An introduction to transoesophageal echocardiography: II. Clinical applications

Donald Oxorn MD CM FRCPC,*†
Gerald Edelist MD FRCPC,*
Mark Stafford Smith MD CM FRCPC‡

Purpose: *As progress has been made in the acquisition of cardiac images with transoesophageal echocardiography, the technique has moved from the confines of the cardiology laboratory into the operating room, the intensive care unit, and the emergency department. This has afforded anaesthetists the opportunity to become familiar with, and develop expertise in its practice. The purpose of this article is to present a review of transoesophageal echocardiography with reference to anaesthetic practice.*

Source: *The principle source of material was a computerized Medline™ search of the English language literature from 1986 to 1995.*

Principle findings: *After discussing the technique of probe insertion, and describing some of the standard images, transoesophageal echocardiography's clinical utility is critically assessed. Comparisons with available monitoring techniques are made with reference to ventricular function, valvular heart disease, pericardial, aortic and congenital heart disease, and the management of the multiple traumatized patient. Issues of certification and maintenance of competence are also discussed.*

Conclusion: *Although the benefit of transoesophageal echocardiography is intuitive in many clinical situations, in others, it has not been shown to improve upon presently existing monitoring techniques. The need for adequate training and collaboration with cardiology colleagues is emphasized.*

Objectif: *Tout en progressant sur le plan technique, l'échographie transoesophagienne a débordé le cadre du laboratoire de cardiologie pour atteindre celui de la salle d'opération, de l'unité de soins intensifs et de la salle d'urgence. Il a été alors possible pour l'anesthésiste de se familiariser avec la technique et d'accroître sa compétence. L'objectif de ce travail est de présenter une perspective de l'échographie transoesophagienne appliquée au domaine de l'anesthésie.*

Source: *La source principale de cette revue est une recherche par ordinateur sur Medline™ des publications en anglais de 1986 à 1995.*

Données principales: *Après discussion de l'insertion de la sonde et la description d'images standard, l'utilité de l'échographie transoesophagienne est évaluée. Des comparaisons avec les techniques de monitorage de la fonction ventriculaire en usage sont établies en ce qui concerne la cardiopathie valvulaire, les maladies péricardiques, aortiques et les cardiopathie congénitales ainsi que la gestion du polytraumatisé. Les probème de la certification et du maintien de la compétence sont aussi discutés.*

Conclusions: *Bien que les bénéfice de l'échographie transoesophagienne se rapproche de l'intuition dans plusieurs situations, dans d'autres, on n'a pas montré sa supériorité sur les autres techniques de monitorage actuelles. La nécessité d'une formation appropriée et la collaboration avec les collègues cardiologues sont soulignées.*

Key words
ANAESTHESIA: cardiac;
ARTERIES: aorta;
COMPLICATIONS: trauma;
EQUIPMENT: Doppler, echocardiography;
HEART: echocardiography, transoesophageal, myocardial function; heart valves; pericardium, congenital defects;
MEASUREMENT TECHNIQUES: echocardiography.

From the Department of Anaesthesia* and the Division of Cardiology†, Sunnybrook Health Science Centre, University of Toronto, Toronto, Ontario, and the Department of Anaesthesia,‡ Queen Elizabeth II Health Sciences Centre, Dalhousie University, Halifax, Nova Scotia.

Address correspondence to: Dr. Donald Oxorn, Department of Anaesthesia, Sunnybrook Health Science Centre, 2075 Bayview Ave., Toronto, Ontario, Canada M4N 3M5.
Fax: 416-480-6039.

Accepted for publication 15th October, 1995.

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Since the initial description of cardiac ultrasound using a transducer introduced through the oesophagus,[1] transoesophageal echocardiography (TEE) has evolved to allow the generation of high quality, real time ultrasonic images in multiple planes. With the addition of Doppler capability, the ability to assess normal and pathological flows is facilitated. By obviating the need to have access to the patient's thorax, the utility of TEE in anaesthetized and critically ill patients was quickly recognized. Transoesophageal echocardiography has become an integral part of the management of patients undergoing cardiac surgical procedures and, because of the wealth of haemodynamic data yielded, has had an impact on the management of critically ill patients.[2,3] In this article, we will focus on the standard views and the clinical indications for TEE as they apply to the operating room and intensive care unit. We will conclude with a discussion of education, certification, and maintenance of competence in TEE.

Patient preparation and probe insertion

The anaesthetist will most often be called upon to perform TEE in patients who are anaesthetized with their tracheas intubated. Awake patients requiring TEE will be encountered less commonly; these individuals have traditionally fallen into the domain of the cardiologist, but practice is institution-specific. Irrespective of which area of the hospital TEE is being performed, full resuscitative facilities including suction must be readily available.

Questions regarding dysphagia, previous surgery or radiation of the upper gastrointestinal tract, abnormal dentition, cervical spine disease, a bleeding diathesis, and allergies are important components of a general medical history. A suitable period of fasting is important in patients in whom tracheal intubation is not planned. A complete cardiorespiratory physical examination should be followed by a detailed examination of the mouth, teeth, and oropharynx. Dentures, if present, should be removed.

In patients who will remain awake for the TEE examination, the mouth and oropharynx are anaesthetized with topical application of lidocaine. Specific nerve blocks may also be used.[4] Light intravenous sedation with short acting agents may be employed. The use of muscarinic antagonists for mucosal drying is advocated by some, although there is no objective evidence that probe insertion is facilitated.[5] The patient is placed in a lateral decubitus position, and the lubricated probe is introduced. Patient swallowing facilitates its passage into the upper oesophagus.

The anaesthetized patient whose trachea is intubated is usually positioned supine. The probe is passed blindly into the oesophagus; flexion of the patient's head, digi-

LIST OF ABBREVIATIONS
TEE = transoesophageal echocardiography
LA = left atrium
MV = mitral valve
LV = left ventricle
LVOT = left ventricular outflow tract
AV = aortic valve
RV = right ventricle
RA = right atrium
IAS = interatrial septum
TV = tricuspid valve
IVS = interventricular septum
PA = pulmonary artery
PCWP = pulmonary capillary wedge pressure
EDA = end diastolic area
ESA = end systolic area
TTE = transthoracic echocardiography
SWMA = segmental wall motion abnormality
HOCM = hypertrophic obstructive cardiomyopathy
SAM = systolic anterior motion
IE = infective endocarditis
ASE = American Society of Echocardiography
ASA = American Society of Anesthesiologists
SCA = Society of Cardiovascular Anesthesiologists

tal manipulation, temporary deflation of the endotracheal tube cuff and pharmacological paralysis may increase the rate of success. Alternatively, direct laryngoscopy may be used to direct the probe.

