On-line estimation of left ventricular stroke volume using transoesophageal echocardiography and acoustic quantification

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Summary

We have examined the usefulness of transoesophageal echocardiography (TOE) and automated endocardium detection for on-line calculation of left ventricular stroke volume. In 12 of 15 patients undergoing abdominal surgery, stroke volume was derived continuously from the multiple discs (MD) and area–length (AL) methods and compared with stroke volume calculated by thermodilution. In 10 patients (80%), more than three manipulations of the ultrasound transducer were required before measurements. Linear regression analysis of automated TOE methods and thermodilution revealed weak correlations (r<0.75) for stroke volume (114 matched pairs) and its changes (105 matched pairs). Correlation of percentage changes in stroke volume calculated by thermodilution with those derived from MD (r=0.85) and AL (r=0.79) was better. Changes in MD (AL) derived stroke volume by more than 20% identified changes in stroke volume greater than 20% (n=57) with a sensitivity of 74% (70%) and a specificity of 82% (79%). Signal instability, lack of accuracy and only a moderate trend capability currently limit the intraoperative usefulness of automated TOE techniques for continuous estimation of stroke volume from a single long-axis plane. (Br. J. Anaesth. 1996;77:365–369)

Key words

Echocardiographic automated border detection (ABD), which is based on the acoustic quantification of ultrasonic back scatter signals1, has recently been added to the intraoperative assessment of left ventricular (LV) function2–4. ABD algorithms have been devised to derive real-time LV volumes from single-plane long-axis views on a beat-to-beat basis. This technique uses previously established area–length (AL) or multiple disc (MD) formulae5–6 and provides the user with digitized information on end-diastolic and end-systolic LV volume. Few transhrocic studies have investigated the potential of ABD methods for rapid on-line calculation of LV stroke volume5,6. This study was designed to assess the capability of ABD techniques for transoesophageal (TOE) monitoring of LV stroke volume during prolonged surgical procedures.

Patients and methods

After obtaining approval from the local Ethics Committee, we studied 15 consenting patients (aged 37–62 yr) undergoing prolonged major abdominal surgery. Measurement of cardiac output by thermodilution using a pulmonary artery catheter (7.5 F, Baxter Healthcare Corp., Irvine, CA, USA) was part of the routine anaesthetic management. All observations were made with the heart in sinus rhythm.

After induction of anaesthesia and tracheal intubation, a 5-MHz multiplane ultrasound transducer connected to an imaging system with an endocardial edge detection algorithm (Sonos 1500, Hewlett Packard, Andover, MA, USA) was introduced into the oesophagus. After a routine echocardiographic examination, the probe was positioned at the midesophageal level and the transducer crystals rotated electronically (40–80°) until the two-chamber view with the longest LV axis was seen without imaging the LV outflow tract. This image was stored as cine loop for later reference. ABD was activated, and transmission, time-gain compensation and lateral gain control adjusted to obtain optimal back scatter imaging of the endocardium. Gain settings were maintained unchanged throughout the study. After limiting the region of interest, LV volumes at end-diastole and end-systole were calculated continuously and displayed (fig. 1) by a prototype software package integrated into the ultrasound system. The transducer was fixed at the operating table and its position corrected before each measurement of cardiac output when required to regain the reference two-chamber view. Studies were eliminated from analysis when ABD failed to detect more than 75% of the endocardial edge, compared visually with the standard two-dimensional image, or when regional wall motion abnormalities were detected. Real-time volumes were estimated from this view by two algorithms activated independently.
The method of discs (MD), a modification of Simpson’s rule, allowed automated volume calculation from 20 equally spaced discs. The second was the area–length (AL) formula. MD and AL derived stroke volumes were calculated off-line as the difference between end-diastolic and end-systolic LV volume.

Measurements of cardiac output by thermodilution were performed in triplicate during expiration using 10 ml of iced saline. Values of 15% variation, largest to smallest, were accepted for calculating mean cardiac output and mean stroke volume as the ratio of cardiac output and heart rate. Corresponding to each thermodilution bolus, echocardiographic sequences of at least 10 cardiac cycles were recorded on videotape. During a minimum operation time of 4 h, a total of 10–14 mean cardiac output measures and serial echocardiograms were obtained for each patient. Measurements were made at intervals of approximately 15 min or at the request of the attending anaesthetist.

