Perioperative monitoring of left ventricular function: what is the role of recent developments in echocardiography?

Evaluation of left ventricular (LV) function is desirable for risk stratification and optimization of cardiovascular patients requiring major surgery.1 This editorial examines the problems of monitoring and quantifying LV function; it questions whether recent advances in echocardiography can provide us with accurate and useful information in the perioperative period.

LV ejection fraction is a well-established, and the most commonly utilized measure of LV contractility and function. It is the ratio of stroke volume to end-diastolic volume and has major prognostic significance since patients with impaired LV ejection fraction have adverse survival rates. For instance, in an observational study of patients recovering from surgical coronary revascularization, cardiac mortality was significantly greater in patients with LV ejection fraction ≤35% than in those with a higher value (hazard ratio 0.9, 95% CI 0.87–0.96).2 For major non-cardiac surgery, heart failure was found to be associated with an increased risk of perioperative mortality and readmission to hospital when compared with the absence of heart failure (hazard ratio 1.63, 95% CI 1.52–1.74) or the presence of coronary artery disease only (hazard ratio 1.51, 95% CI 1.45–1.58).3 These findings are supported by another study in which heart failure was associated with increased duration of hospital stay and also readmission within one month after elective non-cardiac surgery.4 Despite these important implications, the accuracy of measurement of LV ejection fraction is affected by operator experience and variable preloading conditions in the perioperative period. In addition, conventional methods for measurement are semi-quantitative since they estimate LV ejection fraction from changes in length or area rather than volume.

Traditionally, LV fractional shortening is obtained by measuring the ventricular cavity in a single dimension, at the level of the mitral valve chords, perpendicular to the long axis of the LV. Shortening of this measurement in systole compared with diastole is then converted by an equation into a volumetric value.5 In addition, volume changes may be estimated in two dimensions by obtaining the end-systolic and end-diastolic areas within the endocardial border of the heart. Assuming a standardized geometric shape of the LV, measurements of changes in area are then converted to end-systolic and end-diastolic volumes by summation of imaginary discs. In the intraoperative period when transoesophageal echocardiography (TOE) is utilized, the apex of the LV is the cardiac section furthest away from the transducer and therefore often foreshortened and poorly visible; in this situation, two-dimensional (2D) measurements of area underestimate LV volume.

Recently, 3D acquisition of LV data has been made possible by advances in transducer technology.6 The new design of transducer has more than 3000 piezoelectric elements, organized in a matrix rather than in linear fashion. 3D images in real time display cardiac structures in 4D, time being the fourth dimension. This novel modality contrasts with reconstruction of multiplanar 2D images, a developmental method that does not give instant 3D images. However, compared with 2D imaging, real-time 3D has lower spatial resolution due to reduced line density, and also lower temporal resolution. Moreover, owing to the fixed position of the transducer in the oesophagus when obtaining 3D data, not all structures will be aligned to reflect ultrasound strongly. Current transducers are only able to acquire thin slices of real-time 3D images in either the ‘Live 3D’ or ‘3D zoom’ modes. To obtain sufficient resolution for large structures such as the LV, several of these thin slices have to be assembled over four to six consecutive cardiac cycles, using the ‘Full Volume’
mode. Artifacts may occur as these sequential 3D slices are stitched together. In the intraoperative setting, surgical manipulation, diathermy, and changes in ventilation may cause additional artifacts.

Provided a 3D data set of good quality is acquired, a few simple steps of semi-automated processing are required to obtain LV ejection fraction after importing the data into a software package on the machine. These steps include cropping the data and aligning the orthogonal images so that the LV is not foreshortened. Basal and apical landmarks, together with the endocardial border of the heart, are confirmed according to the specific phase of the cardiac cycle. The image is then processed automatically to display an endocardial cast and to calculate LV ejection fraction using advanced algorithms. Volumetric measurements obtained in this way correlate better with those measured by cardiac magnetic resonance imaging than by 2D echocardiography. Thus, with real-time 3D TOE we can now obtain increasingly accurate measurements of LV function and contractility in the perioperative period.

From the same 3D data set for calculation of LV ejection fraction, it is possible to obtain other individual variables, including end-diastolic volume, end-systolic volume, and cardiac output, that have importance in the perioperative period. Large end-diastolic and end-systolic volumes have prognostic value since they are associated with adverse survival rates after surgery for mitral or aortic regurgitation. Furthermore, cardiac output is an essential measurement owing to its manipulation by fluid administration and inotropic therapy in high-risk surgical patients. Although cardiac output is often obtained by other methods in anaesthesia, for instance, pulse contour analysis and thermodilution, it may be reassuring to obtain concordance between different methods of measurement particularly in critically ill patients. During haemodynamic evaluation, TOE has proved reliable and comparative with standard thermodilution using the pulmonary artery catheter.

In addition to LV volumes and ejection fraction, it may be useful to monitor for myocardial ischaemia in high-risk surgical patients since their outcomes are adversely affected by perioperative myocardial infarction. For instance, in an observational study of patients undergoing vascular surgery, silent myocardial ischaemia was found to be associated with increased mortality (hazard ratio 1.74, 95% CI 1.46–2.06) and major cardiac events (hazard ratio 1.86, 95% CI 1.43–2.41). In another study in vascular patients, perioperative myocardial injury was associated with prolonged hospital stay and increased admissions to critical care.