Extreme force should never be used in the passage of the probe. The use of bite blocks is encouraged, even in patients who appear well anaesthetized.

Close monitoring of cardiorespiratory function is important. Pulse oximetry is mandatory in the patient receiving conscious sedation, and the administration of supplemental oxygen by nasal prongs is encouraged. In patients with marginal cardiorespiratory reserve in whom TEE is deemed essential, consideration must be given to endotracheal intubation.

The use of prophylactic antibiotics in situations of high risk for endocarditis remains controversial. The incidence of bacteraemia is low following esophageal intubation, and probably due to contamination.[6,7]

There are several absolute *contraindications* to the use of TEE. Oesophageal obstruction by stricture or tumour, oesophageal diverticulum, laceration, or fistula, or active upper GI bleeding preclude its use. In patients with oesophagitis, oesophageal varices, remote gastric surgery, gastric ulcer, hiatus hernia, cervical spine disease, or a bleeding diathesis, the benefits of TEE must be weighed against the increased risk conferred by the patient's underlying medical condition.

Several large surveys[8,9] attest to the low incidence of complications with, and high patient acceptance of transoesophageal echocardiography. The incidence of serious morbidity including oesophageal rupture, pulmonary complications, arrythmias, angina, hypotension, pulmonary oedema, cardiac arrest, pharyngeal bleeding, and laryngospasm was 0.18–0.5%. In close to 14,000 patients, only two deaths were reported.[8,9]

Standard views

Standard views of multiplane transoesophageal echocardiography will be described. For an in-depth description, the reader is referred to more complete reviews[10–12] and standard references appended to this article.

Three chamber view

With the transducer in the horizontal plane, the first structures to be encountered are the great vessels at the base of the heart: the superior vena cava, the ascending aorta, and the main pulmonary artery. Advancement of the probe to approximately 30 cm from the incisors yields the three chamber view, consisting of the left atrium (LA), mitral valve (MV), left ventricle (LV) and left ventricular outflow tract (LVOT), the aortic valve (AV), ascending aorta, and the right ventricle (RV) (Figure 1). Slight withdrawal of the probe and 30° rotation of the transducer allows a cross sectional view of the aortic valve and surrounding structures (Figure 2). Rotation of the transducer to 120° allows a longitudinal assessment of the aortic valve, ascending aorta, and LVOT (Figure 3).

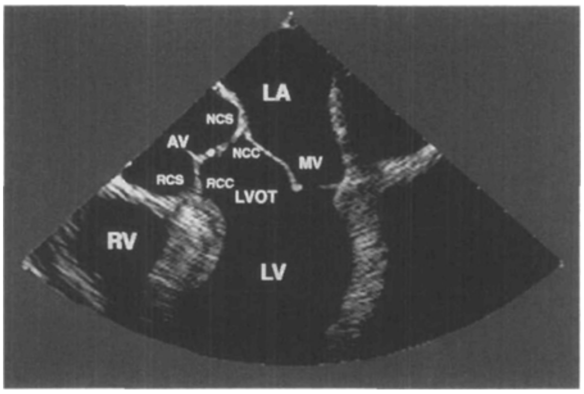

FIGURE 1 Three chamber view. The non coronary and right coronary sinuses of Valsalva (NCS, RCS) give rise to the non and right coronary cusps (NCC, RCC) of the aortic valve. LA = left atrium, MV = mitral valve, LV = left ventricle, LVOT = left ventricular outflow tract, RV = right ventricle, AV = aortic valve.

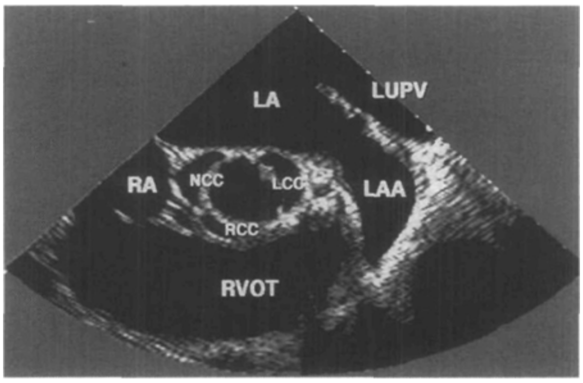

FIGURE 2 Aortic valve, horizontal section. In systole, the aortic leaflets (LCC, RCC, NCC = left, right, and non coronary cusps) are open. LA = left atrium, LUPV = left upper pulmonary vein, LAA = left atrial appendage, RA = right atrium, RVOT = right ventricular outflow tract. Not visualized in this figure are the right and left coronary arteries, which are often seen emanating from the right and left sinuses of Valsalva.

Four chamber view

With the probe returned to the horizontal plane, it is advanced several centimetres and retroflexed. The LVOT, aortic valve, and ascending aorta disappear, and the right atrium (RA), interatrial septum (IAS), tricuspid

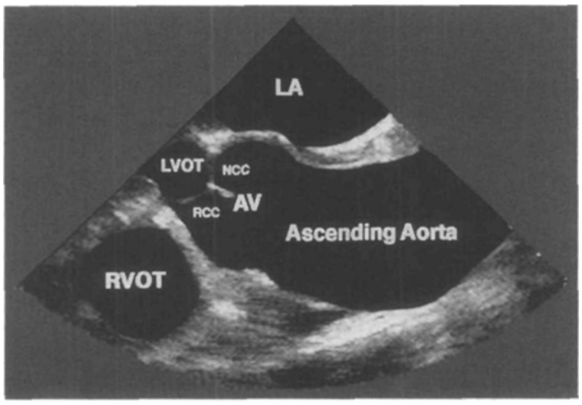

FIGURE 3 Longitudinal section of the aortic valve in diastole; the non and right coronary cusps (NCC, RCC) of the aortic valve (AV) are closed. LA = left atrium, RVOT = right ventricular outflow tract, LVOT = left ventricular outflow tract.

valve (TV), right ventricle and interventricular septum (IVS) come into view (Figure 4, A, B).

