Original Article

Noninvasive estimation of left atrial pressure with transesophageal echocardiography

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ABSTRACT

Background: The pulmonary artery catheter (PAC) has historically been used to measure cardiac filling pressures of which pulmonary capillary wedge pressure (PCWP) has been used as a surrogate of left atrial pressure (LAP) and left ventricular end-diastolic pressure. Increasingly, the use of the PAC has been questioned in the perioperative period with multiple large studies unable to clearly demonstrate benefit in any group of patients, resulting in a declining use in the perioperative period. Alternative methods for the noninvasive estimation of left-sided filling pressures are required. Echocardiography has been used to provide noninvasive estimation of PCWP and LAP, based on evaluating mitral inflow velocity with the E and A waves and looking at movement of the mitral annulus with tissue Doppler (e'). **Aim:** The aim of our study was to assess the relationship between PCWP and E/e' in cardiac surgical patients with transesophageal echocardiography (TOE). **Design:** A prospective observational study. **Setting:** Cardiac surgical patients in a single quaternary referral university teaching hospital. **Methods:** The ratio of mitral inflow velocity (E wave) to mitral annular tissue velocity (e') (the E/e' ratio) and PCWP of 91 patients undergoing general anesthesia and cardiac surgery were simultaneously recorded, with the use of TOE and a PAC. **Results:** The correlation between E/e' and PCWP was modest with a Spearman rank correlation coefficient of 0.29 (P = 0.005). The area under the receiver operating characteristic curve for using E/e' to predict elevated PCWP (≥18 mmHg) was 0.6825 (95% confidence interval: 0.57–0.80), indicating some predictive utility. The optimum threshold value of E/e' was 10 which had 71% sensitivity and 60% specificity to predict a PCWP ≥18 mmHg. **Conclusions:** Noninvasive measurements of E/e' in general cardiac surgical patients have only a modest correlation and does not reliably estimate PCWP.

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INTRODUCTION

The pulmonary artery catheter (PAC) has historically been used to measure cardiac filling pressures[1] of which pulmonary capillary wedge pressure (PCWP) has been used as a surrogate of left atrial pressure (LAP) and left ventricular end-diastolic pressure. Several large studies show that PCWP and LAP correlate in patients with cardiovascular disease.[2,3]

Estimation of LAP is a core component of the evaluation of left ventricular diastolic function.[4] Elevated left ventricular filling pressures predict long-term adverse outcomes, even in patients with normal ejection fractions.[5] A restrictive diastolic filling pattern adversely impacts major morbidity and mortality in patients undergoing cardiac surgery.[6]

Increasingly, the use of the PAC has been questioned in the perioperative period with multiple large studies unable to clearly demonstrate benefit in any group of patients, resulting in a declining use in the perioperative

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period.[7] Alternative methods for the noninvasive estimation of left-sided filling pressures are required.

Echocardiography has been used to provide a noninvasive estimation of PCWP and LAP. This has been based on evaluating mitral inflow velocity with the E and A waves and looking at the movement of the mitral annulus with tissue Doppler (e' and a').[4] Most of this work has been done using transthoracic echocardiography in awake patients, but use of mitral inflow and tissue Doppler have been described using intraoperative transesophageal echocardiography (TOE) to assess diastolic function,[8] though not specifically to evaluate PCWP and LAP. Diastolic dysfunction as measured by E/e' predicts adverse cardiac events in patients undergoing coronary graft surgery.[9]

In brief, the ratio of the mitral inflow velocity to the mitral annular tissue Doppler velocity (E/e') has been demonstrated to correlate with PCWP and LAP.[10] Published guidelines suggest that filling pressures are elevated when the PCWP is >12 mmHg, and the left ventricular diastolic pressure is >16 mmHg.[4] An E/e' ratio <8 is associated with normal filling pressures and E/e' >15 associated with elevated filling pressures.[4,11] When the value is between 8 and 15, PCWP and LAP are indeterminate, and other variables are required.[4]

Recently, this relationship has been called into question, particularly in normal subjects and patients with mitral valve disease. There is considerable overlap between normal and abnormal.[4] In addition, this ratio is not well-validated in positive pressure ventilated patients undergoing general anesthesia but is recommended in recent guidelines for the assessment of diastolic function.[12]

The aim of our study was to assess the relationship between PCWP and E/e' in cardiac surgical patients with TOE.

METHODS

The study was approved by the Medical Ethical Committee at the University Hospital, Leuven. Informed consent was waived given that TOE and the PAC are used routinely.

Consecutive patients having cardiac surgery, where intraoperative TOE and the PAC were used, and where one of the authors was available were included in the study.

Patients were excluded if, for whatever reason, both TOE and a PAC were not used as part of their intraoperative care.

At the mid esophageal 4 chamber view, the peak early mitral inflow velocity (the E wave) was recorded with pulsed wave Doppler. At the mid esophageal 4 chamber view, the peak early tissue velocity (e') was recorded with tissue Doppler at the lateral mitral annulus to derive the E/e' ratio. All measurements were made according to published guidelines.[8,13]

Simultaneously, PCWP was recorded from the PAC (Edwards Lifesciences Swan-Ganz CCOmbo, Ref: 744HF75 thermodilution catheter).

