Assessment of Left Ventricular Dimensions by Transoesophageal Echocardiography in Patients During Coronary Artery Bypass Surgery

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Objective: Normative values of left ventricular (LV) end-diastolic area and diameter (EDA and EDD) for intraoperative transoesophageal echocardiography (TEE) have not been established. We aimed to define the ranges of LV EDA and EDD for intraoperative TEE examinations in patients undergoing coronary artery bypass graft (CABG) surgery.

Methods: A MEDLINE search for studies reporting LV EDA and EDD in CABG patients was performed. Individual-level dataset from 333 anaesthetised and mechanically ventilated patients with preserved LV function (study population) were received from 8 studies. EDA and calculated EDD values in the study population were compared with summary mean EDD values obtained by transthoracic echocardiography (TTE) in 2 studies of 500 awake patients with coronary artery disease (CAD). Further, the influence of prespecified factors on EDD was evaluated through a multivariate regression model.

Results: LV EDA and EDD values measured by TEE in anaesthetised CABG patients were 16.7±4.7 cm² and 4.6±0.6 cm, respectively. EDD values measured by TEE in anaesthetised patients were 10% to 13% less those measured by TTE in 2 studies of awake patients (p<0.001). Body surface area, age and fractional area change but not sex were factors that affected LV EDD.

Conclusion: LV EDD values measured by intraoperative TEE in anaesthetised and mechanically ventilated CABG patients were 10% to 13% less than those measured by TTE in awake CAD patients. This finding indicates that independent normative values specific for intraoperative TEE should be established for guiding intraoperative clinical decisions.

Keywords: Echocardiography, transthoracic, echocardiography, transoesophageal, coronary artery disease, intermittent positive-pressure ventilation, coronary artery bypass

Introduction

Transoesophageal echocardiography (TEE) has been recommended for all patients undergoing cardiac surgery and is accepted worldwide for the evaluation of unexplained haemodynamic instability in intraoperative management and decision making (1, 2).

Left ventricular (LV) end-diastolic chamber dimensions, i.e. LV end-diastolic area and diameter (EDA and EDD), are regularly used to identify patients with low or normal LV volemia and to guide intravenous administration of fluids (2-5). However, the clinical utility of EDA and EDD for intraoperative decisions and prognosis depends on the accuracy and reliability of normal values. In fact, the availability of normative reference values for cardiac chamber quantitation is a prerequisite for the accurate clinical application of echocardiography (6). Two large studies recently published normal values assessed by...
The aim of this study was 1) to define the physiologic ranges of LV EDA and EDD measured by transgastric TEE in anaesthetised and mechanically ventilated patients undergoing coronary artery bypass grafting (CABG), as obtained by TEE immediately before surgery; 2) to compare the values obtained by intraoperative TEE with reference values obtained by TTE in awake, spontaneously breathing patients with coronary artery disease (CAD); and 3) to determine which patient factors affect LV EDA and EDD in patients undergoing CABG. We hypothesised that the ranges for LV EDA and EDD measured by intraoperative TEE are different from those measured by TTE studies on awake patients.

Methods

This individual-level data analysis included data from several published studies (3, 14-19). All patient data from studies included in this analysis were approved by the local institutional review boards, and written informed consent was obtained from all included patients.