Ventricular trans gastric short axis
At approximately 40 cm from the incisors, the probe will have reached the level of the diaphragm. Slight resistance may be felt as the probe is advanced into the stomach. With the probe anteflexed, both ventricles will be seen in cross section. Advancement should continue until the antero-lateral (AL) and postero-medial (PM) papillary muscles of the mitral valve are visualized. At this level, the territory of all three coronary arteries is represented, (Figure 5) and the presence or absence of ventricular dysfunction can be determined.

Descending aorta
At the level of the 3 chamber view, the probe is rotated to face posteriorly. The descending aorta can now be seen in cross section. Advancement of the probe allows more distal portions of the descending thoracic aorta to be seen. Rotation of the transducer 90 degrees allows the aorta to be visualized in longitudinal section (Figure 6, A, B).

Clinical Utility

Ventricular function
One of the most important aspects of patient assessment in the operating room and intensive care unit, is the continuous monitoring of cardiovascular function. In healthy patients having minor procedures, ECG display and non-invasive blood pressure determination are usu-

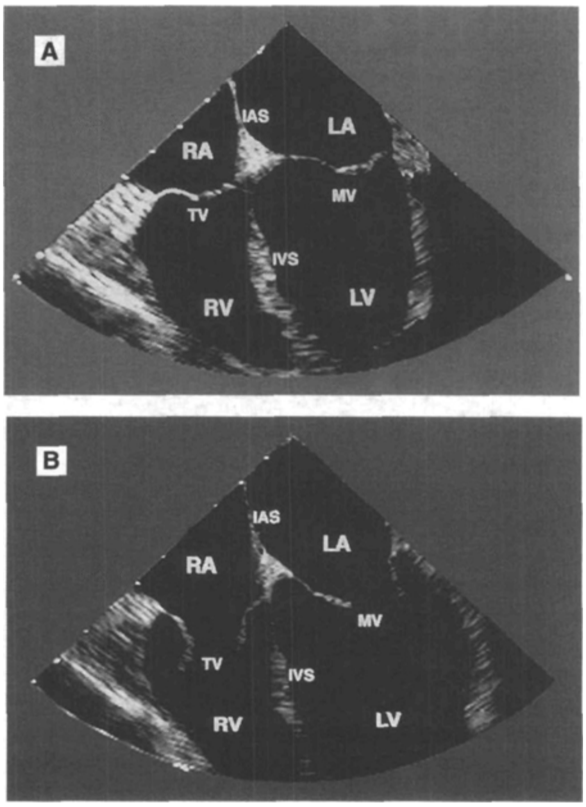

FIGURE 4 (A) and (B). Four chamber view; (A) systole, atrioventricular valves closed, (B) diastole, atrioventricular valves open. LA = left atrium, MV = mitral valve, LV = left ventricle, RA = right atrium, TV = tricuspid valve, RV = right ventricle, IAS = inter-atrial septum, IVS = inter-ventricular septum.

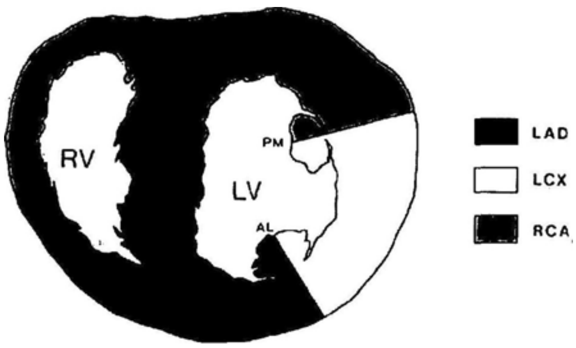

FIGURE 5 Trans gastric short axis: The right and left ventricles are seen in short axis, at the level of the antero-lateral (AL) and postero-medial (PM) papillary muscles of the mitral valve. All three coronary arteries are represented at this level. LV = left ventricle, RV = right ventricle, LAD = left anterior descending artery, LCX = circumflex artery, RCA = right coronary artery.

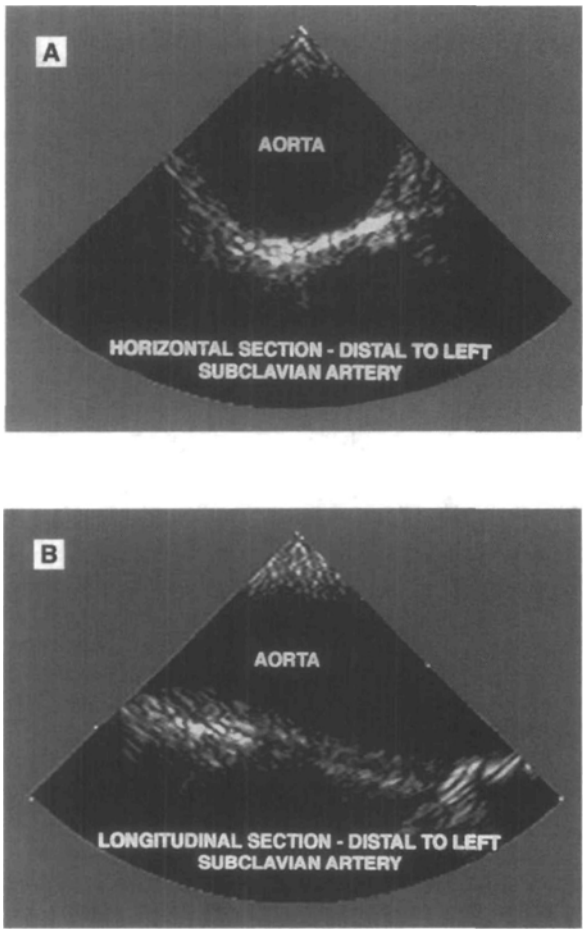

FIGURE 6 (A) and (B). Descending thoracic aorta. (A) horizontal plane, (B) longitudinal plane.

ally sufficient. As surgical complexity increases and patient reserve diminishes, more sophisticated monitors, such as the pulmonary artery (PA) catheter are often employed; because of its well known complications,[13] anaesthetists have sought less invasive ways of obtaining the same haemodynamic data. As will be seen, TEE fulfills some of these goals, but is not practically suited at present to replace traditional methods.

