Transoesophageal Echocardiography and Left Ventricular Function

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## Abbreviations

<table>
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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>TOE</td>
<td>Transoesophageal Echocardiography</td>
</tr>
<tr>
<td>PAC</td>
<td>Pulmonary Artery Catheter</td>
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<td>RWMA</td>
<td>Regional Wall Motion Abnormalities</td>
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<tr>
<td>LV</td>
<td>Left Ventricle</td>
</tr>
<tr>
<td>EF</td>
<td>Ejection Fraction</td>
</tr>
<tr>
<td>ED/ESA</td>
<td>End-Diastolic/Systolic Area</td>
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<tr>
<td>ED/ESV</td>
<td>End-Diastolic/Systolic Volume</td>
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INTRODUCTION [1, 3, 4]

Multiplane two-dimensional Transoesophageal Echocardiography (TOE) provides high-resolution images of cardiac structure throughout the cardiac cycle and, using Doppler techniques, allows evaluation of hemodynamics. Direct imaging of the left ventricle makes it an excellent tool for the assessment of ventricular wall thickness, chamber size and contractile performance.

Transoesophageal echocardiography can provide measurements of global systolic function, which may aid in clinical decision-making, provide information with regards to prognosis, or direct pharmacological and other therapies.

TOE is useful in the operating theatre, because the required transthoracic windows are often not available and surgery makes acquisition of high quality pictures very difficult. It was initially introduced as a monitoring device, but since its inception, and taking the above into account, it has evolved into an excellent diagnostic tool.

The field of Transoesophageal Echocardiography encompasses a massive syllabus, but this review will focus only on how we can assess left ventricular systolic function
In its earliest form, introduced in 1976 by Harvey Feigenbaum, TOE was an M-mode transducer combined with a maneuverable coaxial cable. This provided adequate images of the base of the heart, but visualization of the function of the left ventricle was difficult with these early techniques.

The introduction of phased array transducers in the early 1980’s, by the Indiana group among others, improved this considerably. They worked out a system for rocking the standard M-mode transducer back and forth over a 30° sector. Commercial development of this technology allowed the angle of view to be increased to 60° and then subsequently up to almost 90° which is available today.

In 1982 the construction of a two-dimensional transducer within a gastroscopic housing produced the first forerunner of the modern TOE probe. In the mid 1980’s colour flow and pulsed wave Doppler availability greatly increased the applicability of the technique in multiple arenas, including intraoperative imaging and critical care.

The development of higher frequency elements made possible by the lesser requirement of acoustic penetration when in close proximity of the heart, and the absence of other intervening tissues, thereafter increased the resolution capability. Compared to other ultrasound modalities, the probe of the TOE sits less than 60-90mm away from the aortic and mitral valves.

This close proximity allows the use of low power very high frequency ultrasound, and consequently extremely high special resolution.
The ability to obtain high resolution images of the left and right ventricles has been aided by the evolution from monoplane to biplane and subsequently to multiplane imaging which allows the rotation of the scan plane through 180°.

![Figure 2: Multiplane TOE][1, 2]

Initially the assessment of ventricular function was limited to subjective observation with quantitative evaluation only available in off-line modes, but with the development of edge detection technology and continuous wave Doppler imaging the ability to provide online estimates of global function has been improved.

These assessments are now readily obtainable and reproducible, and particularly useful in the setting of the critically ill patient, those patients undergoing cardiovascular surgery, and those patients in which surface images have been judged inadequate.
The earliest approaches to 3D echocardiography were based on the reconstruction of a series of 2D scans. The images were obtained from varying probe positions and at different periods of the cardiac cycle and then stitched together off-line.

Images obtained at the same period in the cardiac cycle needed to be positioned in their proper orientation to one another, and then the surface can be rendered for display.

More recently transducer technology has evolved at the same time computing power expanded to allow the development of the matrix array transducer. The elements of this transducer are arranged in a rectangle, and can collect data from many lines of sight simultaneously, constructing the data in real-time. Currently these transducers have more than 3000 elements. This allows 3D visualization of valves, masses, the infant left ventricle and color Doppler jets, but is not large enough to display the entire adult LV.