Study population

We searched the MEDLINE database to identify studies reporting EDA or indexed EDA (EDA/I) values measured by transgastric TEE in the short-axis view at the transgastric mid-papillary level (TG mid SAX) in patients undergoing CABG (20). The search covered the period between January 1990 and May 2014. The following search terms were applied: ‘transoesophageal echocardiography cardiac surgery’, ‘transoesophageal echocardiography CABG left ventricle’, ‘transoesophageal echocardiography aorto-coronary bypass’, ‘transoesophageal echocardiography CABG short-axis’, ‘transoesophageal echocardiography CABG LVEDA’, ‘echocardiography cardiac surgery anaesthesia’, ‘CAD end-diastolic’, ‘CAD EDA’, ‘CAD LVEDA’, ‘CAD EDAI’ and ‘CAD LVEDAI’. We identified a total of 1131 citations. Eligibility criteria consisted of EDA values measured by TEE in the TG mid SAX view (20) including the papillary muscle (21). Further eligibility criteria were clinically stable haemodynamic conditions without the use of vasopressors or vasodilators during measurements and EDA measurements without the use of automatic border detection for the determination of EDA. Fifteen studies satisfied the eligibility criteria. The corresponding authors were contacted and asked to provide individual patient-level data. We obtained the original data from 7 publications (3, 14-19). The authors of the 8 other studies did not respond or were not able or willing to provide individual patient data. In addition, a co-author (JP) shared individual patient data from an unpublished TEE study that also satisfied the eligibility criteria. Thereof, we selected the study population, including 333 patients who fulfilled the following additional prespecified individual patient criteria: 1) preserved LV function defined as LV ejection fraction (EF) ≥45% or fractional area change (FAC) ≥40% (22), 2) isolated CABG surgery, 3) no previous cardiac surgery requiring sternotomy and 4) no relevant valvular heart diseases. The collected data of the study population included patient demographics, LV EDA and LV end-systolic area (ESA). In 2 studies (13, 16), TEE data immediately before surgery but after anaesthesia induction and at the end of surgery were available for 78 patients. In both studies, before surgery was defined as the time period after induction of anaesthesia but before sternotomy and after surgery was defined as the time period after sternal closure but before transfer to the intensive care unit.

Awake population

To compare EDD and EDA values in anaesthetised and awake patients, we searched MEDLINE for studies providing EDA values in awake CAD patients. Because the search retrieved no studies using the abovementioned MEDLINE search strategy, we expanded the search to include EDD using the following terms: ‘CAD echocardiography’, ‘CAD end-diastolic diameter’ and ‘CAD LVEDD’. We identified a total of 876 citations. Eligibility criteria consisted of haemodynamically stable CAD patients with preserved LV function (EF ≥45% or FAC ≥40%) and the availability of TTE estimates of LV EDD in the parasternal long-axis (LAX) view. Two studies, including 139 and 361 patients, fulfilled these criteria (23, 24). Because we were not able to obtain individual patient data from these 2 studies, we compared the TEE values from the study population with the summary estimates reported in the 2 TEE studies in the awake population.

Endpoints

The endpoints were LV EDA and EDD measured in the TG mid SAX view. EDD values were reported in only one TEE study. In contrast, the summary values in the awake population (23, 24) consisted exclusively of EDD measurements. To compare EDD values, TEE EDA values were mathematically converted into EDD values. Given the circular symmetry of the LV cavity at the TG mid SAX view (20), we used the equation: $\text{EDD} = \sqrt{(4 \times \text{EDA}/\pi)}$. 

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Factors influencing EDA/EDD values

Patient factors potentially influencing LV EDA and EDD values were tested using a linear regression model as described below. In addition, we tested if EDA values and calculated EDD values were different among male and female patients. Further, we analysed whether EDA values obtained immediately before surgery were different from EDA values obtained immediately after surgery using data from 2 studies.

Statistical analysis

No formal sample size calculation was performed for this study. Data are presented as mean±SD or number (percentage) as appropriate. Mean±SD (95% CI) of the pooled data were compared using a two-sided t test for unpaired and paired measurements, as appropriate. To evaluate factors influencing EDA and EDD, we inserted 4 prespecified independent variables into the linear regression model. Sex was inserted as a dichotomous variable, whereas age (per year increase), LV FAC (per % increase) and body surface area (BSA; per m² increase) were entered as continuous variables into the model. A p value <0.05 was considered significant. Statistical analyses were performed using IBM Statistical Package for the Social Sciences (version 21; IBM Corp., Armonk, NY, USA).

Results

Characteristics of the study population and the awake population

Individual dataset were obtained from 304 patients in 7 published studies (3, 14-19) and from 85 patients in one unpublished study (Table 1). In all studies, LV EDA and ESA were measured by manual planimetry of the endocardial boarders at end-diastole and -systole according to the guidelines reported by Lang et al. (21). The average LV EDA and EDD values (mean±SD) obtained from each study were displayed in Figure 1. Data from 56 patients were excluded due to impaired LV function (EF <45% or FAC <40%), providing a final sample size of 333 patients in the study population. Patient characteristics and the average LV dimensions from the study population are listed in Tables 2 and 3, respectively. The mean age in the study population was 64±9 years, and the proportion of male patients was 82%.

