Intraoperative echocardiography assessment of left and right ventricular function

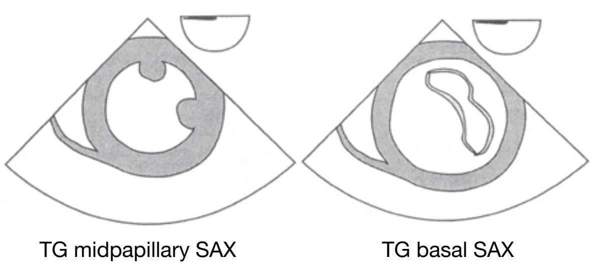
Harvey NJ
Department of Anaesthesia, Glenfield Hospital, University Hospitals of Leicester, UK
Correspondence to: Dr Nick Harvey, e-mail: nicholas.harvey@uhl-tr.nhs.uk

Over the past 25 years, echocardiography technology has improved tremendously and intraoperative transoesophageal echocardiography (TOE) has become the gold standard cardiac monitor and diagnostic tool. Although there is limited scientific evidence to substantiate this belief, there is a perception that intraoperative TOE provides valuable information that significantly influences clinical management and improves patient outcome.[1,2] Several investigators have documented its benefits in the critically ill patient and during complex cardiovascular surgery.[3,4,5] Two recent retrospective analyses related to alterations during routine cardiac surgery from intraoperative TOE have also suggested its cost effectiveness.[6,7]

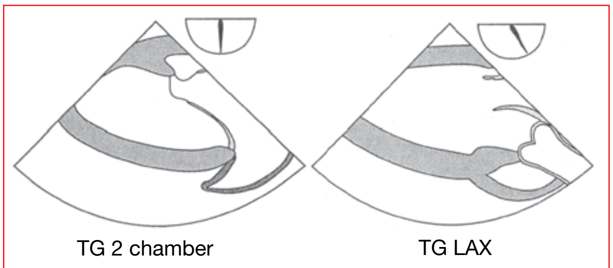
In 1996, an American Society of Anesthesiologists/ Society of Cardiovascular Anesthesiologists task force published practice guidelines on the indications for intraoperative TOE.[8] Category I indications are supported by strong evidence and expert opinion that TOE is indicated, very useful and will improve clinical outcome. Haemodynamic instability is an important Category I indication for the use of TOE. Haemodynamic evaluation and the assessment of global and regional left ventricle (LV) function with TOE has proved reliable and comparative with the pulmonary artery (PA) catheter and standard thermodilution techniques.[9] A recent survey has shown that, among anaesthesiologists with echocardiography training in the USA and Canada, TOE was preferred to the PA catheter as a monitor in critically ill patients and complex cardiovascular surgery.[10]

Several standard views are useful to evaluate global or regional LV function:[11]

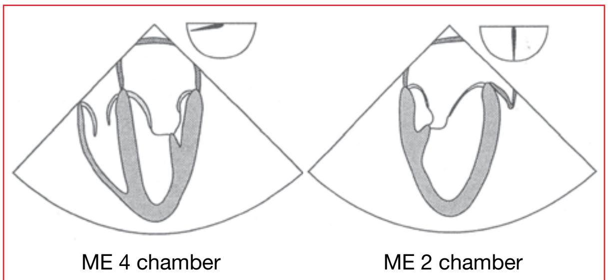
- Transgastric short-axis views at basal, midpapillary and apical level (allows evaluation of all three coronary artery territories, volume status, and contractility). (Images: Shanewise et al).



- Transgastric lo ng-axis view (visualisation of regions close to apex, measurement of aortic valve and LV outflow tract velocity time integral).



- Midoesophageal four-chamber and two-chamber views (left and right heart chambers visualised, volume loading, contractility).



The long-axis views are usually foreshortened, which means the ultrasound beam may not follow the true long axis to the apex. It is therefore difficult to assess the true apex by TOE.

