IMAGING TECHNIQUES

Transoesophageal Echo-Doppler in cardiology

Peter Hanrath

Medical Clinic I, University Hospital RWTH Aachen, Germany

586

Transoesophageal echocardiography (TOE) has opened a new sonographic window to the heart and the thoracic aorta. The technical development of this ultrasound based diagnostic tool, as well as its clinical application in a large variety of important cardiovascular diseases, has been cultivated scientifically mainly by European cardiologists within the last 15 years. Miniaturised electronic phased array transducer technology incorporated in a gastroscope-like instrument formed the basis for the breakthrough of TOE in clinical cardiology.¹ The wide clinical application of TOE in the past has without doubt significantly improved our diagnostic possibilities and contributed much to a better understanding of the pathophysiology of many diseases such as aortic dissection or cardiogenic stroke. Both factors influenced significantly the therapeutic management and led to a better outcome of a variety of cardiovascular diseases.

This review will focus on the clinical application of TOE. There is general agreement that a TOE examination is indicated in all patients where conventional transthoracic echocardiography (TTE) fails to provide conclusive diagnostic information (for example, emphysema) or where TTE is impossible (during surgery). Beyond that TOE is generally performed when it is expected to add important information to the data first obtained by TTE, because of the higher image resolution or the potential to acquire images of cardiac or vascular structures that usually are not accessible by the transthoracic approach.

Determining the sources of embolism

Stroke and peripheral embolisation are major causes of morbidity and mortality. Stroke is the third leading cause of death in the USA. Around 80–85% of all strokes are of ischaemic origin, and a fifth of these strokes are caused by cardiogenic embolism. The higher diagnostic sensitivity of TOE in determining sources of embolism is mainly based on the proximity of the oesophagus and the heart, thus allowing unique sonographic views of the atria (especially the left atrial appendage), a better morphological delineation of atrial septal structures and anomalies, and the detection of atherosclerotic lesions within the thoracic aorta.

In a busy referral centre the most frequent indication for TOE examination is the detection of a possible source of embolism. According to their underlying disease patients can be

categorised into those with either a high or a low risk of embolic events. In clinical practice TOE plays a major role in the evaluation of patients with high embolic risk, especially in patients with atrial fibrillation, thrombo-arteriosclerotic changes of the thoracic aorta, infective endocarditis, and prosthetic valve replacement. But the assessment of low risk groups, in particular patients with patent foramen ovale and atrial septum aneurysm, is also possible. In young patients with otherwise unexplained stroke, the delineation of a patent foramen ovale by peripheral contrast injection or the combination of patent foramen ovale with atrial septum aneurysm can be displayed very elegantly by TOE as a potential gate of paradoxical embolisation.^{2,3} Several recently published studies have shown a link between these abnormalities and an increased rate of strokes or transient ischaemic attacks. Furthermore, it was shown that patients with major pulmonary embolism and simultaneous patent foramen ovale have in particular a high risk of death and arterial thromboembolic complications compared to those patients with pulmonary embolism and no patent foramen ovale.⁴

About 70% of strokes associated with atrial fibrillation are caused by cardiogenic embolism, most commonly of left atrial origin. TOE is a perfect tool to visualise the left atrium, especially the left atrial appendage, which is the usual site for thrombus formation and which is seldom seen with TTE (fig 1).⁵ In the past TOE in combination with pulsed wave Doppler has augmented our knowledge and understanding of the thromboembolic risk of patients with atrial fibrillation.⁶ A low flow state in the left atrium identified by TOE is characterised by a large left atrium, the presence of left atrial spontaneous echocontrast, and a reduced flow rate within a large left atrial appendage. Low flow conditions are associated with an increased thromboembolic risk and are also associated with a high recurrence rate of atrial fibrillation after initial successful cardioversion. From serial TOE studies we have also learned that, after initial exclusion of thrombotic material within the left atrium, late embolic events after successful cardioversion may occur and are thought to be caused by “atrial stunning”. The question of whether early TOE guided cardioversion with preceding short time anticoagulation using heparin and consecutive coumadin is safer and more cost effective than conventional coumadin treatment needs further clarification. The long term effect of early TOE guided cardioversion for the maintenance of sinus rhythm also needs to be studied.⁷