Videotape recordings were analysed by taking 25 consecutive cardiac cycles from each series of echocardiograms corresponding to each measurement of mean cardiac output by thermodilution. Mean values of MD and AL derived stroke volume were compared with stroke volume calculated by thermodilution by linear regression, Bland–Altman analysis and analysis of variance (ANOVA). Changes in MD and AL derived stroke volume were tested for sensitivity and specificity of indicating clinically relevant changes in thermodilution stroke volume (defined as changes of more than 20%). To account for the variability in ABD determined LV volumes, we calculated 95% confidence limits of LV stroke volume, obtained from 25 consecutive cardiac cycles at each measurement. Only stroke volume data with a confidence range of less than ±20% from the mean were accepted for direct comparison with thermodilution stroke volume. Consequently, only changes in mean ABD derived stroke volume of more than 20% were considered significant.

**Results**

Technically adequate echocardiograms with activated ABD were obtained in 12 patients within a few minutes after insertion of the probe. Three additional patients were excluded after being entered into the study because intraoperative echocardiographic criteria were not fulfilled. In 10 patients (83%) more than three measurements required prior manipulations of the probe to correct for the pre-selected view or regain good image quality. In total, 114 corresponding measurements of ABD and thermodilution derived stroke volume (range 37–161 ml) and 105 calculations of stroke volume changes (−65–117 ml) were available for comparison; 16% of all ABD data were excluded from comparison because of unacceptable variability.

Underestimation of thermodilution stroke volume by ABD methods occurred throughout the study in all but one patient. Linear regression analysis revealed poor correlation between both ABD methods and thermodilution in determining stroke volume ($r = 0.66$ and $r = 0.68$). Results of Bland–Altman analysis showed a mean systematic stroke volume difference of approximately 25 ml (fig. 2), with mean estimation of cardiac output being 2.5 litre min$^{-1}$ less than cardiac output calculated by thermodilution. No significant effects of heart rate, end-systolic or end-diastolic volume were detected between the methods. Changes in thermodilution stroke volume correlated moderately with those for

![Figure 1](image-url)  
**Figure 1** Transoesophageal echocardiographic view of the left ventricle in its long axis. Left: Single-plane application of the method of discs allowed calculation of the volume of the left ventricle from 20 equally spaced discs ($A_i$, with $i = 1$ to $i = 20$) and the length of the long chamber axis ($l$). Right: Single-plane application of the area–length method allowed calculation of the volume of the left ventricle from the cross-sectional chamber area and long axis chamber length ($l$).
MD and AL derived stroke volume ($r = 0.75$ and $r = 0.69$). However, Bland–Altman analysis revealed high standard deviations for both ABD methods (fig. 3). Significant good correlations between ABD methods and thermodilution were obtained for percentage changes in stroke volume (fig. 4).

Direction of changes in thermodilution stroke volume were indicated correctly in 79% (MD method) and 72% (AL method) of all measurements. Changes in MD derived stroke volume (AL stroke volume) by more than 20% identified thermodilution stroke volume changes greater than 20% ($n = 57$) with a sensitivity of 74% (70%) and a specificity of 82% (79%). The mean positive predictive value of significant ABD derived stroke volume changes for thermodilution stroke volume changes >20% was 0.60. The mean negative predictive value of non-significant ABD derived stroke volume for thermodilution stroke volume changes <20% was 0.75.

**Discussion**

We have examined an advanced transoesophageal echocardiographic technique for its accuracy and trend capability in estimating LV stroke volume during abdominal surgery. With reference to thermodilution, both ABD methods had poor accuracy in determining actual stroke volume, while they correctly identified approximately 75% of changes in stroke volume greater than 20%. The technique was applicable during operation in 80% of patients. The use of the methods required frequent probe manipulations and was associated with signal instability.