The ability to directly measure flow velocities rather than pressure, together with direct visualisation of ventricular filling, valvular function and cardiac structures, allows TOE to aid the trained clinician in acute situations. Real-time echo images allow accurate qualitative evaluation of cardiac output. Visualisation of the left and right ventricles, interpreting regional and global abnormalities, and detection of systolic or diastolic dysfunction can greatly assist the clinician. TOE also allows quantitative evaluation of ventricular function. The echocardiographer should integrate all real-time information and not only look at a single view. Hypovolaemia or severe LV dysfunction is easy to detect. However, the detection of various degrees of segmental wall motion abnormalities can be a difficult skill to learn and is therefore operator dependent.

Systolic function

Systolic LV function can be described with diameter, area or volume changes.[12] With M-mode, the difference between end-diastolic and end-systolic diameters of the LV can be used to calculate fractional shortening (normal > 30%). With 2-D echo, the difference in end-diastolic and end-systolic LV areas at midpapillary short-axis view can be used to calculate fractional area change (normal > 45%). The change in LV volume between systole and diastole is used to calculate the stroke volume (SV) and ejection fraction (EF-normal > 60%). LV volume is calculated by the "Simpson's" method of summation of discs. Remember that all these measurements are operator and preload dependent, and may not correlate well with global function in patients with left ventricular wall motion abnormailty (LVWMA) in other areas of the LV. Over the past 15 years, the automated border detection technique of acoustic quantification to obtain area changes was a step towards 3-D echocardiography. The recent introduction of real time 3-D technology is a great advance in evaluating ventricular volumes and function.

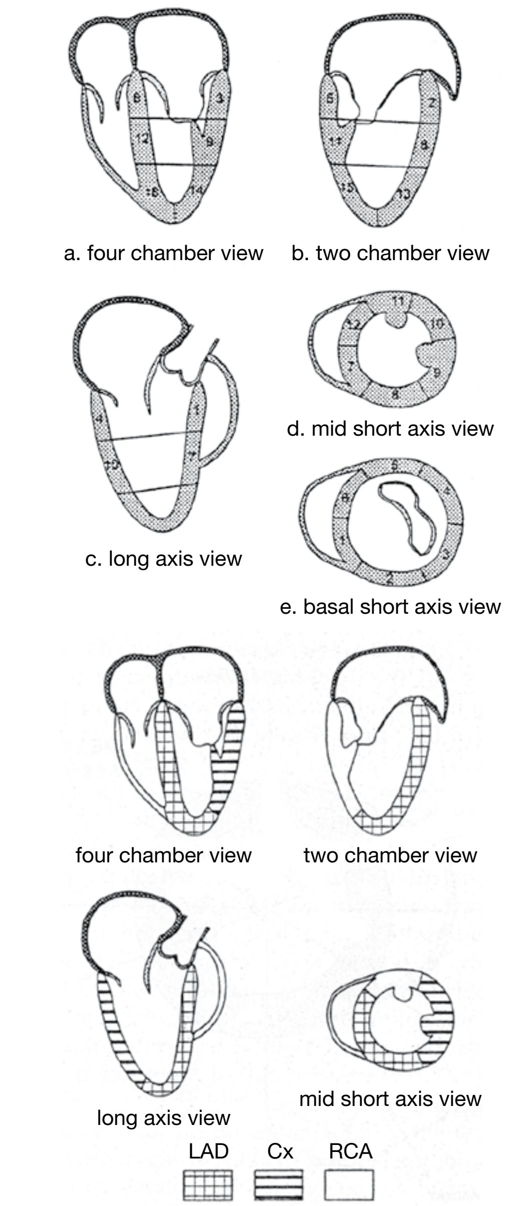
To quantify cardiac output, Doppler echocardiography can be used to measure blood flow velocity across the mitral valve, aortic valve or left ventricular outflow tract. If the area through which the blood is passing is known, one can calculate the stroke volume and therefore cardiac output:

stroke volume = velocity time integral x area

Measurement of cardiac output with Doppler assumes that blood flow is laminar, velocity profile is uniform and the area through which blood flows is circular and constant. These assumptions are not always correct. It is also important for the Doppler beam to be parallel to the blood flow. This method is repeatable, but not continuous, and is dependent on operator skill. Recent studies indicated that, 95% of the time, a properly performed TOE estimate of cardiac output should be within 1 l/min of the thermodilution measurement.[13]

