)

evidence or expert consensus, and Category III indications had little scientific or expert support. The Category III level may have been in part due to the absence of evidence, rather than the presence of evidence refuting any claim to benefit or value. As with the European consensus, which was published a few years later [8], the indications referred to clinical problems, which may be multiple in some patients.

In 1997 the American College of Cardiology (ACC) and the American Heart Association (AHA) published guidelines for the clinical application of echocardiography [10]. These guidelines referred to the overall indications for echocardiography, rather than addressing the relative merits of transthoracic and transesophageal studies. The guidelines were updated in 2003 [11], and that publication included a new and in-depth analysis of the indications for intraoperative echocardiography. These recommendations are shown in Table 1.2.

Once again the levels of evidence were stratified, although on this occasion the indications were divided into Classes I, IIa, IIb, and III, as follows:

- Class I – conditions for which there is evidence and/or general agreement that a given procedure or treatment is useful and effective
- Class II – conditions for which there is conflicting evidence and/or a divergence of opinion about the usefulness/efficacy of a procedure or treatment
    - IIa – weight of evidence/opinion is in favor of usefulness/efficacy
    - IIb – usefulness/efficacy is less well established by evidence/opinion
- Class III – conditions for which there is evidence and/or general agreement that the procedure/treatment is not useful/effective and in some cases may be harmful

Taking into account the original 1996 literature and the newer literature considered in the update, the authors identified a total of 706 publications that have contributed to this recent evidence base on intraoperative TEE.

Table 1.2. Indications for intraoperative TEE [11]

Class I
1. Evaluation of acute, persistent, and life-threatening hemodynamic disturbances in which ventricular function and its determinants are uncertain and have not responded to treatment
2. Surgical repair of valvular lesions, hypertrophic obstructive cardiomyopathy, and aortic dissection with possible aortic valve involvement
3. Evaluation of complex valve replacements requiring homografts or coronary reimplantation, such as the Ross procedure
4. Surgical repair of most congenital heart lesions that require cardiopulmonary bypass
5. Surgical intervention for endocarditis when preoperative testing was inadequate or extension to perivalvular tissue is suspected
6. Placement of intracardiac devices and monitoring of their position during port-access and other cardiac surgical interventions
7. Evaluation of pericardial window procedures in patients with posterior or loculated pericardial effusions
Class IIa
1. Surgical procedures in patients at increased risk of myocardial ischemia, myocardial infarction, or hemodynamic disturbances
2. Evaluation of valve replacement, aortic atheromatous disease, the Maze procedure, cardiac aneurysm repair, removal of cardiac tumors, intracardiac thrombectomy, and pulmonary embolectomy
3. Detection of air emboli during cardiotomy, heart transplant operations, and upright neurosurgical procedures
Class IIb
1. Evaluation of suspected cardiac trauma, repair of acute thoracic aortic dissection without valvular involvement, and anastomotic sites during heart and/or lung transplantation
2. Evaluation of regional myocardial function during and after off-pump coronary artery bypass graft procedures
3. Evaluation of pericardiectomy, pericardial effusions, and pericardial surgery
4. Evaluation of myocardial perfusion, coronary anatomy, or graft patency
5. Dobutamine stress testing to detect inducible demand ischemia or to predict functional changes after myocardial revascularization
6. Assessment of residual duct flow after interruption of patent ductus arteriosus
Class III
1. Surgical repair of uncomplicated secundum atrial septal defect

Table 1.3. New intraoperative TEE findings in two large series of patients

New finding	Mishra *et al.* [13]	Click *et al.* [14]
Mitral regurgitation	0.4%	—
Aortic regurgitation	0.2%	—
Tricuspid regurgitation	0.3%	—
Overall different valve pathology	1.0%	7.5%
Left ventricular thrombi	0.6%	1.1%
Ventricular septal defect	0.05%	—
Ascending/descending aorta pathology	0.7%	—
New ischemic areas	1.6%	—
Patent foramen ovale	—	3.1%
Overall	4%	15%

Given that some of the conditions considered are pathophysiological states, for example the risk of ischemia and/or myocardial infarction, rather than specific diagnoses, it could be argued that the 10 indications identified as being worthy of Class I and Class IIa cover the majority of cardiac surgery in adults and pediatrics. Thus, unless there are specific contraindications to TEE, many centers view the intraoperative use of TEE as a routine procedure with potential value in all cardiac surgery patients.