<table>
<thead>
<tr>
<th>Year</th>
<th>Development</th>
</tr>
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<tbody>
<tr>
<td>1970</td>
<td>Transoesophageal Doppler of aorta</td>
</tr>
<tr>
<td>1976</td>
<td>M-mode transducer mounted on steerable catheter</td>
</tr>
<tr>
<td>1977</td>
<td>Two-dimensional mechanical array oesophageal probe</td>
</tr>
<tr>
<td>Early 1980s</td>
<td>Phased array transducers introduced</td>
</tr>
<tr>
<td>1982</td>
<td>Pulsed-wave Doppler TOE</td>
</tr>
<tr>
<td>1985</td>
<td>Color flow Doppler TOE</td>
</tr>
<tr>
<td>1989</td>
<td>Biplane TOE transducer</td>
</tr>
<tr>
<td>1992</td>
<td>Multiplane TOE transducer</td>
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</table>
In daily clinical practice 90-95% of patients will have adequate views on Trans-thoracic Echocardiography (TTE), limiting the usefulness of TOE in assessing ventricular function. However, in the remaining 5% of the population with limited trans-thoracic views, the TOE may be invaluable. The predominant role for the TOE has been in critical care and in the operating room. A number of specific indications for TOE assessment have been identified:

1. Inadequate transthoracic image quality
2. Intraoperative ventricular function monitoring – specifically:
   a. Continuous global function assessment
   b. Volume status information
   c. Regional function assessment as a reflection of acute coronary ischemia
   d. Left atrial pressure estimation
3. Cardiac transplant candidacy evaluation
4. In critical care
   a. Evaluation of unexplained hypotension
   b. Assessment of ventricular interdependence
   c. Post cardiac arrest
   d. Evaluation for cardiac ischemia

The use of TOE to monitor left ventricular performance was one of the earliest applications in the intraoperative arena. This form of monitoring allows the anaesthetist to identify the causes of haemodynamic fluctuation and to detect segmental dysfunction, which may reflect myocardial ischemia.

Intraoperative TOE is unique in its ability to provide continuous monitoring of ventricular function, and yet remain separate from the operative field. It may be continued post-operatively in patents that continue to be hypotensive, those on inotropes/vasopressors, and/or those with sluggish return of ventricular function post-cardiopulmonary bypass. In these patients and others with unexplained hypotension TOE can provide insight into whether the cause of the dysfunction is as a result of the vascular tone or primarily cardiac in origin.

In the setting of critical care, TOE is just as useful. Up to 64% of patients who receive TTE do not get adequate images, compared with only 3% of those receive TOE. Compounding this issue is the fact that one study by Hwang et al showed that significant information was missed in up to 50% patients by TTE, but was picked up using TOE.
Despite the fact that the ability of TOE to guide specific therapies and provide useful diagnostic information in the critical care arena is well described, many incidences of TOE use in this set up can be ascribed to lack of adequate surface images.

In the intensive care unit TOE is simple, safe and effective in the management of critically ill patients and provides alternative information to the pulmonary artery catheter (PAC).

Another role for TOE is to assess cardiac function in potential heart donors, where mechanical ventilation may limit the window obtained by transthoracic echocardiography. Inadequate windows may lead to inappropriate exclusion of donors who are actually suitable.

The high definition pictures obtained by TOE can give an estimate of global left ventricular function, exclude mechanical damage (e.g. contusion, valve rupture) in the case of poly-trauma and exclude coronary artery disease in the case of the older donor.

The ASA in association with the American society of Echocardiographers and the American college of Cardiologists have published guidelines based on evidence for and against the use of intraoperative TOE.

The indications are classified as Category I, IIa, IIb and III; Category I indications are those for which there is evidence and/or general agreement that a given procedure or treatment is useful and effective.
### Table 2: ASA Guidelines: Indications for Intraoperative TOE

<table>
<thead>
<tr>
<th>Class I</th>
<th>Class IIA</th>
<th>Class IIB</th>
<th>Class III</th>
</tr>
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<tbody>
<tr>
<td>1. Evaluation of acute, persistent, and life-threatening hemodynamic disturbances in which ventricular function and its determinants are uncertain and have not responded to treatment</td>
<td>1. Surgical procedures in patients at increased risk of myocardial ischemia, myocardial infarction, or hemodynamic disturbances.</td>
<td>1. Evaluation of suspected cardiac trauma, repair of acute thoracic aortic dissection without valvular involvement, and anastomotic sites during heart and/or lung transplantation.</td>
<td>1. Surgical repair of uncomplicated secundum atrial septal defect.</td>
</tr>
<tr>
<td>2. Surgical repair of valvular lesions, hypertrophic obstructive cardiomyopathy, and aortic dissection with possible aortic valve involvement.</td>
<td>2. Evaluation of valve replacement, aortic atheromatous disease, the Maze procedure, cardiac aneurysm repair, removal of cardiac tumors, intracardiac thrombectomy, and pulmonary embolectomy.</td>
<td>2. Evaluation of regional myocardial function during and after off-pump coronary artery bypass graft procedures.</td>
<td></td>
</tr>
<tr>
<td>3. Evaluation of complex valve replacements requiring homografts or coronary reimplantation, such as the Ross procedure.</td>
<td>3. Detection of air emboli during cardiotomy, heart transplant operations, and upright neurosurgical procedures.</td>
<td>3. Evaluation of pericardiectomy, pericardial effusions, and pericardial surgery.</td>
<td></td>
</tr>
<tr>
<td>4. Surgical repair of most congenital heart lesions that require cardiopulmonary bypass.</td>
<td>4. Evaluation of myocardial perfusion, coronary anatomy, or graft patency.</td>
<td></td>
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<tr>
<td>5. Surgical intervention for endocarditis when preoperative testing was inadequate or extension to perivalvular tissue is suspected.</td>
<td>5. Dobutamine stress testing to detect inducible demand ischemia or to predict functional changes after myocardial revascularization.</td>
<td></td>
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<tr>
<td>6. Placement of intracardiac devices and monitoring of their position during port-access and other cardiac surgical interventions.</td>
<td>6. Assessment of residual duct flow after interruption of patent ductus arteriosus.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Evaluation of pericardial window procedures in patients with posterior or loculated pericardial effusions.</td>
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</tbody>
</table>
COMMON VIEWS USEFUL IN EVALUATION VENTRICULAR FUNCTION[3] [4,8, 9]