SYSTOLIC FUNCTION

Overall systolic function is assessed by the measurement of cardiac output. Perhaps equally important is the quantification of the various components of cardiac output (preload, contractility, and afterload), as the treatment of low cardiac output often depends on which of its components is disturbed. The gold standard in bedside measurement of cardiac output is thermodilution with the use of the PA catheter. A qualitative assessment of global systolic function may be made echocardiographically by visual inspection of wall motion. This method is accurate and reproducible, but obviously requires an experienced echocardiographer.[14] Cardiac output may also be measured by TEE and Doppler echocardiography. Mean velocity of blood flow is integrated over the time of one cardiac cycle and multipled by the diameter of the conduit through which the blood passes yielding stroke volume; multiplication by the heart rate gives cardiac output. Comparisons between thermodilution cardiac output and TEE have yielded mixed results. Earlier studies emphasized that difficulties in measurement of the velocity time integral and conduit area[15] led to poor correlation. Recently, more advanced probes have been used to measure cardiac output across the aortic valve,[16] the mitral valve,[17] and the right ventricular outflow tract.[18] Highly significant correlation coefficients of 0.93 to 0.97 with concurrent thermodilution measurements were found. However, considerable limitations exist with TEE measurement of cardiac output in the operating room. Assumptions above valve orifice geometry are made, and the velocity data from a limited number of heart beats is extrapolated to a time frame of one minute; cardiac rhythms other than sinus, and the presence of valvular and subvalvular disease may introduce error. The appropriate echocardiographic views may be difficult to obtain, especially if the position of the heart is changing as in mediastinal or thoracic surgery.

Preload is defined as the stretch on the myocardium at end diastole, by the blood present in the ventricle. As difficulties exist in the clinical measurement of cardiac volumes, the pulmonary capillary wedge pressure (PCWP) has been employed as a reflection of left atrial pressure and ultimately left ventricular end diastolic volume. This relationship weakens, however, in the presence of changing ventricular compliance.[19] Preload may be approximated with TEE by the measurement of the end diastolic area (EDA) of the LV, imaged with the trans gastric short axis view at the mid papillary level. This may be done by manual planimetry, or with automated detection of the endocardial border.[20] When compared with PCWP, EDA has been found to correlate more closely with other indicators of cardiac performance.[21,22] When measured during aortic reconstructive surgery, EDA was found to correlate closely with end diastolic volume as measured by first pass radionuclide angiography.[23] Ventricular volumes may be calculated with formulas developed for transthoracic echocardiography (TEE), but there are inherent limitations when similar principles are used with TEE;[24] multiple cuts must be obtained, the apex of the LV is often not seen, and the time required is prohibitive in the rapidly changing milieu of the operating room.

Measurement of LV contractility is difficult, because most variables thought to reflect it are load sensitive; despite these limitations, ejection fraction has gained wide acceptance as a measure of LV contractility. It may be quantitated with TEE by comparing end systolic and end diastolic areas of the left ventricle, imaged with the trans gastric short axis view at the mid papillary level; close correlation with ejection fraction measurement by radionuclide angiography[23] and epicardial echocardiography[25] is seen. The end systolic pressure-volume relation is a load independent index of contractility,[26] and has been estimated by combining measurement of echocardiographically derived LV end systolic area with femoral arterial pressure.[27] The major limitation of the studies to date is that they examine patients with normal ventricular function. It is possible that areas of ventricular dysfunction outside the mid papillary level may not be represented in calculations of contractility, and lead to its overestimation.

Left ventricular wall stress has been proposed as a measure of afterload[28] but its measurement is cumbersome and not readily applicable to management of patients in the operating room. It has not been found to correlate with systemic vascular resistance as measured by PA catheter.[21]

In summary, although most components of systolic function can be accurately measured with TEE, most anaesthetists and intensivists are familiar with the haemodynamic data acquired from pulmonary artery catheterization and, as at present, it will remain the mainstay for routine haemodynamic monitoring. In departments where TEE equipment and expertise are readily available, it may be used in selective cases where rapid assessment of cardiovascular function is needed.

ISCHAEMIA MONITORING

When normal systolic contraction occurs, both the myocardium and endocardium thicken and move inwards. Abnormal contraction may be manifest as hypokinesis, (diminished thickening), akinesis (absent thickening), or dyskinesis (paradoxical movement outwards). Transoesophageal echocardiography has inherent appeal as a monitor of intraoperative myocardial ischaemia. The trans gastric short axis view of the LV at the mid papillary level has representation from myocardium supplied by all three major coronary arteries; new segmental wall motion abnormalities (SWMA) detected by TEE are most often the result of acute ischaemia. Smith *et al.*[29] found that during cardiac or major vascular surgery, the appearance of SWMA was an earlier and more sensitive indicator of myocardial ischaemia than five lead ECG. In patients with SWMA that persisted to the conclusion of surgery, there was a high incidence of postoperative myocardial infarction. Leung,[30] in a study of patients undergoing coronary artery bypass grafting, also found a higher incidence of SWMA than ischaemic ECG changes. The SWMAs were seen most often after cardiopulmonary bypass, and portended a poor outcome. Other investigators have demonstrated a poor correlation between SWMA and adverse outcomes.[31]

The varied findings are a result of many factors. The criteria for a clinically important SWMA has not been validated. As well, not all acute SWMAs are due to ischaemia. Changes in loading conditions, tethering of normal myocardium adjacent to a region of acutely ischaemic myocardium, and post ischaemic, "stunned" myocardium may all present as an SWMA. Most intraoperative studies have monitored the LV by the trans gastric short axis plane at the mid papillary level; ischaemic myocardium at the apex or base of the LV, or the RV in its entirety might not be appreciated.[32]

Although echocardiography is more sensitive than ECG at detecting intraoperative ischaemia, and can be used in the presence of rhythm disorders such as left bundle branch block, the probe is generally inserted after the induction of anaesthesia, whereas ECG monitoring may be undertaken throughout the perioperative period. Diagnosis of intraoperative ischaemia is not as accurate when wall motion analysis is undertaken in the operating room as it is by offline analysis of intraoperative echocardiograms.[29,30,33]

Although TEE holds promise in the detection of intraoperative myocardial ischaemia, it appears more predictive of adverse outcomes in cardiac than non cardiac surgery. The use of multiple echocardiographic planes will probably add to its clinically utility. It remains, however, a technique that is highly dependent on the skill of the operator, and in need of validation as an on line monitor in the operating room.