The 2 studies reporting EDD values measured in awake CAD patients enrolled 139 and 361 patients with preserved LV function, with 101 (73%) and 301 (83%) male patients, respectively (23, 24). The mean ages were 54±9 years and 58±10 years, respectively. Both TTE studies used M-mode imaging, and LV EDD and end-systolic diameter were measured in the parasternal LAX view using the leading-edge-to-leading-edge technique at end-diastole and -systole according to the guidelines reported by Lang et al. (21).

EDA and EDD values

The average LV EDA and calculated LV EDD values in the study population were 16.7±4.6 cm² and 4.6±0.6 cm, respectively. Excluding the patients from the unpublished study did not change these values. The average LV EDD values reported by Ghali et al. (23) and Gruchala et al. (24)

Table 1. Characteristics of studies providing individual data of 389 patients

<table>
<thead>
<tr>
<th>First author, year</th>
<th>Patients</th>
<th>Male</th>
<th>Age (years)</th>
<th>Normal LV function*</th>
<th>Main anaesthetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheung et al., 1994 (3)</td>
<td>31</td>
<td>N/A</td>
<td>N/A</td>
<td>25 (81)</td>
<td>Volatile</td>
</tr>
<tr>
<td>Seeberger et al., 1998 (18)</td>
<td>76</td>
<td>63 (83)</td>
<td>61±8</td>
<td>73 (97)</td>
<td>Volatile</td>
</tr>
<tr>
<td>Skarvan et al., 2003 (19)</td>
<td>42</td>
<td>35 (83)</td>
<td>64±10</td>
<td>33 (78)</td>
<td>Volatile</td>
</tr>
<tr>
<td>Poelaert et al., 2004 (16)</td>
<td>42</td>
<td>33 (79)</td>
<td>64±10</td>
<td>42 (100)</td>
<td>Propofol</td>
</tr>
<tr>
<td>Preisman et al., 2005 (17)</td>
<td>16</td>
<td>14 (88)</td>
<td>63±8</td>
<td>11 (69)</td>
<td>Volatile</td>
</tr>
<tr>
<td>Michaux et al., 2006 (15)</td>
<td>47</td>
<td>42 (84)</td>
<td>63±8</td>
<td>40 (85)</td>
<td>Volatile</td>
</tr>
<tr>
<td>Couture et al., 2007 (14)</td>
<td>50</td>
<td>38 (76)</td>
<td>68±8</td>
<td>44 (88)</td>
<td>Volatile</td>
</tr>
<tr>
<td>Poelaert, NP</td>
<td>85</td>
<td>N/A</td>
<td>63±11</td>
<td>65 (76)</td>
<td>Propofol</td>
</tr>
</tbody>
</table>

Data are numbers (percent) or mean±SD. All patients subsequently underwent coronary artery bypass graft surgery. *Normal LV function was defined as ejection fraction ≥45% or fractional area change ≥40%.

N/A: not available; N/P: not published.

Figure 1. End-diastolic Diameter Area (EDA) and Diameter (EDD) in Patients Undergoing CABG Surgery

Mean±SD from the 8 studies (3, 14-19) providing individual patient data are indicated.

N/P: not published
were 5.1±0.5 cm and 5.3±0.7 cm, respectively (Figure 2). These TTE LV EDD values were 10% and 13% greater than the TEE LV EDD value of 4.6±0.6 cm (p<0.001 for both comparisons).

**Factors influencing EDA and EDD values**

Average TEE LV EDA values in females (15.3±4.6 cm²; n=44) were less than those in males (17.2±4.7 cm²; n=199; p=0.012). The average LV EDD values were also less in females compared to those in males (4.4±0.7 cm vs. 4.6±0.6 cm, p=0.008). When using indexed values corrected to BSA, LV EDAI and EDI values were comparable among female and male patients.

In the multivariable linear regression model, BSA (0.83, 95% CI 0.40-1.26, p<0.001) and age (0.010, 95% CI 0.002-0.018, p=0.020) were positively correlated with LV EDD, whereas FAC (−0.024, 95% CI −0.030-0.019, p<0.001) was negatively correlated with LV EDD. Sex did not correlate with LV EDD (p=0.224). Similar correlations were obtained using LV EDA as the independent variable.

Among the 78 patients who underwent TEE measurements before and after surgery, postoperative TEE LV EDA values (16.2±6.3 cm²) were significantly lower than preoperative values (17.4±6.0 cm²; p=0.006), whereas LV ESA values did not change significantly. FAC also did not change significantly before and after surgery (50%±15% vs. 49%±16%; p=0.410).