Each of the following views is useful as they display specific coronary distributions and ventricular segments. Multiplane TOE imaging allows the visualization of regional function in an infinite number of scan planes.

**Transgastric Short Axis View:**
The short axis view at the midpapillary level gives an idea of segmental ventricular performance. All three coronary artery territories are displayed in this view, and it is useful for detecting acute ischemia. Intraoperatively this view is often maintained throughout the procedure.

**Transgastric Long-Axis View:**
This is useful as the left ventricular apex is readily visualized in this plane. It is also useful for measuring cardiac output using continuous wave Doppler at the aortic valve.

**Mid-Oesophageal Four Chamber View:**
Allows simultaneous visualization of both the left and right ventricles, analogous to the identically named trans-thoracic view. Foreshortening of the left and right ventricular cavities is a common problem, and the apices of the ventricles are often not fully seen. Segmental function of the lateral and septal walls is best assessed in this view.
Mid-Oesophageal Two Chamber View:
This view can be used for biplane measurements of ventricular volume and is good for assessing segmental function of the anterior and inferior walls.

SYSTOLIC FUNCTION ASSESSMENT

a. Global Left Ventricular Function [4-6, 10-20]

Global ventricular function can be assessed qualitatively immediately after introduction of the TOE probe:
- Right ventricular collapse
- Severe left ventricular dysfunction
- Cavity obliteration

These indices are all readily apparent to the astute observer. Such overt scenarios, however, are usually the exception, and more subtle gradations and a number of descriptors of ventricular function are commonly used.

It is important to note that in an awake patient the placement of the TOE probe will cause sympathetic discharge and augment the ventricular function, improving the above indices.
<table>
<thead>
<tr>
<th>Method</th>
<th>Measurement</th>
</tr>
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<tbody>
<tr>
<td><strong>Load Dependent</strong></td>
<td></td>
</tr>
<tr>
<td>Fractional area change</td>
<td>ED area − ES area/ED area</td>
</tr>
<tr>
<td>Fractional shortening</td>
<td>ED dimension − ES dimension/ED dimension</td>
</tr>
<tr>
<td>Ejection fraction</td>
<td>Change in LV volume/ED volume</td>
</tr>
<tr>
<td>Cardiac output</td>
<td>VTI × cross-sectional or valve area × heart rate</td>
</tr>
<tr>
<td>dP/dt</td>
<td>Change in LV pressure/change in time</td>
</tr>
<tr>
<td><strong>Load Independent</strong></td>
<td></td>
</tr>
<tr>
<td>Rate-corrected mean velocity of fibre shortening</td>
<td>Fractional area change/Ejection time</td>
</tr>
<tr>
<td>Circumferential wall stress[^31]</td>
<td></td>
</tr>
<tr>
<td>Meridional wall stress[^31]</td>
<td></td>
</tr>
<tr>
<td>Pressure volume and area loops</td>
<td>Volume/area as a function of systemic or LV pressure</td>
</tr>
</tbody>
</table>

The most widely used descriptor of left ventricular function is the Ejection fraction. This figure may be estimated qualitatively or measured quantitatively. Objective measures of ejection fraction rely on the measurement of ventricular dimensions and areas, usually obtained in the short axis view at the level of the mid-papillary muscle. This view is reproducible, readily obtained and frequently used, but does have some limitations. It represents only the basal segments, unlike the long axis views, and it may therefore falsely over or underestimate the contractility of the more apical segments. It is important to remember that the ability to visualize and trace the endocardial border is very important when attempting to obtain accurate volume measurements.