Stroke data banks and textbooks published up to the beginning of the 1990s indicated that in up to 40% of patients with embolic stroke no aetiology was found. Atrial fibrillation and carotid artery disease were considered the two major entities responsible for stroke or peripheral embolisation. Thus “cryptogenic” stroke was a big diagnostic dilemma. In 1990 a new finding in three patients with embolic disease—namely, a protruding plaque in the aortic arch as cause of embolisation, detected by TOE—

Correspondence to:
Professor Peter
Hanrath, Medical
Clinic I/University
Hospital RWTH
Aachen, Pauwelsstraße
30, D-52074 Aachen,
Germany
phan@pcserver.mk1.
rwth-aachen.de

Figure 1. Different sources of embolism detected by transoesophageal echocardiography. Left: clot within the left atrial appendage. Middle: clotting thrombus within the patent foramen ovale. Right: atherothrombotic plaques within the descending thoracic aorta. Ao, aorta; LA, left atrium; LAA, left atrial appendage; RA, right atrium

was reported.⁸ Since then atherosclerotic lesions of the thoracic aorta have been recognised as an important cause of stroke and peripheral embolisation (fig 2). TOE is now the modality of choice—well ahead of computer tomography or nuclear magnetic resonance tomography—for the diagnosis of these atheromas. The prevalence of these atheromas is about 27% in patients with previous embolic events. The risk of a second embolic event is high—12% have recurrent stroke within one year.

With the more widespread use of TOE it became evident that the prevalence of thoracic atheromas is nearly in the same order of magnitude as other major aetiologies such as atrial fibrillation or carotid artery disease. Plaque thickness and superimposed mobile thrombi are independent risk factors for embolic events. If mobile components are

attached to these atheromas embolic complications may occur in 20–30% of these patients within two years.⁹

Aortic atheromas are an important cause of stroke during open heart surgery. The increasing number of elderly patients with severe atheromatous disease of the aorta has focused clinical interest on the rational management of severe atheroma of the ascending aorta and the associated risk of intraoperative embolisation. Simple palpation of the aorta at surgery underestimates the degree of disease. Intraoperative TOE provides unique information which may alter the conduct of the operation, especially with regard to the site of cross clamping of the aorta. If atheromas are seen in the arch or ascending aorta the intraoperative stroke rate is significantly increased compared to those without atheroma.

Figure 2. Aortic atheroma. Results of study showing size and event rate of aortic plaques in stroke. From *N Engl J Med* 1996;334:1216–21.

Table 1 Diagnosis proven at surgery, necropsy or by at least two methods (computed tomography/angiography)¹⁰

	TOE	CT	Angiography
Sensitivity (%)	99	83	88
Specificity (%)	98	100	94
Positive predictive value (%)	98	100	96
Negative predictive value (%)	99	86	84

CT, computed tomography; TOE, transoesophageal echocardiography.

Aortic dissection

Within the last 15 years TOE has become a valuable modality for the diagnosis and management of diseases of the aorta. This diagnostic tool has also greatly contributed to our present improved understanding of the pathogenesis of diseases of the aorta, especially aortic dissection.

Based on TOE observations intramural haematomas as well as ruptured penetrating arteriosclerotic plaques are suggested to be major precursors of aortic wall dissection.

TOE is the imaging modality of choice for diagnosis and exclusion of thoracic aortic dissection (fig 3). In a European multicentre study diagnostic sensitivity (99%) and specificity (98%) in the high 90s have been reported (table 1).¹⁰ Compared with aortography, computed tomography, and nuclear magnetic resonance tomography, TOE has the advantage that it can be performed at the bedside.

Combined with colour flow imaging, TOE allows not only the identification of the intimal flap with the true and false lumen, and identification of the entry and re-entry, but also the detection of associated complications such as aortic regurgitation, pericardial effusion, involvement of the coronary arteries, incomplete perforation, and thrombosis in the false lumen. Nowadays in most centres patients with proximal aortic dissection diagnosed by TOE, who are surgical candidates, are taken directly to the operating room, thus saving valuable time. In addition TOE can be used for follow up examinations after surgical or medical treatment to detect late complications such as aneurysm formation at the site of operation, or to provide useful prognostic information in terms of progression of thrombosis in the false lumen.