Regional function

The American Society of Echocardiography proposed a model where the LV is divided into three levels (basal, mid and apical) and 16 segments.[14]



(Images - Shanewise et al)

Ventricular wall motion abnormalities have been shown to be a highly sensitive indicator of regional myocardial ischaemia,[15,16] particularly when several cross sections in the transverse and longitudinal planes are used.[17] Regional wall motion abnormalities (RWMA) develop within seconds after a reduction in myocardial blood supply. Normal wall thickening progresses to mild hypokinesia, severe hypokinesia, akinesia, and then dyskinesia, indicating myocardial ischaemia.[12] RWMA can be difficult to quantify. The ventricle twists when contracting, causing different myocardial sections to move in and out of the imaging plane during one cardiac cycle. The endocardial and epicardial borders can often not be completely identified, preventing accurate quantification of wall thickening. The recent development of tissue Doppler imaging (TDI) may be the most versatile method to measure and quantify myocardial function.[18]

Diastolic function

Echocardiography can be used to perform non-invasive evaluation of diastolic function, by assessing the pulmonary vein and mitral valve inflow patterns into the left atrium (LA) and LV respectively.[19] Together with LA size and function, and the effects of the Valsalva manoeuvre, these inflow patterns permit an accurate assessment of LV relaxation and filling. The mitral inflow pattern is measured at the leaflet tips and demonstrates a peak velocity during early filling (E wave), late filling during atrial contraction (A wave), the E/A ratio, and the deceleration time from peak early filling extrapolated to the baseline. Pulmonary venous inflow into the LA is dependent on the pressure difference between the two chambers. Changes in the S, D, and A waves may be interpreted together with the changes in mitral inflow pattern to diagnose impaired relaxation, pseudonormalisation or restricted LV function.[20] Tissue Doppler imaging has significantly improved the diagnostic power of echocardiography. This modality allows the evaluation of high-amplitude, low-velocity signals of the moving myocardial wall or mitral annulus. It is relatively load independent and should be used in addition to traditional Doppler-derived indices for comprehensive assessment of diastolic function.[21]

Right ventricular assessment

The association of right ventricle (RV) dysfunction with morbidity and mortality after cardiac surgery has made its assessment during intraoperative TOE a vital part of the complete echo examination. The survival rate associated with severe RV failure maybe as low as 25-30%, highlighting the importance of early diagnosis and aggressive management. The unique ability of TOE to discriminate right from left heart failure and detect life-threatening conditions where right heart dysfunction predominates - for example in acute pulmonary hypertension and pulmonary embolus - makes it a powerful diagnostic and monitoring tool in the perioperative environment.

The anatomy of the RV is unique and complex, appearing triangular when viewed laterally, but crescent-shaped in cross-section. The complete assessment of the RV also includes right atrial, tricuspid and pulmonary valves, together with the venae cava and pulmonary vessels.

The most useful TOE views are illustrated on the following page.