When there is a significant imbalance between myocardial oxygen supply and demand, alterations in myocardial wall motion, such as hypokinesia, akinesia, and dyskinesia, may be observed before electrocardiographic changes. Abnormalities in wall motion may occur in any of the arbitrary 17 segments of the LV that receive blood from one or more of the three main coronary arteries. While identification of abnormalities in each of these segments is possible in theory, it is essentially qualitative and therefore subject to observer bias and misinterpretation caused by tethering or translation rather than ischaemia. Thus, it is unsurprising that routine transoesophageal monitoring of wall motion in patients at risk of perioperative myocardial ischaemia is not strongly recommended (Class IIb recommendation) in the current guidelines.

However, with real-time 3D echocardiography, multiple slices, from the apex to base, can now be displayed simultaneously. Visualization of the LV in this way may assist in improving accuracy of detection of abnormal regional wall motion and, hence, myocardial ischaemia. Initial investigations with administration of dobutamine suggest that these multi-sliced displays achieve high specificity for detection of angiographically confirmed ischaemic heart disease. In addition, the timing of contraction of each of the 17 segments from the computer-generated endocardial cast may be displayed graphically to detect delays in contraction and hence possible myocardial ischaemia.

It is possible that other quantitative methods of assessment of regional myocardial contraction and relaxation may improve detection of myocardial ischaemia. Deformation of each segment of the myocardium may be obtained by measurement of the relative movement of two tissue speckles. Tracking of these tissue speckles may be quantified by obtaining the ratio of change in distance between two speckles to the original distance between them; this ratio is called strain. Current software packages enable semi-automated measurements of segmental strain along all three axes of the LV (longitudinal, radial, and circumferential). These relatively objective measurements may assist detection of abnormalities in myocardial deformation and hence myocardial ischaemia in each segment of the LV.

Although this technology enables rapid detection of myocardial deformation, it is not specific for myocardial ischaemia as abnormalities of deformation occur in patients with cardiomyopathy and systemic diseases such as hypertension and diabetes mellitus. There is also heterogeneity in absolute values of strain from the same data analysed between software from different manufacturers.

In addition to ejection fraction and myocardial ischaemia, monitoring of LV filling pressure is desirable in high-risk surgical patients and in critical care for two main reasons. First, in the perioperative period, when there are fluid shifts and blood loss, optimal administration of replacement fluids and hence optimal filling pressure are required to maintain adequate cardiac output and organ perfusion. Secondly, elevated baseline LV filling pressures in high-risk patients may indicate severe LV diastolic dysfunction. In patients referred for echocardiography, this phenomenon has prognostic value since it is associated with adverse outcome and death. In a study of
patients undergoing elective vascular surgery, diastolic dysfunction was shown to be associated with postoperative congestive heart failure and prolonged duration of hospital stay.\textsuperscript{20} In anaesthetic practice, the pulmonary artery catheter has enabled us to measure pulmonary capillary wedge pressure and hence LV filling pressure. However, with advances in perioperative echocardiography, we can not only detect high LV filling pressure but also investigate its aetiological factors (e.g. pericardial effusion or myocardial disease) and quantify severity of diastolic dysfunction.\textsuperscript{21}

LV filling pressure may be estimated rapidly as a result of developments in pulse-wave Doppler echocardiography. It is estimated from the ratio of the peak velocity of blood flowing across the tips of mitral valve leaflet ($E$) to the peak myocardial velocity of the mitral annulus ($e'$) in diastole. $E/e'>15$ indicates high filling pressure, whereas $E/e'<8$ suggests normal filling pressure. Advances in filtering of ultrasound enable the Doppler signals to be optimized so that red cells can be differentiated from myocardial tissue. In contrast to red cells, the mitral annulus is an intense reflector that moves slowly. Thus, when measuring mitral annular velocity in tissue velocity imaging mode, Doppler ultrasound reflections of low amplitude and high frequency shifts are filtered out, so that the velocity of the mitral annulus can be measured accurately.

The $E/e'$ ratio has been shown to be useful since it correlates with LV filling pressure measured by the pulmonary artery catheter in ventilated patients in critical care.\textsuperscript{22,23} This association arises because blood flow across the mitral valve (represented by $E$) is determined by left atrial-driving pressure, kinetics of LV relaxation, and age, whereas mitral annular velocity depends only on kinetics of LV relaxation and age. Thus, when $E$ is divided by $e'$, kinetics of LV relaxation and age are eliminated to give left atrial-driving pressure and hence LV filling pressure.\textsuperscript{24} While the $E/e'$ ratio is useful for determining LV filling pressure and assisting in the quantification of possible diastolic heart failure, it is inaccurate in the presence of mitral valve disease.

Of the three main developments in echocardiography for monitoring of LV function, speckle strain and tissue Doppler imaging are supported by many current echocardiographic systems and hence available for perioperative application. However, real-time 3D TOE will take a few years before it becomes widespread. Presently, there is only one manufacturer, few machines, and a paucity of training opportunities. Furthermore, purchase of 3D TOE systems in many institutions may be precluded by budgetary restrictions, until further competition occurs.

In conclusion, real-time 3D TOE is now possible and represents an historic milestone. Speckle tracking, tissue Doppler imaging, and real-time 3D TOE are promising techniques that enable accurate quantification of LV function and cardiovascular risk stratification. By enhancing clinical management in high-risk patients, they may help us to meet rising expectations of superior outcome in the perioperative period. In the near future, we envisage that further data concerning perioperative outcomes associated with these imaging modalities will become available. Moreover, with improved automation, miniaturization and educational prospects over time, we foresee that these techniques will be embraced routinely by more and more anaesthetists.\textsuperscript{25}

**Conflict of interest**

None declared.

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