**Discussion**

Based on individual-level dataset from 333 patients in 8 clinical studies, LV EDA and EDD measured by intraoperative TEE in anaesthetised and mechanically ventilated CABG patients with preserved LV function during haemodynamically stable conditions prior to thoracotomy were 16.7±4.6 cm² and 4.6±0.6 cm, respectively. Intraoperative LV EDD values measured by TEE were 10% to 13% less than published LV EDD values measured by TTE in awake CAD patients (23, 24). This finding suggests that the common clinical practice of applying reference values obtained by TTE in awake patients as normative values for anaesthetised and mechanically ventilated patients studied by TEE is misleading. Consequently, this practice may result in erroneous judgement of volemia which may lead to inappropriate intraoperative decisions regarding choice of therapy and prognosis. Further, this discrepancy between TTE and intraoperative TEE measurements highlights the need for studies designed to establish normative reference values particularly for intraoperative TEE measurements in anaesthetised and mechanically ventilated patients. This conclusion is in agreement with 2 recently published studies (6, 7) that claimed to report reliable and accurate TTE reference values for chamber quantitation.

However, the normative values described by TTE in young and healthy people may not be representative of the values in other populations to which they are applied (6, 7, 12, 13). Although some studies have reported nearly identical LV EDA and EDD values by both TTE and TEE in awake patients (25-27), the discrepancy between TEE and TTE measurements of LV EDA and EDD found in this study can be explained by several real but subtle differences in the standard clinical imaging protocols used for TEE and TTE. Although the difference in the echocardiographic approach, i.e. TTE vs. TEE, is unlikely to be causative (25-27), the stan-
dard cross-sectional imaging planes for measuring LV cavity dimensions in TTE and TEE are slightly but significantly different. Diameter measurements using the TTE parasternal LAX view are performed at the level of tips of the mitral valve leaflets (28). In contrast, LV cavity diameter in the study population was measured using the TEE transgastric LV SAX view at the mid-papillary level, as recommended in the TEE guidelines published in 1999 (20) and valid until 2013. The normal anatomic shape of LV has a smaller diameter at the mid-papillary level (closer to the LV apex) where the TEE measurements are performed compared with the mitral valve leaflet tips (closer to the LV base) where the TTE measurements are performed. The recently updated TEE guidelines acknowledged for this difference between TEE and TTE cross-sectional imaging planes for measuring LV cavity diameter and made the recommendation to measure LV diameter using the transgastric LAX or the transgastric 2-chamber views (2). Although this methodological difference between TTE and TEE are convincing explanations for the differences found in the current study and may be minimised in the future with the updated TEE guidelines (2), reference ranges for LV EDA and EDD using this newly recommended approach have not been established. Clinicians are, therefore, likely to continue using the TG mid SAX view to measure LV EDA and EDD according to the first set of published guidelines (3, 20).

Interestingly, the normative value of LV EDD was determined at 4.43±0.48 cm using TTE in the NORRE study, including young and healthy people (6). This value is comparable to the LV EDD value of 4.6±0.6 cm, as determined in our TEE population but substantially lower than the values between 5.1 and 5.3 cm reported in the studies by Ghali et al. (23) and Gruchala et al. (24) as assessed by TTE. It seems likely that the older age and cardiac comorbidities, including CAD, increase end-diastolic dimensions (29). However, the use of anaesthetic drugs and positive pressure ventilation as well as a relative intraoperative hypovolemia might compensate for the “dilative effect” of older age and cardiac disease on chamber dimensions.

Anaesthetic drugs and positive pressure ventilation may have relevantly influenced LV cavity dimensions in the TEE study population by affecting systemic vascular resistance, venous tone and venous return (30). The physiologic effects of general anaesthesia and positive pressure ventilation on LV cavity size were recently demonstrated in a magnetic resonance imaging study in healthy adults (10) and several echocardiographic studies in healthy subjects and in patients with cardiac disease (9, 31-33). All these studies reported that LV cavity dimensions were reduced during anaesthesia and positive pressure ventilation, most likely as a consequence of decreased venous return and LV preload.