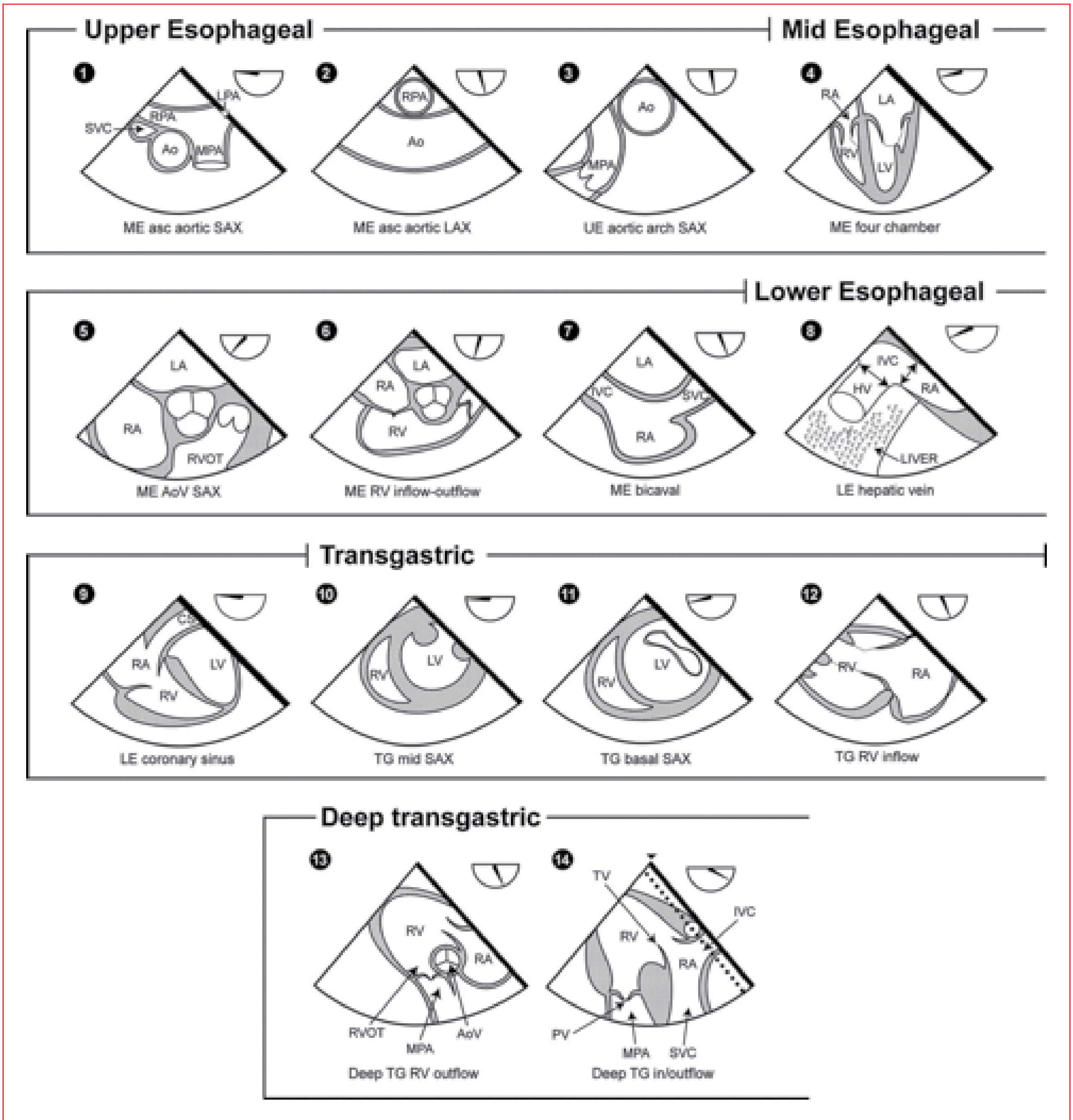
The midoesophageal four-chamber view is ideal for visualising the RV lateral wall, measuring RV internal dimensions and RV fractional area change (RVFAC). The coronary sinus, tricuspid regurgitation and atrial and ventricular septal defects can be imaged in the midoesophageal views. The transgastric views allow short-axis (SAX) views of the RV and septum, RV inflow and RV outflow tract, inferior vena cava, as well as hepatic veins. The great vessels are best seen in the upper oesophageal views, whereas tricuspid annular tissue Doppler is best assessed in the deep transgastric views.