Hence the measurement of left ventricular ejection fraction is affected by operator experience and variable preloading conditions in the perioperative period.
Other methods that may be useful in representing global left ventricular function include fractional shortening, fractional area change and volumetric estimates of ejection fraction. These are all variations on a similar theme. Dimensional fractional shortening is defined as the change in left ventricular dimension (EDD-ESD) divided by the end diastolic dimension (normal >28%).

\[
FS = \frac{(LVIDed - LVIDes)}{LVIDed} \times 100
\]

Fractional Area Change is defined as the change in left ventricular area (EDA – ESA) divided by the end diastolic area (normal >36%). This can be seen as a correlate of ejection fraction.

\[
FAC = \frac{(EDA-ESA)}{EDA} \times 100
\]

A volume-based representation of ejection fraction can be obtained by estimating end-systolic and end-diastolic volumes through two-dimensional quantitative methods, with the aid of a computer program. The resulting left ventricular volumes are inferred and yield an estimated ejection fraction.

Volume quantification on TOE is difficult due to left ventricular cavity foreshortening in the longitudinal view, leading to inaccurate estimates of volumetric ejection fraction. Nonvolumetric methods, used first in transthoracic echocardiography, are now being used in TOE studies. An example of these is the multiple diameter method developed by Doerr et al, where multiple transverse diameters are taken from short axis views and then used with the fractional shortening from a long axis view to estimate the ejection fraction. The technique used also means that the inability to visualize the true apex due to foreshortening is inconsequential.

**Volume Estimates**

Obviously important in assessing the function of the left ventricle is the ability to estimate the volume or preload of the left ventricle. Volume estimates made using the transoesophageal probe are not as reliable as those made using the trans-thoracic probe, as foreshortening is inevitable in the long-axis view of the left ventricle if the imaging plane is not directed through the apex. These estimates can be made from either measurement of left ventricular cavity area, or from volumetric models.

As mentioned above the end-diastolic cross-sectional area of the left ventricle measured using the short axis view at the mid-papillary level is commonly used as a surrogate of volume status, and changes in the end-diastolic dimension at this level correlate well with diastolic volume. The utility of these end diastolic volumes or areas to reflect ventricular filling pressures is uncertain and perhaps limited. The short axis of the ventricle is affected much more by changes in preload than the long axis, and is readily reproducible, making it very useful.
These simplistic measures work well in relatively symmetrical ventricles, but they need to be used with caution in grossly asymmetric ventricles – those with extensive RWMA or asymmetric hypertrophy. Even simpler measures may be used to reflect changes in left ventricular end-diastolic volume, namely end-diastolic circumference and the short axis left ventricular end-diastolic diameter.

Left ventricular end-systolic dimension is a reliable indicator of global left ventricular contractile function. The end-systolic dimension may also provide important clues as to the presence of central hypovolaemia. Leung and Levin have shown that in up to 80% of patients, left ventricular cavity obliteration may indicate hypovolaemia.

There are a number of algorithms used for estimating the ventricular volumes from the two-dimensional TOE. The most commonly used of these are the modified Simpson’s rule and the length-diameter method. The use of these methods however is limited by the above-mentioned problem of foreshortening of the ventricular cavity in the four-chamber view. Volume determination provides three-dimensional representation as opposed to the two-dimensional surrogates mentioned above.

Simpson’s Rule divides the cavity into multiple cylindrical slices of known volume, the sum of these then represents the ventricular volume. The area length method uses the short axis area of the left ventricle, and the left ventricular long axis to calculate the volume.

**Figure 3: Diagrammatic Representation of Simpsons Rule**
A number of researchers have attempted to establish the adequacy of echocardiographically derived left ventricular volumes compared with scintigraphic methods:

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Variables</th>
<th>TOE</th>
<th>Control</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urbanowiz et al</td>
<td>LV Volume</td>
<td>Blood Pool</td>
<td>Scintigraphy</td>
<td>Borderline (r = 0.74)</td>
</tr>
<tr>
<td></td>
<td>LV EF</td>
<td>Thermodilution Cardiac Output</td>
<td>Good (r = 0.82)</td>
<td></td>
</tr>
<tr>
<td>Clements et al</td>
<td>LV Area</td>
<td>Radionuclide Volume</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LV EF</td>
<td>Radionuclide EF</td>
<td>Excellent</td>
<td></td>
</tr>
<tr>
<td>Smith et al</td>
<td>LV Volume and EF</td>
<td>Simpson's Rule</td>
<td>Ventriculography</td>
<td>Good for EF estimation</td>
</tr>
<tr>
<td></td>
<td>LV Volume and EF</td>
<td>Simpson's Rule</td>
<td>Ventriculography</td>
<td>Good for Volume estimation</td>
</tr>
</tbody>
</table>

It was shown that Echocardiographic methods significantly underestimate the volumes and ejection fractions compared to cineventriculographic values.