The analysis of factors potentially affecting LV dimensions revealed that LV EDA and LV EDD were larger in males compared with females, but EDA and EDD values indexed for BSA were comparable. In agreement, there was no association of sex with indexed EDD and EDA in the linear regression model after adjustment for BSA. Some weak positive associations between age and LV EDD were found in agreement with normal changes that occur in the aging heart (29). Also in agreement with earlier studies (3, 34), we found that LV EDA varied in response to differences in the systolic function measured by FAC. Finally, LV EDA was significantly less immediately after surgery compared with its value immediately before sternotomy. Changes in heart rate, autonomic nervous system tone, decreased intravascular volume or diastolic dysfunction as a consequence of reperfusion may all have contributed to this condition.

Study limitations
This retrospective study has several strengths and limitations: First, the study was based on values pooled from published studies that were identified using detailed search strategies and predefined eligibility criteria, but the literature search was limited to a single electronic database and did not comply formally with current standards for systematic reviews. However, the original objective of the study was to collect individual patient-level data from the previously published studies rather than comparing the summary data from different studies. Further, EDD was not included as a search term in the primary MEDLINE search, but a post-hoc search that included “EDD” and “end-diastolic diameter” as search terms did not reveal any additional TEE studies in anaesthetised patients who could have been included in the analysis. Second, not all individual patient-level dataset were complete regarding patient characteristics and comorbidities. Third, the study relied on the investigators to adhere to the methodology described in their studies for performing the echocardiographic measurements. The studies were not standardised in terms of the precise cross-sectional imaging planes used, the timing of measurements, the haemodynamic conditions of the subjects, the intravascular volume status, the circulatory effects of any concurrent therapy, the mechanical ventilator settings, or the anaesthetic regimens administered. However, all the included TEE studies explicitly stated that measurements of LV cavity size were performed using the TG mid SAX view and that all measurements were performed during a period of stable haemodynamic conditions. Evidence to suggest that the methodology of the studies used in this analysis was uniform was that the patient-level measurements from each of the individual studies were not heterogeneous and yielded similar ranges for LV EDA and EDD (Figure 1). Fourth, due to the study design, measurements might not be completely comparable regarding preload. Fifth, although patient-level individual data were not obtainable from 8 additional intraoperative TEE studies that fulfilled the eligibility criteria and were not available from the 2 TTE studies performed in awake patients, the consistency of the available data suggested that the inclusion of additional patient-level individual data may not change the results. Sixth, comparing LV cavity dimensions obtained by TEE and TTE.
required the conversion of LV EDA measurements in the study population to LV EDD assuming that the shape of the LV cavity in TG SAX view was circular (20). This assumption seems to be limited by the fact that CAD is a regional disease but was generally valid because the eligibility criteria limited the study population to those with normal LV function. Further, published data support a nearly perfect correlation between EDD and EDA when measured independently (3), and the use of LV EDA measurements to generate LV EDD utilises a greater number of data points to generate the parameter and did not rely on a single linear measurement at 2 discrete points of the LV endocardium. Finally, the slightly older age of the study population is an unlikely confounder because the correlation between age and LV EDA and EDD in the multivariable linear regression was very weak.

**Conclusion**

Data from prior studies were used to determine the physiological ranges for LV EDA and EDD in anaesthetised and mechanically ventilated patients with preserved LV function measured by intraoperative TEE using the TG mid SAX view. The study found that values for LV EDD obtained by intraoperative TEE in the study population were 10% to 13% less than those obtained by TTE in a similar population of awake CAD patients. These findings question the common practice of applying normative values defined by TTE in awake patients for guiding intraoperative decisions and prognosis and indicate a need to establish specific normative reference values for intraoperative TEE measurements performed using the standard cross-sectional imaging planes.

**Ethics Committee Approval:** Ethics committee approval was received for this study from the ethics committee of Kantonale Ethikkommission beider Basel.

**Informed Consent:** Written informed consent was obtained from all patients who participated in this study.

**Peer-review:** Externally peer-reviewed.


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**References**


8. De Hert SG, Van der Linden PJ, ten Broecke PW, Vermeylen KT, Rodrigus IE, Stockman BA. Effects of desflurane and sevoflurane on length-dependent regulation of myocardial function in coronary surgery patients. Anesthesiology 2001; 95: 357-63. [CrossRef]


12. Feneck RO LL. The transesophageal echo examination In: Core topics in transesophageal echocardiography 2010. [CrossRef]


14. Couture P, Denault AY, Pellerin M, Tardif JC. Milrinone enhances systolic, but not diastolic function during coronary ar-