Infective endocarditis and its complications

Infective endocarditis represents the fourth leading cause of life threatening infections after urosepsis, pneumonia, and intra-abdominal sepsis. There is still a continuous rise in the incidence of infective endocarditis, with a yearly rate of 15–20 000 new cases in the USA despite significant improvement in diagnosis and treatment. This rise is mainly caused by increasing numbers of intravenous drug abusers, patients with artificial valves, and elderly patients.

Figure 3. Dissection of the thoracic aorta. Upper: dissection of the membrane in the ascending aorta in the long axis view. Lower: ascending (left) and descending (right) aorta showing dissection of the membrane in the short axis view. AoA, ascending aorta; AoD, descending aorta.

By the combination of echocardiographic findings with clinical parameters (history, physical findings, laboratory tests) according to the Duke criteria the diagnostic accuracy to define infective endocarditis has been greatly improved. More than 11 studies in over 2000 patients comparing the von Reyn criteria (excluding echo findings) with the Duke criteria (including echo findings) showed an increased sensitivity and specificity of the Duke criteria, supporting the diagnostic utility of echocardiography—especially TOE—in the clinical setting of infective endocarditis.

TOE has considerably facilitated the process of making a correct diagnosis in the context of suspected endocarditis because TOE has a higher sensitivity (> 90%) compared to TTE (< 70%) for detecting vegetations, especially smaller vegetations < 5 mm.¹¹

TOE enhances the visualisation of prosthetic valves, especially the detection of vegetations or valvar and paravalvar insufficiencies, with sensitivities over 80% versus 30% by TTE.¹²

TOE facilitates the detection of left ventricular outflow tract complications (fistula, perforation), especially abscess formation (fig 4), with a sensitivity over 80% versus 30% by TTE as proven in several studies (fig 5).¹³

Based on these facts—in the setting of suspected infective endocarditis—and according to the American Heart Association guidelines, TOE is the primary diagnostic method of choice, especially in patients with artificial valves, in patients with intermediate or high

Figure 4. Infective endocarditis and abscess detected by transoesophageal echocardiography. Left: mitral valve perforation and aortic regurgitation in infective endocarditis. Right: abscess formation of the aortic valve. LA, left atrium; LV left ventricle.

clinical suspicion of infective endocarditis, and in patients with high risk of infective endocarditis related complications such as *Staphylococcus aureus* bacteraemia.

Evaluation of artificial valves

Prosthetic valve abnormalities, dysfunction or other associated pathologies are being recognised in an increasing number of patients, as the rate of valve replacement surgery grows.

TOE has gained increasing acceptance as a valuable method for assessing prosthetic valve function. The improved signal to noise ratio combined with the high resolution from high frequency transducers and the lack of problems related to acoustic penetration through mechanical valves has made TOE the technique of first choice for the investigation of patients, especially those with mechanical mitral valve replacement.

Additional pathomorphological findings such as thrombi in the left atrium, especially the left atrial appendage, or valvar and paravalvar leakages can be easily detected by TOE and are nearly always missed, especially in mechanical prostheses, by the transthoracic approach because of shadowing. In addition, bioprosthetic degenerations such as thickening or calcification of the leaflets, leaflet tears or prolapse are extremely well visualised by TOE.

Intraoperative application

After introduction of the phased array TOE technology in clinical cardiology this technique was rapidly recognised as a unique imaging modality to view the heart from a surgical perspective. Intraoperative application of TOE allows continuous monitoring of the surgical procedure without disturbing the sterile field, in contrast to epicardial echocardiography.

During myocardial revascularisation procedures TOE allows non-invasive evaluation of global left ventricular function. It can identify regional wall motion abnormalities as possible markers of myocardial hypoperfusion before and immediately after bypass. In the growing area of “off-pump” bypass surgery TOE monitoring is a “must”.

In reconstructive mitral valve surgery the information obtained by TOE imaging is of greatest value. The pathomorphology of valvar dysfunction can be clearly defined by TOE, especially in the case of mitral regurgitation, where satisfactory valve repair gives the best short and long term results. Decisions based on TOE made at the time of operation may effect both early and late survival and the need for reoperation or replacement of the valve during the operation.¹⁴

Intra-aortic balloon pump insertion can be guided by TOE, allowing visualisation of the descending aorta in order to detect severe atheroma and to avoid potential complications.