Ellis et al were the first of many groups to show that the correlation between the ventricular volume or area obtained on TOE and pulmonary capillary wedge pressure or pulmonary artery diastolic pressure is very poor. This reflects changes in ventricular compliance, which the echocardiography is unable to account for.

Automated Border Detection (ABD)

It is obviously important to be able to differentiate the border between the blood and myocardium when measuring the left ventricular volume and function. Manually tracing the outline of the endocardium can be very difficult and time consuming. ABD systems use acoustic quantification to differentiate myocardium and blood based on their different echocardiographic signals. In this way the endocardial border is highlighted.

The left ventricular cross-sectional area can then be displayed continuously online, and ABD can be used in algorithmic volume methods to provide values for end-systolic and end diastolic volume. Using ABD, a single pane longitudinal view of the left ventricle can provide left ventricular volume data, and on-line calculation of stroke volume can be accomplished relatively easily. Rapid estimations of ventricular performance can be combined with measurements of arterial pressure to provide pressure volume loops, or pressure area loops as a load-independent representation of contractility.
The predominant limitation of acoustic quantification is the need for excellent endocardial definition to be able to detect the border. Although two dimensional resolution of TOE is usually adequate, the problem of lateral image drop out poses a challenge for many ABD systems. Technical adjustments to attempt to minimize this have decreased this problem in later TOE systems. Another problem with ABD is that it tends to under-estimate the volume of the left ventricle.

This happens because border detection excludes the papillary muscles from the volume of the ventricle, where traditional techniques include the papillary muscles in left ventricular volume. Papillary muscle interference can be limited by moving the scan plane towards the apex.

Clinically the biggest problem using ABD is the need to maintain a stable image throughout complex surgical procedures.

The need to verify the accuracy of such a system has lead to many authors publishing with varying results. Early in the development of ABD Perez et al compared on-line measurements of the ventricular cavity with off-line analysis. They showed good correlation in over 70% patients. Greim et al, who compared on-line stroke volume calculations with those obtained by thermodilution, later questioned this. He reported very poor correlation between the two techniques. More recently Gorscan compared stoke volume measured using on-line techniques and directly measured in the aorta during CPB. He then used caval occlusion to produce rapid changes in stroke volume. He demonstrated an excellent correlation (r=0.93) using this technique.

More recent developments in 3D echocardiography, either by manual tracking of the endocardial border, or automatic border detection, allows the direct measurement of the ESV and EDV from the 3-dimensional echo picture. Alternatively a series of discs can be performed, where the volumes of the short axis planes are derived and then summed. These three dimensional methods have proved to be more accurate than the 2D methods, and correlate well with MRI and other reference standards.

**Estimation of Cardiac Output**
Cardiac output, although more or less replaced by ejection fraction as a marker of ventricular performance, is still an important surrogate of global function. Using Doppler techniques it is possible to measure the stroke volume by measuring the velocity time interval at a valve or outflow tract (aortic, pulmonary or mitral) and multiply that by the valve area:

\[\text{Velocity Time Interval (cm)} \times \text{Valve area (cm}^2) = \text{Stroke Volume (cm}^3)\]

Using the stroke volume, the cardiac output can be obtained by multiplying the stroke volume by the heart rate.
As mentioned above any valve can be used, but the aortic valve is used most often and this correlates well with thermodilution measurement of the cardiac output. Different authors, using continuous wave Doppler at aortic, pulmonary and mitral valve have achieved r values ranging form 0.78 to 0.94. Others have used the VTI as a surrogate for cardiac output, but the correlation in this case is less convincing.

Other authors have used pulsed wave Doppler to measure cardiac output, and also shown good correlation with thermodilution.

Multiplane TOE has shown that cardiac output can even be calculated at the mitral valve as long as the valve is not regurgitant.

Another method of determining cardiac output is using mathematical models to estimate the end systolic and end diastolic volumes from two dimensional cross-sectional views, and then estimate stoke volume and cardiac output using these values. Modest correlation has been shown with thermodilution techniques.

**Systolic Index of Contractility (dP/dt)**

This is the most load independent of the “Load-dependent” indices. It requires that there be a measurable mitral regurgitant jet present, and it is a measure the initial acceleration of this jet back into the left atrium, representing the contractile force generated during left ventricular isovolmic contraction.

Normal dP/dt is greater than 1200mmHg/s, and less than 800mmHg/s indicates impaired systolic function.

**Myocardial Performance Index**

This is the ratio of total left ventricular isovolemic time to ejection time

\[
MPI = \frac{(IVRT+IVCT)}{Systolic\ ejection\ period}
\]

Normal MPI is 0.4 or less. An MPI of greater than 0.6 could imply either systolic or diastolic dysfunction.