Notwithstanding the clear authority of these guidelines, it is pertinent to consider some of the evidence base for their conclusions.

Savage *et al.* [12] demonstrated that in high-risk coronary patients the routine use of intraoperative TEE resulted in major changes in surgery in 33% of the patients, and in major changes in the hemodynamic management in 51% of the patients. Mishra *et al.* [13] examined 5025 patients, including 3660 coronary bypass (CABG) surgeries and 1365 valve surgeries. Routine TEE examination before cardiopulmonary bypass (CPB) led to a major change in surgical planning in 5% of the coronary cases and in 3.5% of the valve cases. Following CPB, hemodynamic interventions were introduced on the basis of the TEE-derived information in 26% of the CABG patients and in 10.5% of the valve patients.

Click *et al.* [14] reported unexpected findings before CPB in 15% of the patients undergoing routine TEE during cardiac surgery. In 95% of these cases, these new findings resulted in major changes in the planned surgery. In the same series, 4% of the patients required major changes in surgery including a second run on CPB, or complex hemodynamic management after CPB (Table 1.3). Schmidlin *et al.* [15] reported a series of 2296 cardiac operations with the routine use of TEE: 9.6% of the patients received additional surgery and 49% required changes in the hemodynamic management based on TEE assessment and monitoring.

Studies on the intraoperative management of patients undergoing valve replacement have shown that TEE contributes frequently to intraoperative decision making and assessment, and on occasion to a substantial alteration in the surgical plan [16,17]. Similar findings have been shown in patients undergoing mitral valve repair [18–22]. Intraoperative TEE has been found to be useful in locating the size and source of air embolization following withdrawal of cardiopulmonary bypass [23], and in stratifying the risk of embolization from aortic atheroma in cardiac surgery patients [24].

The incidence of new intraoperative findings during a TEE examination has been identified as a reason for routine TEE examination during cardiac surgery, but also as a cause for concern. Clearly, a full preoperative examination and work-up should remove the possibility of unexpected and new findings on intraoperative TEE examination. However, the demonstration of new information is a common finding in many series of patients, and from major institutions. This does not necessarily imply an inadequate preoperative study, but may be due to the higher definition of a TEE examination in patients with poor transthoracic acoustic windows, the non-routine use of preoperative TEE in the majority of institutions, and recent changes that may have occurred in the clinical status of the patient.

Routine intraoperative use of TEE has been shown to lead to an improvement in both surgical and anesthetic management, which presumably is translated into better and more consistent outcomes for patients. However, for TEE to be routinely available during cardiac surgery there needs to be both adequate equipment and sufficient trained operators, both of which may be a major limitation to the provision of a comprehensive service. In this situation, the perioperative TEE service may need to be limited to Class I indications.

However, even in those circumstances where a comprehensive intraoperative TEE service is available, patients should have their primary echocardiographic evaluation before surgery, not during it. Whilst it is doubtless useful to be able to check the preoperative findings, in particular intraoperative TEE should not replace preoperative assessment of a valve lesion by transthoracic echocardiography or catheterization. Intraoperative transesophageal echocardiography can confirm the preoperative diagnosis, provide additional details that may guide the surgical procedure, and help to guide management of hemodynamics. It remains the best means of immediately assessing the technical results of the surgical procedure in the operating room [25].

