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Minimally invasive intraoperative estimation of left-ventricular end-systolic elastance with phenylephrine as loading intervention†

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Editor's key points

- Simple, non-invasive assessment of changes in cardiac contractility during and after surgery could help guide therapies to optimize tissue oxygen delivery.
- Unlike most measures of cardiac contractility, end-systolic elastance is largely independent of preload and afterload.
- Left-ventricular (LV) end-systolic elastance is calculated from a series of LV pressure–volume loops derived from measures of aortic pressure and LV volumes.
- This study found that it is feasible to estimate LV end-systolic elastance using a non-invasive continuous arterial pressure monitoring device along with LV volumes using echocardiography.

Background. Left-ventricular end-systolic elastance (Ees) is an index of cardiac contractility, but the invasive nature of its assessment has limited perioperative application. We explored the feasibility of a minimally invasive method of Ees estimation for perioperative assessment of cardiac function and evaluated the suitability of phenylephrine as a loading intervention.

Methods. In 17 surgical patients, Ees was determined as the slope of the end-systolic pressure–volume relation, which was obtained from non-invasive or invasive continuous arterial pressure measurements and left-ventricular volume determinations using transoesophageal echocardiography (TOE). Ees was determined using as loading interventions preload reduction by inferior vena cava compression (IVCC) and afterload increase by phenylephrine administration.

Results. Median invasive Ees determined with phenylephrine estimated 1.05 (0.59–1.21) mm Hg ml^{-1} and with IVCC 0.58 (0.31–1.13) mm Hg ml^{-1}. Bland–Altman analysis to evaluate the level of agreement between minimally invasive and invasive Ees estimation revealed a bias of -0.03 (0.12) mm Hg ml^{-1} with limits of agreement from -0.27 to 0.21 mm Hg ml^{-1} and the percentage error was 33%. Agreement between Ees obtained with phenylephrine and IVCC revealed a bias of 0.15 (0.69) mm Hg ml^{-1} with limits of agreement from -1.21 to 1.51 mm Hg ml^{-1} and a percentage error of 149%.

Conclusions. It is feasible to determine Ees combining continuous non-invasive arterial pressure measurements and left-ventricular volume determinations with TOE. However, administration of phenylephrine cannot substitute IVCC as a loading intervention, indicating that estimation of Ees in the intraoperative setting remains a challenge.

Keywords: echocardiography, transoesophageal; monitoring, intraoperative; myocardial contraction; phenylephrine

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Perioperative haemodynamic monitoring is aimed towards maintaining adequate tissue perfusion. The latter is the result of the functional interaction between the heart (contractility), the vascular system (afterload) and filling state (preload). In the perioperative period, decision-making is routinely based on measurements of heart rate, arterial

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pressure, central venous pressure, and sometimes cardiac output. Although very suitable to judge changes in global perfusion, vascular load and filling state, these parameters are not adequate for assessing cardiac contractility *per se*, because they reflect loading conditions or are sensitive to them.

Left-ventricular (LV) end-systolic elastance (Ees) allows load-independent characterization of cardiac contractility.[1 2] A detailed background on Ees is provided in the Supplementary Appendix. Briefly, Ees is the linearly approximated slope of the end-systolic pressure–volume relation, which can be obtained from a series of LV pressure–volume loops obtained under different loading conditions, like IVCC, while maintaining a constant inotropic state (Fig. 1A and B).[3] As demonstrated in Figure 1C, positive (+) or negative (−) inotropic interventions, as may be present in the perioperative period, induce a proportional change in Ees.[4]

Perioperative changes in Ees can be measured using transoesophageal echocardiography (TOE) and invasive arterial pressure measurements.[5 6] In this study, we aim to further enhance the practicability of this method, by investigating whether non-invasive arterial pressure measurements may replace the invasive arterial pressure measurement during Ees assessment. As invasive IVCC is not always applicable during surgery we further investigated whether a phenylephrine-induced augmentation in afterload provides a valid alternative as loading condition. We hypothesized that minimally invasive Ees estimations with non-invasive arterial pressure measurements show a high level of agreement with the more invasive approach, and that phenylephrine-based Ees estimates agree with those based on IVCC.