A difficulty often encountered when making an assessment of Left Ventricular function is that many of the measures above are dependent on left ventricular preload and afterload at the time at which the study is done. There are a few measures to calculate the left ventricular function where the calculations are not load dependent, but they are intricate and can often not be done in real-time.
Tissue Doppler Imaging
This involves the use of pulsed wave Doppler technology adapted to measure myocardial velocities instead of blood flow. During normal left ventricular contraction the mitral annulus descends towards the apex of the heart. Tissue Doppler imaging can measure the velocity of this descent.

This measurement correlates with traditional measures of global left ventricular function, for example Ejection fraction and dP/dt, and it decreases with myocardial ischemia and increases as expected in the presence of inotropes. It seems relatively resistant to modest changes in afterload, but is highly preload dependent.

Load Independent Measures of Left Ventricular Performance
All the above measures of LV function tend to be load dependent. Changes in both preload and afterload can affect the ejection fraction without changing contractility.
Load independent measures of function include Left ventricular mass, Rate corrected mean velocity of fibre shortening and measures of wall stress for example circumferential wall stress and meridional wall stress. These measurements of wall stress, while reflective of intrinsic contractility, should be recognized as derived entities and as such may be of little clinical use.

One of the most readily accessible and often the most obvious measurements to be made is that of ventricular muscle mass. Chronic pressure overload will lead to concentric ventricular hypertrophy. In compensated left ventricular hypertrophy, muscle mass increases in relation to cavity volume.

This is detected as an increase in left ventricular wall thickness. An end diastolic posterior wall thickness of greater than 1.1cm is suggestive of concentric left ventricular hypertrophy.

Chronic volume overload also causes left ventricular hypertrophy, but in contrast to pressure overload the hypertrophy leads to an increase in cavity size without an increase in ventricular wall thickness. An end-diastolic short-axis left ventricular diameter of greater than 5.5cm, or a cross-sectional area of greater than 22cm² at the mid-papillary level suggests eccentric hypertrophy.

Mean velocity of fibre shortening:

\[ MVFS = \text{fractional area shortening}/\text{left ventricular ejection time}. \]

Left ventricular ejection time is obtained by M-mode evaluation of the aortic valve, and corrected by dividing this time by the square root of the R-R interval.

Circumferential and Meridional wall stresses are measures of systolic wall tension and meridional wall stress is independent of ventricular dimensions.
Their utility is in the ability to measure systolic function in both hypertrophied and dilated hearts, giving an index of function that is relatively independent of loading conditions.

Pressure dimension relationships are evolving as sensitive correlates of contractility. These are obtained non-invasively from blood pressure measurements and automated border detection estimates. The clinical use of these measurements is somewhat limited as these determinations need to be made offline.

All these global measures of Left Ventricular function are based on a single cross section of the left ventricle. The presence of asymmetry or dysynergy, especially when the affected area is not in the plane of the image will render the index a poor indicator of global function. Often a qualitative assessment of global function may be made based in a visual inspection of the entire ventricle.

b. Regional Left Ventricular Function [5, 13, 16, 17, 19-22]

It is well recognized that the onset of regional wall motion abnormalities is congruous to the impaired perfusion of epicardial blood vessels and occurs well before any electrocardiographic changes. These wall motional abnormalities are therefore concomitant with ischemia and may appear as reduced thickening or diminished inward motion of the endocardium during systole and occur within a given coronary distribution.

TOE has proved superior in detecting acute ischemia when compared to both multi-lead electrocardiographic monitoring and invasive haemodynamic monitoring. In the operating room and in the critical care setting TOE is ideally suited to monitoring regional systolic function where the onset of ischemia can be identified and quickly remedied before the onset of electrocardiographic or haemodynamic consequences.
Standard echocardiographic views include at least four views of the left ventricle. The left ventricular short axis view at the level of the tips of the papillary muscles is the most useful of the views for assessing regional function. This allows the clinician a view of all three coronary distributions, and is easily reproducible from observer to observer. According to the ASEC 17-segment model the Short Axis View at the mid-papillary (mid-cavity) level is divided into six segments as shown below:

7) Anterior
8) Anteroseptal
9) Inferoseptal
10) Inferior
11) Inferolateral
12) Anterolateral

Figure 4: ASE 17 segment model for the Left Ventricle

Figure 5: Trans-Gastric Mid-Papillary Short Axis view of the left ventricle showing its six segments
Individual myocardial segments are visualized and wall motion is assessed in terms of wall thickening and endocardial movement toward the center of the cavity. Areas that do not thicken, or do not move inward during systole are described as regional wall motion abnormalities. These wall motion abnormalities may be graded as:

1) Normal
2) Hypokinetic (mild/moderate/severe)
3) Akinetic
4) Dyskinetic

Application of our anatomical knowledge of the blood supply to the abnormal segments allows attribution of the RWMAs to the circulation of one of the three coronary arteries.