MYOCARDIAL INFARCTION

Transoesophageal echocardiography is well suited for the diagnosis of myocardial infarction, by the demonstration of akinetic or dyskinetic myocardium. Complications of myocardial infarction, such as mitral regurgitation, ventricular septal defect, left ventricular aneurysm, pump failure, and cardiac tamponade are readily demonstrated. In the setting of cardiopulmonary resuscitation, TEE has been used as a diagnostic tool, as a monitor of resuscitative efforts, and in the evaluation of new methods of resuscitation.[34]

DIASTOLIC FUNCTION

Symptoms of congestive heart failure are usually attributed to impaired systolic function, left sided valvular regurgitation and stenosis, and ventricular restriction as seen with pericardial disease. Impaired ventricular filling may be secondary to diastolic dysfunction, and may produce symptoms which are suggestive of the aforementioned entities.[35,36] The invasive assessment of diastolic function is clinically impractical; however, parameters of left ventricular filling, obtained noninvasively by Doppler determination of pulmonary venous and mitral inflow velocities,[37-39] closely approximate left ventricular filling dynamics as measured by cineangiography[37] and nuclear cardioangiography.[40] The major limitation in the Doppler assessment of diastolic function is that loading conditions, as well as ventricular relaxation and compliance, affect trans mitral and pulmonary venous Doppler velocities.

Valvular heart disease

For the anaesthetist, assessment of valvular heart disease is most important in patients undergoing cardiac surgery, for either valve replacement or repair, and the critically ill patient with native or prosthetic valve dysfunction. Transoesophageal echocardiography can be used to assess valve leaflet structure and motion, the severity of regurgitation, and the presence of vegetations. Doppler techniques permit calculation of valve areas and pressure gradients.

MITRAL REGURGITATION

Inferential echocardiographic evidence of severe mitral regurgitation includes increased left atrial size, an enlarged, hyperdynamic left ventricle, and abnormal leaflet motion (prolapse, flail). Colour flow Doppler is the most commonly used method for the demonstration of regurgitant flow (Figure 7). The use of planimetry allows calculation of the mosaic regurgitant jet area, which correlates closely with transthoracic and angiographic assessment of regurgitation severity; a maximal jet area <3 or >6 cm^2 predicts mild or severe mitral regurgiation respectively, with 98% accuracy compared to angiography.[41,42] The presence of a large area of turbulent flow on the ventricular side of the mitral valve may indicate of severe degrees of mitral regurgitation, and mathematical analysis of the velocity profile of the pre-mitral turbulence allows quantitation of the regurgitant flow.[43] Eccentric jets which hug the wall of the left atrium are typically seen with mitral valve prolapse and are difficult to quantitate. Measurement of the regurgitant jet width at its origin may allow differentiation between mild and severe mitral regurgitation.[44]

Visualizing either the left or right upper pulmonary veins as they enter the left atrium allows pulse Doppler assessment of pulmonary venous flow velocities. During systole, blood flows from the pulmonary vein towards the transducer and into the left atrium. With severe mitral regurgitation, blood flow during systole flows from the LV into the LA and down the pulmonary vein away from the transducer. This reversal of systolic flow is indicative of severe mitral regurgitation.[45]

Intraoperatively, a semi-quantitative assessment combined with pulmonary venous Doppler velocities is usually undertaken; the quantitative methods are too cumbersome for practical use.

MITRAL STENOSIS

Mitral stenosis occurs almost exclusively in the setting of rheumatic heart disease, and has distinctive echocardiographic characteristics. The posterior leaflet is thickened and immobile, and the anterior leaflet assumes a hockey stick appearance during diastole, due to commissural fusion. The subvalvular apparatus may be diseased as well. Doppler can be used to calculate the peak and mean velocities of mitral inflow, with sampling usually done at the leaflet tips; the modified Bernoulli equation allows estimation of peak and mean pressure gradients across the mitral valve.[46] Doppler analysis of mitral inflow velocities can also be used to calculate the valve area. The software contained in the ultrasound machine uses the modified Bernoulli equation to calculate the pressure gradient between the LA and LV throughout early diastolic filling. The rate with which the pressure gradient diminishes correlates with the mitral valve's effective orifice size.[47] When sampling flow for Doppler velocity assessment, it is always important to ensure that the sampling location is consistent, as even slight movement of the TEE probe relative to the valve orifice may lead to error.

Planimetry can be used to directly measure the mitral valve area. Co-existant mitral regurgitation can be determined with the use of colour Doppler.

As the degree of stenosis progresses, the left atrium enlarges, and spontaneous echo contrast (an appearance similar to smoke) indicative of stagnant blood becomes evident.[48] Spontaneous echo contrast also heralds an increased risk of systemic arterial embolization.[49] Direct visualization of the left atrial appendage may reveal thrombii, especially if the patient is in atrial fibrillation and has not been anticoagulated.

AORTIC REGURGITATION

Transoesophageal echocardiography correlates of aortic regurgitation include valvular abnormalities such as bicuspid valve, dilated ascending aorta, and left ventricular dilation. It is most easily recognized with the use of

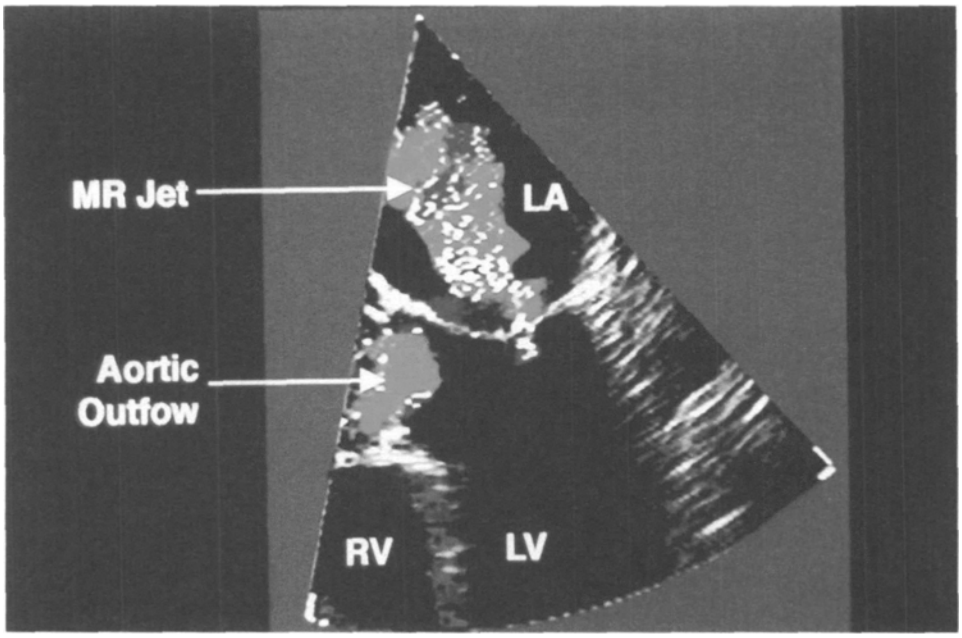

FIGURE 7 Mitral regurgitation. With colour Doppler applied to the three chamber view in systole, a regurgitant jet is seen in the left atrium. Also appreciated is normal systolic flow in the LVOT. The area of the regurgitant jet is 7.2 cm^2, which is consistent with severe mitral regurgitation.[41,42]