There are few methods currently available for monitoring stroke volume on a beat-to-beat basis. Stroke volume is commonly derived from thermodilution, which is invasive and gives only intermittent data. In contrast, acoustic quantification analyses continuously radiofrequency data and applied to transoesophageal echocardiography has the potential to accurately measure LV cavity area. ABD algorithms for on-line calculation of LV volumes from single long-axis views are based on formulae recommended by the American Society of Echocardiography. Recent transthoracic studies in a canine heart model and in humans have confirmed that ABD derived stroke volume from a single long-axis plane correlates closely with stroke volume.
agreement in a previous transoesophageal study. ABD methods with thermodilution showed better ability to measure stroke volume. Correlation of stroke volume, they are disappointing with regard to measurement of stroke volume, and may be suitable for intraoperative trend analysis. Methods reflect percentage changes in stroke volume do not require data work up on various standard images. They allow rapid, serial estimates of cardiac filling and do not require data work up on various standard images.

Figure 4 Linear regression of percentage changes in stroke volume (SV) obtained by (A) the multiple disc (MD) method \( y = 1.0x + 1.6; r = 0.85; \text{SEE} = 32; n = 105 \) and (B) the area–length (AL) method \( y = 0.9x + 2.0; r = 0.79; \text{SEE} = 24; n = 105 \) in relation to changes in thermodilution (TD) stroke volume.

obtained by other established methods. In common with this study, however, ABD methods consistently underestimated actual stroke volume and the limits of agreement were wide. A major drawback of this single-plane approach is the inability to see the apex of the left ventricle, which makes assessment of LV areas and axes by more than one plane a preferable technique for volume determination. However, in the intraoperative situation, single-plane measurements provide practical advantages, because they allow rapid, serial estimates of cardiac filling and do not require data work up on various standard images. While our results suggest that single-plane ABD methods reflect percentage changes in stroke volume and may be suitable for intraoperative trend analysis of stroke volume, they are disappointing with regard to measurement of stroke volume. Correlation of ABD methods with thermodilution showed better agreement in a previous transoesophageal study. Katz and coworkers calculated regression coefficients from \( r = 0.74 \) to \( r = 0.82 \) for MD and AL derived stroke volume compared with thermodilution stroke volume, when a maximum of two data sets were obtained in each of 18 patients. An excellent correlation between transthoracic ABD and the thermodilution technique was reported recently by Tardif and colleagues who measured cardiac output in critically ill patients. In our study, the different approach and design may have contributed to the lower agreement between the ABD methods and thermodilution for several reasons. First, careful technical settings are critical to maintain precision of ABD data over hours. In our study, repeated manipulations of the probe were necessary as a result of surgical manoeuvres such as chest retraction or upper abdominal exploration. Artefacts and worsening of signal transmission with time may have occurred as a result of drying of the ultrasound transmission gel between the oesophageal mucosa and the transducer head. In addition, changes in end-diastolic LV volume required repeated adjustment of the limiting region of interest and played a role in the continuous performance of ABD methods. These factors may have contributed to the high variability in 16% of automated TOE data that required exclusion from further analysis.

Although there are several sources for ABD signal instability, we believe that a more important shortcoming of this monitoring technique is its lack of accuracy in true volume determination. This may become more prominent during major surgery involving various haemodynamic states that affect cardiac filling and contractility. Possibly, the error of a foreshortened long-axis image is potentiated by major changes in LV volume or heart rate that might result in significant variation in the selected imaging planes. Evaluation is required on the use of other single planes such as the standard four-chamber view, which, in common with the two-chamber view, is reproducible and offers the potential for applying ABD methods. Another possible approach for intraoperative monitoring of stroke volume by acoustic quantification, which is based on the LV short-axis view, has been examined extensively by Gorcsan and colleagues. This technique, however, most often requires intra-gastric positioning of the transducer probe and from our experience has a very high incidence of signal instability during abdominal surgery.

In summary, our results suggest that monitoring stroke volume with single-plane ABD methods does not hold promise as a clinically reliable technique because of the poor accuracy in computing stroke volume and signal instability, even during stable haemodynamic states, and its only moderate ability to detect acute changes in stroke volume during abdominal surgery.

References

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