The problem with this classification is that it is relatively subjective and based on visual inspection. Recently quantitative systems have been developed. These are based on digitalized measurements. Semi-quantitative scoring systems assign a wall motion grade according to degrees of myocardial thickening, or amount of inward movement. Adequate resolution of the endocardial border is imperative to any form of regional wall motion assessment.
Although the short-axis, mid-cavity view is preferred for assessing the regional ventricular function, up to 30% of wall motion abnormalities may be missed, and multiplane evaluation must be used for a full assessment. Despite a full multiplane assessment wall motion abnormalities of the apex may still be missed due to unavoidable ventricular foreshortening.

Other pitfalls that may hamper adequate evaluation of regional systolic function are tethering of an adjacent myocardial segment, cardiac pacing, conduction abnormalities and oblique imaging planes. Rotation and translation of the heart while it is beating may also prevent adequate evaluation of certain segments. While identification of wall motion abnormalities in the segments mentioned above is possible in theory it is essentially qualitative and subject to observer bias and misinterpretation due to the many factors just listed. This explains why the ASA and ASE do not strongly recommend routine transoesophageal monitoring for ischemia in patients at risk.

Tissue Doppler, Strain Rate, Strain and Speckle Tracking are relatively new additions to the echocardiography toolbox.

These have been used in other areas of myocardial assessment, but have recently been added to the armoury for detecting regional myocardial dysfunction. Radial Strain Rate has recently been shown to correlate well with regional myocardial blood flow.

As they can confirm the qualitative assessments of wall motion abnormalities, they can assist the novice echocardiographer in their interpretation of regional myocardial function.

One would expect that soon after restoration of myocardial blood supply the regional wall motion abnormalities would be reversed, but global ischemia and superimposed reperfusion injury has a deleterious effect on the myocardium, limiting the immediate response one may see to the improved blood flow to the previously ischemic areas. The entities of stunning and hibernation also contribute to this effect. The absence of an immediate effect after revascularization limits the usefulness of the

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</thead>
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<tr>
<td>Normal</td>
<td>&gt;30%</td>
<td>+++</td>
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<tr>
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TOE in assessing the success of coronary artery bypass surgery. A number of authors have shown that after revascularization myocardial segments that were normal pre-bypass displayed wall motion abnormalities at 5 minutes post bypass and this only returned to normal at 30 minutes post bypass. Areas that had RWMA pre-bypass showed significant improvements at 30 minutes post bypass.

**ASSESSMENT OF LEFT VENTRICULAR FUNCTION DURING CARDIAC SURGERY** [2, 7, 11, 23-29]

An area where transoesophageal echocardiography has been very useful is in valve surgery, specifically mitral valve repair. Here the surgeon needs to understand the precise mechanism of the dysfunction, and the assessment needs to be done dynamically with the heart beating, and the ventricle maintaining full cardiac output. Colour-Flow Doppler allows us to visualize not only exactly which leaflet is dysfunctional, but also which of the scallops is abnormal. Taking all this into account the surgeon can plan the surgery before the heart is stopped. After the patient comes off bypass, the adequacy of the repair can be assessed, and if the result is not acceptable a second bypass run can be undertaken, preventing a second visit to theatre at a later stage.

During Coronary artery bypass grafting transoesophageal echocardiography provides useful information regarding the ischemic territory. Pre-repair, the echo can give information about ischemic areas that may not have been recognized before aortic cross-clamping, and during cardioplegia echo contrast agents may be given to highlight areas that are most under perfused.

Echocardiography may also be used to evaluate the improvement in regional function after revascularization.

The value of TOE in routine surgery is changing. In 2000 one author reported that it may not add significantly to the information obtained from invasive monitoring, but he was of the opinion that TOE may aid the anaesthesiologist in the management of the high-risk patient with poor left ventricular function.

More recently however, with the greater availability of TOEs and the fact that they are considered relatively non-invasive, they are becoming more and more routine and the information is becoming invaluable. Indeed some surgeons and anaesthetists would be hesitant to continue without TOE available.