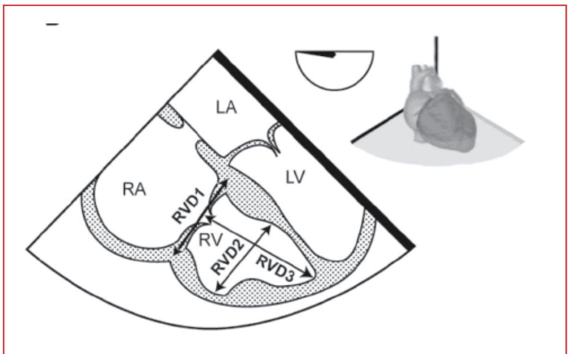
Echocardiographic assessment of the RV is more challenging than the left because of its complex shape, difficulty in endocardial surface recognition and marked load dependence of several indices of RV function.

Right ventricular size and shape

The best correlation between 2-D echo and RV volumes have been obtained using maximal SAX dimension and RV area measured in the four-chamber view.

In the near future, 3-D technology may enable better assessment of RV volumes, however software for routine RV volume quantification is not routinely available. RV hypertrophy is defined as ventricular wall thickness > 5 mm at end diastole of the inferior or lateral walls. Assessment of septal curvature can offer insight into RV pathology, as the interventricular septum is usually curved toward (convex) the RV. In the adult with acquired pressure overload, the RV dilates early and the ventricular septum is displaced toward the LV cavity, especially at end-systole distorting RV and LV geometry (D-shaped LV). In volume overload, the RV is dilated and rotated clockwise about the apex, becoming





	Reference range	Mildly abnormal	Moderately abnormal	Severely abnormal
RVD1, cm	2.0 - 2.8	2.9 - 3.3	3.4 - 3.8	≥ 3.9
RVD2, cm	2.7 - 3.3	3.4 - 3.7	3.8 - 4.1	≥ 4.2
RVD3, cm	7.1 - 7.9	8.0 - 8.5	8.6 – 9.1	≥ 9.2

more cylindrical in shape, again displacing the septum towards the LV mainly at end-diastole.

Indices of RV function

The most commonly used echocardiographic indices of RV function include:

- Geometric indices reflecting extent of contraction such as RVFAC, RVEF, and tricuspid annular plane systolic excursion (TAPSE).
- Myocardial velocity indices such as tricuspid annular plane maximal systolic velocity and

isovolumic acceleration (IVA).

- Haemodynamic indices such as RV dp/dt.
- Time interval indices such as RV myocardial performance index or Tei index.

Echo-derived RVFAC, an index of RV systolic function, is the ratio of RV systolic area change to the end diastolic area measured in the four-chamber view. Normal values lie between 32% and 60%. TAPSE measures the longitudinal systolic motion of the free edge of the tricuspid annulus. It is measured using M-mode in the four-chamber view, typically on the lateral annulus.

RV diastolic function has not been as extensively studied as that of the LV, but useful variables include right atrial pressure (RAP), RV filling profiles, and hepatic vein velovities. In non-ventilated patients, the inferior vena cava size and collapse index correlate well with RAP. An IVC size < 2 cm with collapse of > 50% on inspiration corresponds to a RAP < 5 mm Hg.

Echocardiography is a mainstay of perioperative RV function. Although it is challenging, it provides useful information on RV size, shape and function.

New echocardiographic techniques for evaluating ventricular function

Recent advances in ultrasound technology and newer imaging modalities have enabled improved assessment of left ventricular myocardial function. These include tissue Doppler imaging (TDI), colour Doppler myocardial imaging (CDMI), and speckle tracking and real-time 3-dimensional echocardiography (RT-3DE).