Training and accreditation in TEE

The use of TEE as a diagnostic tool in the echo lab, and as a diagnostic and monitoring tool during and after cardiac or other major operations, has increased significantly. As a result, patient benefit is maximized not only by expert consensus on indications for the procedure, but also by the proficiency and training of the echocardiographer. Both of the early documents on guidelines for practice make it clear that training and continuing education, practice, and update is necessary for an effective service [8,9].

The AHA/ACC updated guidelines published in 2003 [26] contain recommendations for the cognitive and technical skills required for competence in TEE (Table 1.4), cognitive and technical skills needed

Table 1.4. Cognitive and technical skills required for competence in TEE [26]

Cognitive skills
• Basic knowledge outlined in Tables 2 [Basic cognitive skills required for competence in echocardiography] and 4 [Cognitive skills required for competence in adult TEE]
• Knowledge of the appropriate indications, contraindications, and risks of TEE
• Understanding of the differential diagnostic considerations in each clinical case
• Knowledge of infection control measures and electrical safety issues related to the use of TEE
• Understanding of conscious sedation, including the actions, side effects, and risks of sedative drugs, and cardiorespiratory monitoring
• Knowledge of normal cardiovascular anatomy, as visualized tomographically by TEE
• Knowledge of alterations in cardiovascular anatomy that result from acquired and congenital heart diseases and of their appearance on TEE
• Understanding of component techniques for transthoracic echocardiography and for TEE, including when to use these methods to investigate specific clinical questions
• Ability to distinguish adequate from inadequate echocardiographic data, and to distinguish an adequate from an inadequate TEE examination
• Knowledge of other cardiovascular diagnostic methods for correlation with TEE findings
• Ability to communicate examination results to the patient, other healthcare professionals, and medical record
Technical skills
• Proficiency in using conscious sedation safely and effectively
• Proficiency in performing a complete transthoracic echocardiographic examination, using all echocardiographic modalities relevant to the case
• Proficiency in safely passing the TEE transducer into the esophagus and stomach, and in adjusting probe position to obtain the necessary tomographic images and Doppler data
• Proficiency in operating correctly the ultrasonographic instrument, including all controls affecting the quality of the data displayed
• Proficiency in recognizing abnormalities of cardiac structure and function as detected from the transesophageal and transgastric windows, in distinguishing normal from abnormal findings, and in recognizing artifacts

to perform perioperative echocardiography at a basic (Table 1.5) and advanced (Table 1.6) level, as well as training and performance maintenance requirements in both laboratory and perioperative settings (Table 1.7). For echocardiographers in the laboratory, recent publications have outlined the requirements for accreditation of echo labs under the auspices of the European Society of Cardiology (ESC) and the European Association of Echocardiography (EAE) [27], and also recommendations for the standardization of performance, digital storage, and reporting of echocardiographic studies as it relates to transthoracic echocardiography [28]. Whilst not exact in every detail, many of these recommendations would be appropriate to TEE studies also, particularly when the TEE study is a comprehensive perioperative study.

Anesthesiologists have become increasingly involved in perioperative echocardiography, for a number of reasons. First, the anesthesiologist's constant intraoperative presence means that instead of performing a "snapshot" preoperative study, there is no constraint to performing serial studies, extending from the preoperative to the postoperative period. Second, the use of TEE as a monitoring as well as a diagnostic tool has allowed us to benefit from a wealth of hemodynamic and other information to aid the patient's perioperative management.

Initially, apart from those anesthesiologists with formal training in cardiology, training in TEE was variable and frequently poorly structured. Attempts

Table 1.5. Cognitive and technical skills needed to perform perioperative echocardiography at a basic level [26]