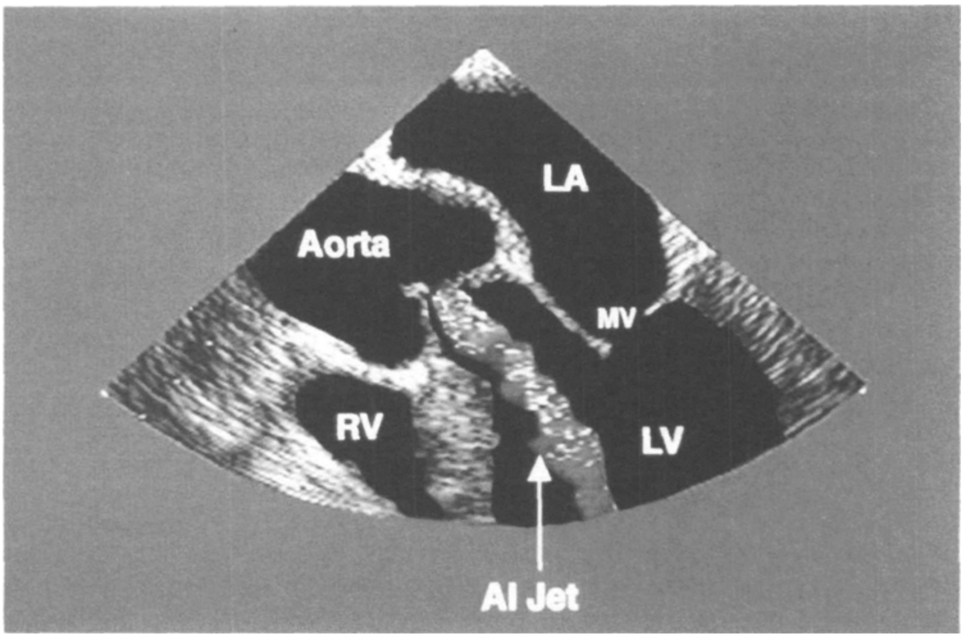

FIGURE 8 Aortic regurgitation. With colour Doppler applied to the three chamber view in diastole, a regurgitant jet is seen passing through the aortic valve into the LVOT and LV.

colour Doppler. With the aortic valve imaged in cross section, flow can be seen occurring during diastole. With longitudinal imaging, the regurgitant flow can be followed from the aorta, through the aortic valve, and into the LVOT (Figure 8). When the jet height on the ventricular side of the aortic valve is divided by the LVOT diameter, a value of 0.6 or greater indicates severe aortic regurgitation with a 96% accuracy compared with angiography.[50] Spectral Doppler can also be used to estimate the severity of regurgitation. As regurgitant volume increases, the time for aortic and left ventricular diastolic pressures to equalize diminishes, and the Doppler velocity signal falls off more rapidly.[51] By imaging the descending thoracic aorta and using pulse wave Doppler to determine the direction of flow, diastolic flow reversal is indicative of severe aortic regurgitation.[52]

AORTIC STENOSIS

The echocardiographic hallmarks of aortic stenosis include heavy calcification and restricted opening of valve leaflets, and dilation of the ascending aorta. There is concentric hypertrophy of the left ventricle, and systolic function is usually preserved until late in the course of the disease. Colour Doppler is used to determine if there is coexistent aortic regurgitation.

Doppler can be used to calculate the peak pressure gradients across the aortic valve, in a similar fashion to that described for the mitral valve (*Vide supra*). In order to sample parallel to aortic flow, a trans gastric image of the ascending aorta must be obtained.[53] The aortic valve area may be measured by planimetry,[54] or the continuity equation.[55,56] The latter technique takes advantage of the fact that flow through the LVOT must equal flow through the aortic valve; multiplication of the Doppler velocity of flow through the LVOT by the LVOT area will equal the Doppler velocity of flow through the aortic valve multiplied by the aortic valve area. As the first three variables are readily measured, the aortic valve area may be calculated.

Obstruction of the LVOT may also occur secondary to subvalvular disease. In hypertrophic obstructive cardiomyopathy (HOCM), there is septal hypertrophy which is disproportionate to the left ventricular free wall. Flow through the narrowed LVOT results in a localized Venturi effect, and systolic anterior motion (SAM) of the anterior mitral leaflet. This causes an obstructive subaortic gradient and mitral regurgitation. Ventricular septal myectomy may be performed in patients refractory to medical management. Intraoperative post myectomy TEE allows assessment of the width of the remaining septum and LVOT, pressure gradients, residual SAM and mitral regurgitation, and postoperative complications such as ventricular septal defect and aortic regurgitation.[57]

TRICUSPID REGURGITATION

If present, measurement of the peak velocity of the regurgitant jet with continuous wave Doppler and application of the modified Bernoulli equation allows calculation of the pressure gradient between the right atrium and right ventricle. If an estimate of right atrial pressure is added, the right ventricular systolic pressure can be approximated; in the absence of pulmonic stenosis, this reflects pulmonary artery systolic pressure, a valve which may aid in the haemodynamic management of critically ill patients.

VALVE PROSTHESES AND REPAIRS

It is in this area where TEE has had its most valuable impact on anaesthetic and surgical practice. Following the repair of mitral, and aortic valves, Doppler and colour Doppler can be used to asses the presence of residual pressure gradients, regurgitant jets, and LVOT obstruction following the termination of cardio-pulmonary bypass.[58–61] This follow up study must be done under conditions which reflect the patient's preoperative haemodynamic state. If necessary, cardio-pulmonary bypass can be re-instituted and further repair or valve replacement undertaken.