Pulse wave TDI and CDMI allow the assessment of contractility based on myocardial motion and deformation. This is in contrast to contractile force determined using blood flow-derived parameters, which are greatly affected by loading conditions. Speckle tracking extracts myocardial motion from the 2-D grey scale image

Summary of echocardiographic indices of the right ventricle

Functional parameters	Normal value	Load dependency[a]
Systolic performance variables		
`RVFAC (%)	32-60%	+ + +
RVEF (%)	45-68%	+ + +
TAPSE	> 15 mm	+ + +
Tricuspid annular plane maximal systolic velocity (using spectral pulsed wave tissue Doppler)	> 12 cm/s	+ +
IVA (using tissue pulsed wave Doppler)	1.4 ± 0.5 m/s^2	+
Diastolic parameters		
IVC dimension (cm), collapse index	< 1.7 cm, CI > 50%	+ + +
Tricuspid early (E) to late (A) filling velocity ratio	1.5 ± 0.3	+ + +
Hepatic vein profile (S: systolic, D: diastolic)	S/D velocity ratio > 1, no S reversal, atrial reversal < 50% S	+ + +
IVRT	< 60 ms	+ + +
Rapid myocardial filling velocity (E_1) (cm/s)	E_1: 15.6 ± 3.9	+ + +
Late diastolic myocardial filling velocity, A_1 (cm/s)	A_1: 15.4 ± 4.5	+ + +
Combined systolic and diastolic parameter		
RVMPI	0.28 ± 0.04	+ +

The severity of RV systolic dysfunction may be graded using RVFAC and RVEF. Using RVFAC, mild dysfunction: 25-31%, moderate dysfunction: 18-24%, severe dysfunction < 17%. Using RVEF, mild dysfunction: 35-44%, moderate dysfunction: 26-34%, severe dysfunction < 25%. Almost all normal values have been established in non-ventilated patients.
[a] Refers to the degree of load dependency from minimal + to significant + + +
IVA = isovolumic acceleration using Doppler tissue imaging
IVC = inferior vena cava
RVEF = right ventricular ejection fraction
RVFAC = right ventricular fractional area change
RVMPI = right ventricular myocardial performance index
TAPSE = tricuspid annular plane systolic excursion
St = maximal systolic tricuspid annular plane velocity
IVRT = isovolumic relaxation time

by complex analysis of the different brightness and shape of the speckles of the image and their motion vectors to obtain velocity strain and strain rate. These modalities are providing insights into longitudinal, circumferential and radial strain.

RT-3DE allows ventricular volumes to be displayed numerically and graphically as time-volume curves and allow EDV, ESV and EF to be calculated. It is superior to 2-D as no geometric assumptions about LV shape are made. It also enables regional myocardial motion to be pinpointed more accurately according to the 17-segment nomenclature.

Practical applications

The use of TOE within the intensive care setting was recognised by the task force in1996.[8] TOE can prove invaluable to assess LV function during unexplained haemodynamic disturbances, suspected valve disease, or thromboembolic problems in the critically ill patient. TOE potentially provide a diagnosis previously undetected. Advances in cardiac surgical techniques have led to the increasing use of minimally invasive (MIDCAB) or off-pump coronary artery bypass grafting surgery (OPCAB), during which TOE evaluation of the heart play a vital role through early demonstration of RWMA.[22] Patient tolerance to the procedure can be monitored in real time. The verification of graft patency can be assessed following bypass grafting by resolution of segmental wall motion abnormalities back to normal prior to chest closure. The intraoperative application of myocardial contrast echocardiography to determine regional flow patterns after revascularisation may help to differentiate conditions of LV dysfunction immediately after separation from cardiopulmonary bypass.[23]

Conclusion

The role of TOE in cardiac surgery is well established. It has the benefits of providing real-time interrogation of cardiac structure and function that can be reliable and reproducible. When evaluating ventricular function, it is important to do a complete examination with multiple views. As with many interventions, a full understanding of the limitations and possible artefacts is required. In future, newer modalities like tissue Doppler imaging, strain rate, and contrast echocardiography will play an important role in the intraoperative assessment of ventricular function.[24] 3-D TOE is a brand new and exciting introduction to our perioperative practice.[25] Perioperative echocardiography is here to stay and will fulfil a vital role for today's anaesthetist.

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