Intracardiac air can be visualised early and “de-airing” can be continued until TOE no longer detects microbubbles, which may be responsible for most of the neuropsychological syndromes often seen in elderly patients after open heart surgery.¹⁵ In addition, TTE imaging is often unsatisfactory in the early postoperative period for various reasons including the presence of air and tubes in the mediastinum. TOE is the best method for imaging the heart in the postoperative period.

Simple visual assessment of the inotropic state of the left ventricle may be of great clinical value. In patients with hypotension and low cardiac output in the intensive care unit, TOE monitoring of the left ventricle has been shown to be a very practical tool that allows rapid discrimination between depressed myocardial function and hypovolaemia as the underlying cause, or the exclusion of tamponade.¹⁶ Thus immediate availability of the haemodynamic

and anatomic information gained from TOE permits rapid adequate therapeutic interventions. With the recent introduction of a miniaturised monoplane TOE probe, which is half the size of a conventional probe, thus allowing nasal insertion, continuous monitoring during the operation and postoperatively seems to be more feasible.

TOE during catheter based interventions

Catheter based interventions for the treatment of congenital lesions in paediatric or adult patients represent an arena in which the use of TOE guidance is beneficial.

The combined use of x ray and TOE imaging is in many cases mandatory for the success of a procedure. It provides instantaneous recognition of the morphological and haemodynamic result and its complications. The recent development of commercially available miniaturised biplane or micromultiplane TOE probes opened the door for an increased use of this imaging modality, especially in children and adults. Specific applications include transseptal puncture, catheter positioning during radiofrequency ablation, balloon atrial septostomy, balloon positioning during pulmonary/aortic valvuloplasty or mitral balloon valvuloplasty, balloon dilatation of venous pathways post Mustard or Senning operation, and transcatheter closure of atrial and ventricular septal defects as well as stenting of the thoracic aorta in patients with dissection or aortic coarctation.¹⁷

In the setting of an atrial septal defect a pre-interventional TOE examination is necessary in order to define the exact morphology and site of the atrial septal defect, as well as its relation to structures in the immediate neighbourhood. Most investigators agree that TOE is superior to fluoroscopy for defining the defect margins and to position the arms of the device. For this reason TOE is routinely used in many centres during these procedures.

Congenital heart disease

Transthoracic two dimensional echocardiography combined with spectral Doppler and colour flow imaging is considered the diagnostic method of choice in the assessment of paediatric patients with congenital heart lesions. In a large series of 240 paediatric patients with congenital heart disease, precordial imaging allowed a correct diagnosis in 93% of all cases, while TOE was necessary in only 7%. However, in 437 adolescent or adult unoperated or postsurgical patients with congenital lesions TTE provided correct morphological and haemodynamic diagnosis in only 57% of cases, TOE being necessary to achieve a diagnosis in the remaining 43%.¹⁸

The detailed description of systemic and pulmonary venous connections, as well as a precise assessment of pulmonary venous flow

Figure 5. Detection rate of abscesses by transoesophageal echocardiography (TOE) versus transthoracic echocardiography (TTE).

patterns and of the structure of the atrial septum in various conditions, constitute one of the strengths of TOE. The distinctive morphology of the right and left atrial appendage provides a reliable guide to determine the atrial anatomy. In addition simple and complex obstructions of the left ventricular outflow tract, including discrete membranous or fibromuscular and long segment tunnel obstruction and their relation to the mitral and aortic valves, are well demonstrated by TOE. The same also holds true for the morphological as well as functional assessment of the subaortic valve apparatus.

Detection of myocardial ischaemia/viability

The diagnostic potential of transthoracic stress echocardiography with its different modalities has become established within the last 15 years for the detection or exclusion of coronary artery disease or to determine viable or non-viable myocardium. However, in 10–15% of patients image quality still remains a diagnostic problem. Based on its unrestricted image quality TOE represents an alternative approach in these cases.