The flow characteristics of numerous mechanical and bioprosthetic valves has been reported.[62,63] Assessment is done in the operating room at the time of surgery, and postoperatively if malfunction is suspected. The valve sewing ring is examined for areas of dehisence, and the moving elements of the valve are carefully inspected. Gross malfunction is usually suspected on clinical grounds.[64,65] As with repair, residual pressure gradients, valvular, and paravalvular regurgitant jets are sought.

ENDOCARDITIS

The use of transoesophageal echocardiography in the diagnosis and management of patients with ineffective endocarditis (IE) has recently been reviewed.[66] Vegetations move independently from the affected valve, can be seen in more than one ultrasound plane, and have a density different from that of surrounding tissues. A detection rate of close to 100% is seen in patients with IE assessed by TEE. In most reported studies, diagnostic accuracy was twice that of TTE, especially in patients with prosthetic valves and difficult transthoracic acoustic windows.[67,68] A positive TEE establishes the diagnosis of IE; a negative study in the face of ongoing clinical suspicion dictates the need for follow-up TEE.

The assessment of complications of IE such as abscess and fistula formation, and leaflet perforation, is facilitated.[69]

Pericardial effusion
A pericardial effusion is seen as an echo free space between the epicardium and pericardium. Cardiac tamponade is suggested by the clinical presentation, and collapse of the right atrium and ventricle during diastole. Transoesophageal echocardiography allows assessment of the effects of pericardiocentesis, and has been used to guide surgical drainage of a loculated purulent pericardial effusion.[70]

Aortic diseases
The thoracic aorta can be viewed in its entirety, with the caveat that portions of the proximal arch are occasionally not visualized because of interposition of the trachea between the aorta and the esophagus.[71]

Transoesophageal echocardiography has become a first line diagnostic tool in the assessment of aortic dissection, with a sensitivity and specificity respectively of 96% and 86% in the ascending aorta, 95% and 94% in the aortic arch, and 97% and 94% in the descending aorta.[72] As well as visualizing the intimal flap, extravascular blood, aortic insufficiency, and pericardial effusion can also be diagnosed by TEE. Colour Doppler may reveal bi-directional flow in the true and false lumens.

Thoracic aortic aneurysms may be visualized, and TEE has the advantage of being able to delineate secondary effects on cardiac function.[73]

Transoesophageal echocardiography has also been applied to the diagnosis of traumatic disorders of the aorta (Figure 9). Its intrinsic appeal over aortography is the rapidity with which it may be performed in any area of the hospital, and its avoidance of toxic contrast dyes. Although initially lacking adequate numbers of patients and proper blinding,[74,75] recent studies have shown TEE to compare favourably with aortography.[76,77] Artifacts have been reported,[78–80] and only through individual experience will each trauma centre be able to determine when the findings of TEE, both positive and negative for aortic injury will preclude aortography.[81]

Atherosclerotic disease of the aortic arch as diagnosed by TEE is a predictor of ischaemic stroke,[82] and during cardiopulmonary bypass, atheroembolii from the aorta have been implicated as a cause of embolic stroke.[83] This has led some authors to recommend femoral cannulation in this clinical setting.[84] Transoesophageal echocardiography has been reported to detect ascending aortic atherosclerosis with a sensitivity of 100% and a specificity of 60%.[85] Although a negative TEE, therefore, implies an extremely low likelihood of important plaque, a positive study should ideally be followed by epicardial echocardiography performed by the surgical team following sternotomy.

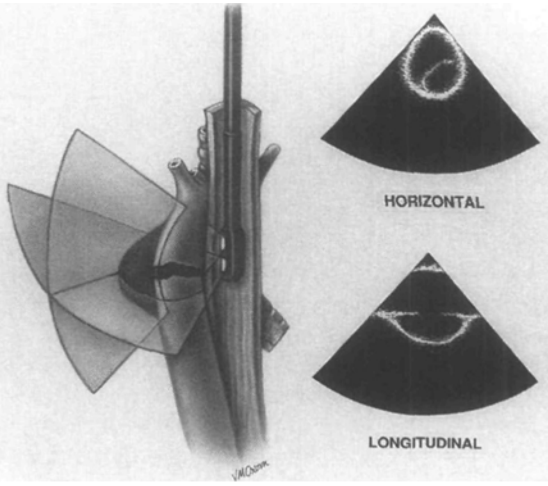

FIGURE 9 Traumatic aortic disruption. *Left hand panel*: The biplane TEE probe is seen in the esophagus. Orthogonal ultrasound planes image the descending aorta, which has a traumatic tear and false aneurysm. *Right hand panel*: the horizontal and longitudinal ultrasound images, which demonstrate a flap of tissue within the aortic lumen.

Trauma
In patients with thoracic trauma, TEE may be helpful in clinical assessment.[75,86,87] In addition to injuries of the aorta, cases of valvular injury,[88–91] pericardial tamponade,[92] penetrating[93–95] and nonpenetrating[96,97] cardiac injury have been reported in which TEE played a diagnostic role. Caution must be exercised, lest the technique be used in the setting of oesophageal injury.

Embolic disorders
In the evaluation of patients with embolic stroke, TEE is recognized as an important tool.[98] It has also been used to intraoperatively diagnose left atrial myxomas prior to recurrent embolization.[99,100] There have been a number of case reports which attest to TEE's utility in the diagnosis and monitoring of treatment of proximal pulmonary embolism.[101–104] Embolii may be seen in the main pulmonary artery or its major branches, and as well, secondary effects on right heart function may be delineated.

Following the report of a TEE diagnosed, intraoperative fat embolism,[105] a number of reports of embolic phenomena during lower limb orthopaedic procedures followed.[106–108] However, not all instances of echocardiographically documented embolii are followed by clinical changes in cardiorespiratory function, or postoperative sequelae.

Venous air embolism can be seen in settings such as pulmonary barotrauma and sitting position neurosurgical procedures, and the use of TEE in their diagnosis has been described.[109] TEE may also be used to detect intracardiac air following valvular surgery, and may assist with the various maneuvres designed to eliminate air prior to separation from cardio-pulmonary bypass.