Cognitive skills
• Basic knowledge outlined in Table 2 [Basic cognitive skills required for competence in echocardiography]
• Knowledge of the equipment handling, infection control, and electrical safety recommendations associated with the use of TEE
• Knowledge of the indications and the absolute and relative contraindications to the use of TEE
• General knowledge of appropriate alternative diagnostic modalities, especially transthoracic and epicardial echocardiography
• Knowledge of the normal cardiovascular anatomy as visualized by TEE
• Knowledge of commonly encountered blood flow velocity profiles as measured by Doppler echocardiography
• Detailed knowledge of the echocardiographic presentations of myocardial ischemia and infarction
• Detailed knowledge of the echocardiographic presentations of normal and abnormal ventricular function
• Detailed knowledge of the physiology and TEE presentation of air embolization
• Knowledge of native valvular anatomy and function, as displayed by TEE
• Knowledge of the major TEE manifestations of valve lesions and of the TEE techniques available for assessing lesion severity
• Knowledge of the principal TEE manifestations of cardiac masses, thrombi, and emboli; cardiomyopathies; pericardial effusions and lesions of the great vessels
Technical skills
• Ability to operate the ultrasound machine, including controls affecting the quality of the displayed data
• Ability to perform a TEE probe insertion safely in the anesthetized, intubated patient
• Ability to perform a basic TEE examination
• Ability to recognize major echocardiographic changes associated with myocardial ischemia and infarction
• Ability to detect qualitative changes in ventricular function and hemodynamic status
• Ability to recognize echocardiographic manifestations of air embolization
• Ability to visualize cardiac valves in multiple views and recognize gross valvular lesions and dysfunction
• Ability to recognize large intracardiac masses and thrombi
• Ability to detect large pericardial effusions
• Ability to recognize common artifacts and pitfalls in TEE examinations
• Ability to communicate the results of a TEE examination to patients and other healthcare professionals and to summarize these results cogently in the medical record

Table 1.6. Skills necessary to perform perioperative echocardiography at the advanced level [26]

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

Table 1.7. Numbers of examinations and other key training recommendations for basic and advanced perioperative echocardiography [26]

	Basic	Advanced
Minimum number of examinations	150	300
Minimum number personally performed	50	150
Program director qualifications	Advanced perioperative echocardiography training	Advanced perioperative echocardiography training plus at least 150 additional perioperative TEE examinations
Program qualifications	Wide variety of perioperative applications of echocardiography	Full spectrum of perioperative applications of echocardiography

were made to improve this, and the first educational programmes in the USA consisted of a combination of cardiology tutorials, self-learning, participation in echo courses, and residency in echo-labs and operating rooms [29,30]. Subsequently, a joint effort of the ASA and SCA produced a common pathway leading to practice guidelines for perioperative transesophageal echocardiograpy [9].

In 1999, the American Society of Echocardiography (ASE) and the SCA jointly published guidelines for performing a comprehensive intraoperative TEE study [31], and the guidelines for training in perioperative echocardiography were published by the same group in 2002 [32]. Two levels of practice were defined: basic and advanced, with different theoretical and practical requirements for each. A written examination administered by the National Board of Echocardiography has been in place since 1996 for those seeking to demonstrate skills and knowledge through an accreditation process.

Table 1.8. European accreditation in TEE: European Association of Echocardiography (EAE) and European Association of Cardiothoracic Anaesthesiologists (EACTA)

Step 1
A written exam held twice a year
This exam consists of multiple choice questions (MCQ, single best answer format) divided into two sections:
• Reporting related to TEE videos displayed on screen
• Theory
To be successful, a candidate *must pass both sections of the written exam* (reporting and theory) at the same time
Step 2
A practical assessment to be completed within 12 months of passing the written examination

TEE accreditation in Europe

In Europe, the problem of training and accreditation in perioperative TEE has been addressed, during the last decade, by the EAE, which is a formal association of the ESC, and the European Association of Cardiothoracic Anaesthesiologists (EACTA). Both groups have worked toward a common process of accreditation and examination in TEE applicable to both cardiologists and anesthesiologists, and indeed any others who may wish to demonstrate skills and knowledge in TEE. The process of accreditation and examination in adult TEE was finally established in 2004, and the first accreditation examination was held in 2005.