In 1990 transoesophageal atrial pacing combined with simultaneous monoplane two dimensional imaging was introduced.¹⁹ In addition pharmacological stress testing in combination with mono- or multiplane TOE imaging has been reported. Although the reported sensitivities and specificities are somewhat higher compared to transthoracic stress echocardiography, the TOE stress test did not receive wide clinical acceptance and is considered only as a diagnostic method of second choice. This is mainly because of the invasive character of the investigation and the prolonged investigation time, causing inconvenience to the patient.

Apart from the different forms of stress application as an indirect marker of coronary artery disease, TOE in combination with Doppler has been used to verify stenotic lesions as well as to evaluate the coronary flow reserve. In the light of new imaging modalities such as

multislice computed tomography and nuclear magnetic resonance tomography, allowing visualisation of all three coronary arteries, and because of the restriction of TOE to the main stem and proximal segments of the left coronary artery, this approach is of less clinical relevance in daily practice.

Three dimensional echocardiography

Although cardiac ultrasound in general has become the most widely used diagnostic imaging method in clinical cardiology during the last three decades, the diagnostic decision making process is based on a mental reconstruction of serial tomographic views into their three dimensional geometry. This is a difficult process, which requires skill and experience.

The most practical approach to three dimensional echocardiography at present is the acquisition of a consecutive series of tomographic views using a multiplane TOE probe together with accurate spatial and temporal information and subsequent off-line reconstruction.²⁰ Although three dimensional reconstruction after acquisition of the basic data is still rather time consuming, the display of synthetic cross sections in various orientations (any plane echocardiography) is rapidly performed.

Three dimensional reconstruction facilitates the study of structures of complex geometry—the right ventricle, complex congenital heart disease, and aneurysmatic formation of the left ventricle are obvious examples where mental reconstruction is less accurate and most needed. It has already been shown that accurate measurements of cardiac chamber volume and myocardial mass are feasible. Furthermore, calculations of new and complex parameters of regional wall motion throughout the cardiac cycle are possible. The possibility of computer slicing through the beating heart and the display of specific structures and pathological conditions with their three dimensional relation may greatly facilitate the diagnosis. The surgeon can now have a “preview” of what will be found during surgery, which will be of great help in mitral valve reconstruction, aneurysmectomy, myectomy, and congenital defect repair, for example. A logical step forward is the imaging of dynamic three dimensional reconstruction with colour flow imaging and myocardial perfusion. In these days of robotic surgery of the mitral valve, TOE with three dimensional reconstruction are essential for such surgical intervention.

Summary

The success rate of TOE is impressive. In just more than one decade this diagnostic technique has become an integrated part of paediatric and adult cardiology, as well as cardiac surgery and anaesthesiology, with a wide range of indications. With modern transducer and computer technology further improvements

Main cardiovascular applications of transoesophageal echocardiography (TOE)

- Determining sources of embolism
- Aortic dissection
- Complication of infective endocarditis
- Prosthetic valve dysfunction
- Intraoperative monitoring/catheter based interventions

will be achieved in image quality, acquisition, and processing. Modern software packages or new matrix array transducer technology will very soon enable on-line reconstructive or real time three dimensional echocardiography, even of the oesophagus.

The combination of morphological and haemodynamic data of high diagnostic quality, and the possibility to use this diagnostic method at the bedside in the intensive care unit or in the operating theatre, guarantee that this diagnostic tool can survive successfully alongside other modern cardiac image modalities such as nuclear magnetic resonance tomography.