Congenital heart disease

Ultrasound of the heart is used routinely with or, increasingly, without cardiac catheterization for intracardiac morphology and haemodynamic assessment in the management of infants and children with congenital heart disease. Since most cardiac structures are easily visualized in children using transthoracic echocardiography, TEE has played a lesser role in routine investigation of paediatric cardiac patients than in adults. However children with abnormal heart location, poor precordial ultrasonic windows (e.g., chest wall abnormalities, previous median sternotomy), or whose management requires detailed images of posterior cardiac structures (e.g., pulmonary veins, Fontan circulation) benefit from diagnostic TEE studies; these are usually performed under general anaesthesia. Adult TEE probes are too large for children <20 kg; this led to the development of miniaturized paediatric TEE probes, first reported in 1989.[110] Until recently, available paediatric TEE probes had reduced image quality compared with adult transthoracic and TEE probes, due to fewer ultrasound crystals.[111] However, high quality paediatric TEE probes for biplane 2-D and Doppler imaging are now available with diameters as small as 7 mm, which can safely be used in neonates as small as 2.3 kg.[112]

Echocardiography during cardiac surgery in young children began with the application of sterile transthoracic TEE probes directly onto the surface of the heart (epicardial echocardiography). Only with the advent of miniaturized TEE probes did continuous intraoperative echocardiography imaging become possible. Both epicardial and transoesophageal echocardiography have proved to be reliable intraoperative tools,[113] used for detailed prebypass imaging of cardiac anatomy, and post-repair assessment of cardiac function and quality of repair,[114,115] while TEE can also be used in intensive care settings for diagnosis and management of postoperative complications.[115]

Transoesophageal echocardiography is now established as an important tool in the diagnosis, and perioperative management of paediatric congenital heart disease. Although the challenge of miniaturization of TEE probes has delayed introduction of this technology, the benefits of its availability to anaesthetists, first demonstrated in adult cardiac surgery, now also appear to be relevant to heart surgery for infants and children.

Care and cleaning of equipment

Guidelines have been published for the cleaning and sterilization of gastroscopes, and these same guidelines have been applied to TEE probes.[116] After the study has been completed and the probe withdrawn, thorough rinsing with tap water is followed by 20 min of soaking in a glutaraldehyde solution. The probe is once again rinsed with tap water, and 20 min are allowed for any residual glutaraldehyde to evaporate. Commercial sleeves may be used to protect the probe when used in patients with infectious diseases.

Certification, and maintenance of competence

With the advent of new technologies, it behooves our professional associations to establish guidelines for training, so that proper credentialling may be undertaken. Guidelines have been published by the American Society of Echocardiography (ASE) for physician training and maintenance of competence in transoesophageal echocardiography.[117] For non-cardiologists, it is recommended that the training be equivalent to that received during a cardiology fellowship. This would entail Level 2 training in TTE (performance of approx. 300 cases), performance of 50 transoesophageal studies, and annual completion of 50–75 TEE studies to maintain competence. Not only is the absolute number of studies performed and interpreted important, but a varied case mix is equally essential.[118] The ASE also recognized that anaesthetists without the aforementioned training may wish to use TEE for intraoperative wall motion analysis. This practice was deemed acceptable if there were physicians with expertise in diagnostic echocardiography *available when needed* for consultative purposes.

The American Society of Anesthesiologists (ASA) and the Society of Cardiovascular Anesthesia (SCA) are developing guidelines for training in, and the indications for intraoperative TEE. An executive summary has been circulated to SCA members, which will ultimately lead to a final document. For anaesthetists interested in becoming involved with TEE, it is well worth reading. Three categories of indications for intraoperative TEE are defined, based on the support of available scientific evidence (strong, weak, or little evidence). Specific physician training objectives are also outlined.

The educational programme in intraoperative TEE at the Cleveland Clinic has recently been published.[119] Over one year, the trainee is exposed to TTE, outpatient TEE, intraoperative TEE, and finally, supervised TEE combined with clinical anaesthesia duties. An accompanying editorial[120] proposed that different approaches to TEE training were feasible, such as a mentor programme in which TEE skills are gradually acquired in close collaboration with an expert in TEE. This would allow clinicians who are unable to dedicate time to TEE training to develop proficiency. Individual institutions must determine what amount of instruction is acceptable. It was stressed that regardless of his or her level of expertise, the anaesthetist must never let the performance of TEE interfere with clinical duties. In many instances, it is desirable to have one individual administer anaesthesia, while another performs the TEE.

A recent survey has demonstrated extreme variability in anaesthesia based TEE practice.[121] In 98 academic departments surveyed, anaesthetists were responsible for study interpretations in half, with cardiologists responsible in the remainder. The amount of training ranged from "informal or short course" in 53% of anaesthetists, to "fellowship, residency or other" in the remainder.

The individual primarily responsible for the interpretation of TEE studies, whether cardiologist or anaesthetist, should be an individual with dedicated training in echocardiography. Development of training guidelines by anaesthesia societies may aid in this regard. In order to assure maintenance of competence, there is a need for ongoing collaboration between anaesthetists and cardiologists.[122]

There are no standards currently published by a Canadian professional body.

Summary

When should anaesthetists become actively involved in the performance and interpretation of TEE

Purchase of the equipment necessary for TEE monitoring requires a financial outlay of approximately $50,000.00 for a multiplane probe, and $150,000.00 to $250,000.00 for an echocardiographic ultrasound machine. The decision to embark on such a programme must take many factors into account.

Indications for TEE based on strong evidence include the diagnosis of life threatening haemodynamic disturbances in surgical and critically ill patients, valvular, congenital, and hypertrophic surgery, and the diagnosis of diseases of the thoracic aorta. These are clinical entities in which other monitoring modalities may yield insufficient diagnostic information. Less clear cut is the use of TEE in the intraoperative monitoring of cardiac function and the detection of myocardial ischaemia, as other less expensive monitors are readily available.

It would seem reasonable, therefore, for anaesthesia departments actively engaged in the management of patients requiring cardiopulmonary bypass to embark on a program of TEE monitoring, recognizing that its success will hinge largely on the training and dedication of the staff involved. In our department, TEE is used most often in open heart procedures, and in the assessment of haemodynamically unstable trauma patients. In departments not involved with these activities, its implementation cannot be justified.

Although some may venture that TEE is better left to cardiologists, I believe that TEE performed by properly trained anaesthetists adds to the quality of patient care, and can only enhance our image amongst our peers and trainees.

Acknowledgements

We wish to thank Dr. Cam Joyner for reviewing the manuscript, and Valerie Oxorn for her illustrations.

Appendix

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