Patients in which unexpected complications occur may necessitate TOE, for example unexpected pump failure, or inability to come off bypass. The results of the echocardiographic examination may point a pathology that is surgically amenable, for example incomplete revascularization or inadequate valve repair, and this could be corrected before the chest is closed. On the other hand the echo could point to an empty heart, where volume may be needed, or direct the anaesthetist towards inotropes or vasodilator drug therapy.
During off pump cardiopulmonary bypass the TOE may be especially helpful. It can assess the severity and location of lesions, directing the surgical plan as to which vessels need to be grafted and in which order. It can also direct haemodynamic management of the patient, direct fluid administration to optimize preload, or inotrope and vasopressor administration. When the vessels are cross-clamped new wall motion abnormalities will be seen. These should resolve within a few minutes after revascularization, and persistent new regional wall motion abnormalities are associated with elevated cardiac enzyme levels and more clinical problems. If these RWMA persist the surgeon should consider reevaluating the patency of the bypass graft.

INTRAOPERATIVE TRANSOESOPHAGEAL ECHOCARDIOGRAPHY DURING NON-CARDIAC SURGERY [2, 6, 7, 14, 17, 19, 22, 30, 31]

The broader application of TOE outside the cardiac operating theatre seems to be limited by high initial cost, training requirements, lack of appreciation of the depth and accuracy of the information available.

In high-risk cardiac patients undergoing non-cardiac surgery TOE has been advocated for monitoring of global left ventricular function, intravascular volume status and regional wall motion abnormalities.

An article by Bakker and Poldermans et al looking at risk reduction in non-cardiac surgery stated that intraoperative monitoring with TOE could be considered in high-risk cardiac patients for routine use, or in those patients where severe haemodynamic instability is expected with large fluid shifts. This is because TOE guides haemodynamic management in these patients and is able to detect new wall motion abnormalities, which have been shown to be strongly predictive of cardiac complications.

Other studies have shown that the absence of regional wall motion abnormalities have a good prognosis (high NPV), but the presence of segmental dysfunction has a low positive predictive value for adverse events.

Catena et al also looked at the use of TOE in non cardiac surgery, pointing out that it was useful for assessing left ventricular preload, systolic and diastolic function, right ventricular size and function and valve function. They are of the opinion that its value in preventing major haemodynamic disturbances lies in its ability to aid in the decision as to whether hypotension is due to pump failure, inadequate circulating volume or arteriolar dilatation and to direct appropriate management.

In the case of myocardial ischemia, TOE allows early identification of ischemic segments and can direct aggressive intra-operative and post-operative resuscitation, ensuring haemodynamic stability and control of the causes of myocardial injury.
Studies have shown that the use of intraoperative TOE has a significant effect on both drug therapy and on fluid administration in the patient undergoing non-cardiac surgery.

Use of TOE as routine monitor for haemodynamic manipulations seems to be dependent on level of training. Overall it seems to be valuable in patients with poor left ventricular function and in those with known coronary artery disease at great risk for ischemic events. The duration and type of surgery will also direct the need for echocardiographic monitoring.

**EVIDENCE TO SUPPORT THE USE OF TRANSOESOPHAGEAL ECHOCARDIOLOGY** [2, 7, 8, 14, 19, 22, 26, 27, 32, 33]

The current guidelines released by the ASE and ASA, as quoted above, outline specific areas where there is good evidence to support the use of transoesophageal echocardiography. Specifically, during surgery for valve repair and replacement, during repair of congenital cardiac defects and in the haemodynamically unstable patient TOE has proven pivotal, in guiding surgeons, assisting with surgical planning and decision-making, and whether further surgery or no surgery is indicated.

After the repair is complete it can be assessed for adequacy. There have been many studies that show that despite the relatively rare incidences that TOE changes surgical plans (only 5-6% of cases), the impact that these changes have on cost saving is significant, and therefore justifies the initial outlays of purchasing equipment, training and upkeep.

There is currently no evidence showing outcome benefit for patients undergoing coronary artery bypass grafting specifically from the use of transoesophageal echocardiography. Despite this some experts still advocate its use to guide anaesthetic and surgical management.

The assessment of global and regional left ventricular function with TOE has proved reliable and comparative with pulmonary artery catheter and standard thermodilution techniques.

There have been no studies that show that TOE is better than any other guide for goal directed therapy or cardiac output monitor, but the evidence that shows that the use of these devices has outcome benefit can surely be extended to a device that has been shown to be comparable to the gold standard.
Swanvelder writes that intraoperative transoesophageal echocardiography has become the gold standard cardiac monitor and diagnostic tool. Yet he points out, as I have above, that there is limited evidence to substantiate this belief.

Transoesophageal echocardiography should never be used as the sole device for the acquisition of data but as an extra tool to build a more comprehensive understanding of the patients’ physiology.

If we are to believe its’ supporters and with the exceedingly low incidences of adverse effects, the rate at which technology and computing power are progressing and the amount and quality of information that is available from this device, TOE seems set to move from the realm of “luxury” to that of “standard” intraoperative monitoring and diagnostic equipment, and a device that most consultant anaesthetists will have to be able to operate.
REFERENCES