1. Schlüter M, Langenstein BA, Presta J, et al. Transoesophageal cross-sectional echocardiography with phased array transducer system techniques and initial clinical results. *Br Heart J* 1982;48:67–72.
- Landmark paper describing the technology and first clinical results with miniaturised phased array transducer technology incorporated in an endoscope.
2. Hausmann D, Mügge A, Becht J, et al. Diagnosis of patent foramen ovale by transoesophageal echocardiography and association with cerebral and peripheral embolic events. *Am J Cardiol* 1991;70:66–72.
3. Zenker G, Ertel R, Krämer G, et al. Transoesophageal two-dimensional echocardiography in young patients with cerebral ischemic events. *Stroke* 1988;19:345–8.
4. Konstantinides S, Geibel A, Kasper W, et al. Patent foramen ovale is an important predictor of adverse outcome in patients with major pulmonary embolism. *Circulation* 1998;97:1946–51.
5. Aschenberg W, Schlüter M, Kremer P, et al. Transoesophageal two-dimensional echocardiography for the detection of left atrial appendage thrombus. *J Am Coll Cardiol* 1986;7:163–6.
6. Manning WJ, Leeman DE, Gotch PJ, et al. Pulsed Doppler evaluations of atrial mechanical function after electrical cardioversion of atrial fibrillation. *J Am Coll Cardiol* 1989;13:617–23.
- Study describing atrial stunning in atrial fibrillation.
7. Klein AL, Grimm RA, Murray RD, et al. Use of transoesophageal echocardiography to guide cardioversion in patients with atrial fibrillation. *N Engl J Med* 2001;344:1411–20.
8. Tunick PA, Kronzon J. Protruding atherosclerotic plaque in the aortic arch of patients with systemic embolization: a new finding seen by transoesophageal echocardiography. *Am Heart J* 1990;120:658–60.
- Landmark article describing the detection of atherosclerotic plaques in the aorta.
9. Tunick PA, Kronzon J. Atheromas of the thoracic aorta: clinical and therapeutic update. *J Am Coll Cardiol* 2000;35:545–54.
- A classic review article describing the published literature on clinical and therapeutic aspects of atheromas of the aorta.
10. Erbel R, Renhollet H, Engerding R, et al. Echocardiography in diagnosis of aortic dissection. *Lancet* 1989;i:457–61.
- Keynote article describing the potential of TOE in aortic dissection in comparison to computed tomography and angiography within a large European multicentre trial.
11. Mügge A, Daniel W, Frank W, et al. Echocardiography in infective endocarditis: reassessment of prognostic implications of vegetation size determined by the

- transthoracic and transoesophageal approach. *J Am Coll Cardiol* 1989;**14**:631–8.
- Large study showing the diagnostic potential of TOE in the setting of acute endocarditis.
12. Daniel WG, Mügge A, Groth J, *et al.* Comparison of transthoracic and transoesophageal echocardiography for detection of abnormalities and prosthetic and bioprosthetic valves in the mitral and aortic position. *Am J Cardiol* 1993;**71**:210–15.
13. Daniel W, Mügge A, Martin RP, *et al.* Improvement in the diagnosis of abscesses associated with endocarditis by transoesophageal echocardiography. *N Engl J Med* 1991;**324**:795–800.
- Keynote article describing the unique diagnostic potential of TOE in the detection of abscess formation. Comparison with intraoperative and postmortem findings.
14. Sheikh KH, Bengston JR, Rankin JS, *et al.* Intraoperative transoesophageal Doppler color flow imaging used to guide patient selection and operative treatment of ischemic initial regurgitation. *Circulation* 1991;**84**:594–604.
- Study demonstrating the potential of colour Doppler imaging during operation in patients with mitral insufficiency.
15. Topol EJ, Humphry LS, Boston AR, *et al.* Value of intraoperative left ventricular microbubbles detected by transoesophageal two-dimensional echocardiography in predicting neurologic outcome after cardiac operations. *Am J Cardiol* 1985;**56**:773–5.
16. Reichert SCA, Visser CA, Koolen JJ, *et al.* Transoesophageal echocardiography in hypotensive patients after cardiac operations. Comparison with hemodynamic parameters. *J Thoracic Cardiovasc Surg* 1992;**104**:321–6.
17. 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). *Circulation* 1997;**95**:1686–744.
18. Sutherland GR, Stumper OF. Transoesophageal echocardiography in congenital heart disease. *Acta Paediatr* 1995;**410**(suppl):15–22.
- Large study describing the advantage of TOE versus TTE in congenital lesions.
19. Lambert H, Kreis A, Trumper H, *et al.* Simultaneous transoesophageal atrial pacing and transoesophageal two-dimensional echocardiography: a new method of stress echocardiography. *J Am Coll Cardiol* 1990;**16**:1143–53.
20. Roelandt JRTC. Three-dimensional echocardiography: new views from old windows [editorial]. *Br Heart J* 1995;**74**:4–6.
- Review of use of TOE for three dimensional reconstruction.