In Europe, accreditation in TEE is obtained in two parts. First, the written exam is a compulsory part of the accreditation. Second, a practical assessment must be completed within a fixed time period, currently within12 months of passing the written examination. The details of the current process are identified in Table 1.8. Prospective candidates can obtain updated information on the accreditation process from the websites of EAE (www.escardio.org/comunities/EAE) and EACTA (www.eacta.org). The performance of the EAE accreditation exams has recently been reviewed [33].

Accreditation is run as a service and is not a compulsory or regulatory certificate of competence or excellence. It is available to sonographers and doctors of all disciplines. In common with similar groups elsewhere, the goals of accreditation are to protect patients from undergoing transesophageal echocardiographic examinations performed by unqualified persons and to set a European standard for competency and excellence, which is expected to be recognized more widely. Accredited echocardiographers are expected to be able to perform and report routine transesophageal echocardiographic studies unsupervised, but whilst European accreditation is designed to test the competency of an individual to be able to perform, interpret, and report routine transesophageal echocardiographic studies unsupervised, the right to report and sign clinical studies in individual countries will be defined by national laws and regulations.

Conclusion

Transesophageal echocardiography has undergone remarkable progress in a very short space of time. This progress has been evident on a number of fronts. The technology has improved immeasurably, and continues to do so apace. This has facilitated the widespread use of TEE, and so has encouraged the establishment of practice recommendations and guidelines. Following on from this, assessments of personal proficiency and the proficiency of laboratories, including quality assurance and digital storage recommendations have followed.

References

1. Side CG, Gosling RG. Non-surgical assessment of cardiac function. *Nature* 1971; **232**: 335–6.
2. Daigle RE, Miller CW, Histand MB, McLeod FD, Hokanson DE. Nontraumatic aortic blood flow sensing by use of an ultrasound esophageal probe. *J Appl Physiol* 1975; **38**: 1153–60.
3. Frazin L, Talano JV, Stephanides L, *et al.* Esophageal echocardiography. *Circulation* 1976; **54**: 102–8.
4. Hisanaga K, Hisanaga A, Nagata K, Yoshida S. A new transesophageal real-time two-dimensional echocardiographic system using a flexible tube and its clinical application. *Proc Jpn Soc Ultrason Med* 1977; **32**: 43–4.
5. Erbel R, Börner N, Stellar D, *et al.* Detection of aortic dissection by transoesophageal echocardiography. *Br Heart J* 1987; **58**: 45–51.
6. Erbel R, Engberding R, Daniel W, *et al.* Echocardiography in diagnosis of aortic dissection. *Lancet* 1989; **1**: 457–61.
7. Sugeng L, Shernan SK, Salgo IS, *et al.* Live 3-dimensional transesophageal echocardiography initial experience using the fully-sampled matrix array probe. *J Am Coll Cardiol* 2008; **52**: 446–9.