Methods

Subjects

The Institutional Review Board of the VU University Medical Center approved this study, and written informed consent was obtained from all subjects (NTR 2941). Twenty-one patients (18–75 yr) undergoing elective open abdominal, cardiac, or vascular surgery were included. Exclusion criteria included contra-indications for radial arterial catheterization, phenylephrine administration and TOE, such as all forms of oesophageal or gastric pathology, and all conditions increasing the risk of TOE-related complications.[7] In patients undergoing abdominal surgery, additional exclusion criteria included known heart

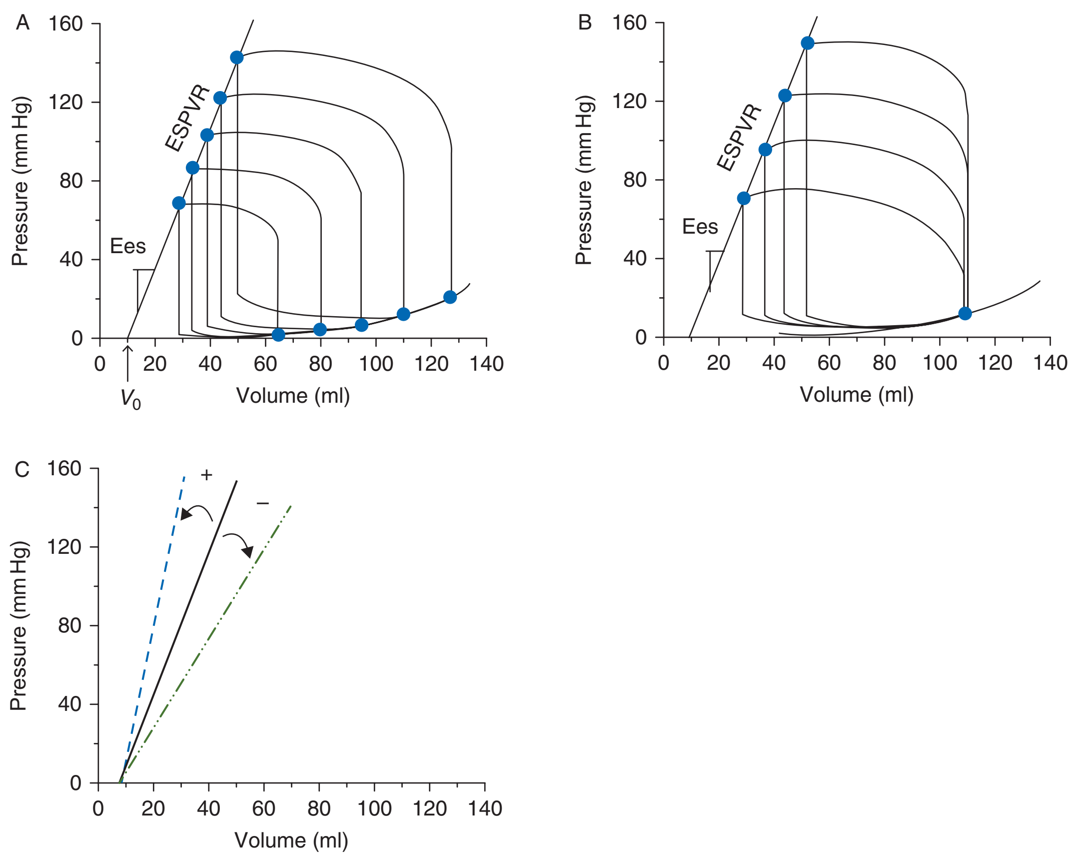

Fig 1 Pressure–volume loops and left-ventricular Ees. The left upper corners of a series of pressure–volume loops are used to construct the end-systolic pressure–volume relation (ESPVR) with its slope Ees. The series of loops can be obtained by performing a loading intervention, such as a decrease in preload (A) or increase in afterload (B). The slope of the ESPVR, Ees, directly responds to positive (+) or negative (−) inotropic influences (C). Figure reproduced with permission from Burkhoff and colleagues.[4]