8. Flachskampf FA, Decoodt P, Fraser AG, *et al.* Working Group on Echocardiography of the European Society of Cardiology. Guidelines from the Working Group. Recommendations for performing transesophageal echocardiography. *Eur J Echocardiogr* 2001; **2**: 8–21.
9. Practice guidelines for perioperative transesophageal echocardiography. A report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. *Anesthesiology* 1996; **84**: 986–1006.
10. Cheitlin MD, Alpert JS, Armstrong WF, *et al.* ACC/AHA Guidelines for the Clinical Application of Echocardiography. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Clinical Application of Echocardiography). Developed in collaboration with the American Society of Echocardiography. *Circulation* 1997; **95**: 1686–744.
11. Cheitlin MD, Armstrong WF, Aurigemma GP, *et al.* ACC/AHA/ASE 2003 guideline update for the clinical application of echocardiography: summary article. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/ASE Committee to Update the 1997 Guidelines for the Clinical Application of Echocardiography). *Circulation* 2003; **108**: 1146–62.
12. Savage RM, Lytle BW, Aronson S, *et al.* Intraoperative echocardiography is indicated in high-risk coronary artery bypass grafting. *Ann Thorac Surg* 1997; **64**: 368–74.
13. Mishra M, Chauhan R, Sharma KK, *et al.* Real-time intraoperative transesophageal echocardiography – how useful? Experience of 5,016 cases. *J Cardiothorac Vasc Anesth* 1998; **12**: 625–32.
14. Click R, Abel M, Schaff HV. Intraoperative transesophageal echocardiography: 5-year prospective review of impact on surgical management. *Mayo Clin Proc* 2000; **75**: 241–7.
15. Schmidlin D, Bettex D, Bernard E, *et al.* Transoesophageal echocardiography in cardiac and vascular surgery: implications and observer variability. *Br J Anaesth* 2001; **86**: 497–505.
16. Nowrangi SK, Connolly HM, Freeman WK, Click RL. Impact of intraoperative transoesophageal echocardiography among patients undergoing aortic valve replacement for aortic stenosis. *J Am Soc Echocardiogr* 2001; **14**: 863–6.
17. Ionescu AA, West RR, Proudman C, Butchart EG, Fraser AG. Prospective study of routine perioperative transesophageal echocardiography for elective valve replacement: clinical impact and cost saving implications. *J Am Soc Echocardiog* 2001; **14**: 659–67.
18. Morehead AJ, Firstenberg MS, Shiota T, *et al.* Intraoperative echocardiographic detection of regurgitant jets after valve replacement. *Ann Thorac Surg* 2000; **69**: 135–9.
19. O'Rourke DJ, Palac RT, Malenka DJ, *et al.* Outcome of mild periprosthetic regurgitation detected by intraoperative transesophageal echocardiography. *J Am Coll Cardiol* 2001; **38**: 163–6.
20. Kawano H, Mizoguchi T, Aoyagi S. Intraoperative transoesophageal echocardiography for evaluation of mitral valve repair. *J Heart Valve Dis* 1999; **8**: 287–93.
21. Saiki Y, Kasegawa H, Kawase M, Osada H, Ootaki E. Intraoperative TEE during mitral valve repair: does it predict early and late postoperative mitral valve dysfunction? *Ann Thorac Surg* 1998; **66**: 1277–81.
22. Grewal KS, Malkowski MJ, Piracha AR *et al.* Effect of general anesthesia on the severity of mitral regurgitation by transesophageal echocardiography. *Am J Cardiol* 2000; **85**: 199–203.
23. Tingleff J, Joyce FS, Pettersson G. Intraoperative echocardiographic study of air embolism during cardiac operations. *Ann Thorac Surg* 1995; **60**: 673–7.
24. Choudhary SK, Bhan A, Sharma R, *et al.* Aortic atherosclerosis and perioperative stroke in patients undergoing coronary artery bypass: role of intra-operative transesophageal echocardiography. *Int J Cardiol* 1997; **67**: 31–8.
25. Bonow RO, Carabello BA, Chatterjee K, *et al.* 2008 Focused update incorporated into the ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation* 2008; **118**: e523–661.
26. Quiñones MA, Douglas PS, Foster E, *et al.* American College of Cardiology/American Heart Association clinical competence statement on echocardiography: a report of the American College of Cardiology/American Heart Association/American College of Physicians–American Society of Internal Medicine Task Force on Clinical Competence. *Circulation* 2003; **107**: 1068–89.
27. Nihoyannopoulos P, Fox K, Fraser A, Pinto F. EAE laboratory standards and accreditation. *Eur J Echocardiogr* 2007; **8**: 80–7.
28. Evangelista A, Flachskampf F, Lancellotti P, *et al.* European Association of Echocardiography. European Association of Echocardiography recommendations for standardization of performance, digital storage and reporting of echocardiographic studies. *Eur J Echocardiogr* 2008; **9**: 438–48.
29. Cahalan MK, Foster E. Training in transesophageal echocardiography: in the lab or in the job? *Anesth Analg* 1995; **81**: 217–18.