All measurements were taken pre-cardiopulmonary bypass at end expiration and during a stable period of hemodynamics with patients ventilated at 6–8 ml/kg with a positive end-expiratory pressure of 5 cm H_2O. Patients were in the supine position with pressure transducers located at the midthoracic position, half way between the sternum and bed, as recommended in recent guidelines.[14]

Measurements were performed by experienced cardiac anesthesiologists with expertise and qualifications in TOE, blinded to invasive PCWP measurements and with no additional involvement in the case, as part of a comprehensive TOE study.

Measurements were taken on two different echocardiography machines, depending on availability – the Vivid S6 (GE Vingmed Ultrasound, Horten, Norway) and the iE33 (Philips Healthcare, Best, The Netherlands). The tissue Doppler imaging functions on both machines were used for optimal e' measurements.

Correlation between PCWP and E/e' was assessed with a Spearman rank correlation coefficient as they were not normally distributed. Receiver operating characteristic (ROC) curve analysis was used to determine the sensitivity and specificity of using different cut-off values of E/e' to detect elevated PCWP (>12 mmHg). We also used ROC curve analysis to determine the sensitivity and specificity of using different cut-off values of E/e' to detect elevated PCWP defined as ≥18 mmHg (from ARDS guidelines).[15] The optimum threshold value was chosen as that which gave the maximum value for the sum of the sensitivity and specificity (Youden index) that is, the point on the

ROC furthest from the line of equality ($y = x$). Mann–Whitney U-tests were used to compare nonnormally distributed data.

All statistical analyses were performed using Stata 12.1 (StataCorp, College Station, Texas, USA).

RESULTS

Measurement of E/e' and PCWP was possible in all 91 patients.

A total of 38 patients underwent coronary artery bypass graft surgery, 24 valvular surgery, 17 combined coronary and valve surgery, 8 aortic surgery, and 4 others (septal defect repair and aneursymectomy).

No patients had known pulmonary arterial hypertension or pulmonary thromboembolic disease.

The patient characteristics are shown in Table 1.

The correlation between E/e' and PCWP was modest with a Spearman rank correlation co-efficient of 0.29 ($P = 0.005$) [Figure 1].

The area under the ROC curve for using E/e' to predict elevated PCWP (>12 mmHg) was 0.60 (95% confidence interval [CI]: 0.47–0.72), which is not significantly different from 0.5 which represents no predictive utility.

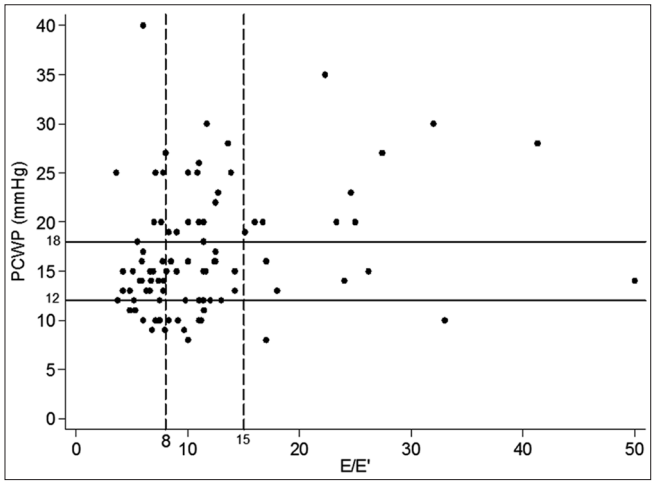

Figure 1: Scatterplot of pulmonary capillary wedge pressure (PCWP) versus E/e'. The horizontal reference lines at 12 mmHg and 18 mmHg represent two clinically relevant cut-off values for PCWP. The two vertical dashed reference lines at 8 and 15 represent two commonly cited E/e' cut-offs to predict PCWP over 12 mmHg

Figure 2 is a dot plot of the E/e' values in patients with normal PCWP (median 8.7) and those with an elevated PCWP (median 10.0). This was not significantly different ($P = 0.15$, Mann–Whitney U-test).

Guidelines suggest that an E/e' <8 is associated with normal PCWPs. In our series, an E/e' ratio of <8 had a sensitivity of 46% and specificity of 67% to detect normal PCWP.

Guidelines suggest that an E/e' >15 is associated with elevated PCWPs. In our series, an E/e' ratio of >15 had a sensitivity of 23% and specificity of 92% to detect an elevated PCWP (>12 mmHg).

The area under the ROC curve [Figure 3] for using E/e' to predict elevated PCWP (≥18 mmHg) was 0.6825 (95% CI: 0.57–0.80), which is significantly different from 0.5 indicating some predictive utility. The optimum threshold value of E/e' was 10 which

Table 1: Patient demographics with the age (years), weight (kg), height (cm), BMI (kg/m^2), mitral inflow velocity (E cm/s), mitral annular velocity (e' cm/s), ratio of mitral inflow velocity to mitral annular tissue velocity (E/e') and PCWP (mmHg)

	Age	Weight	Height	BMI	E	e'	E/e'	PCWP
Mean	69	78.6	170.9	27	76.5	7.8	11.8	16.8
SD	10.6	14	8.6	4.1	22.9	2.7	8	6.3
Minimum	30	48	148	18	34	2	3.6	8
Maximum	89	112	197	37.46	1.34	15	50	40

BMI: Body mass index, PCWP: Pulmonary capillary wedge pressure, SD: Standard deviation

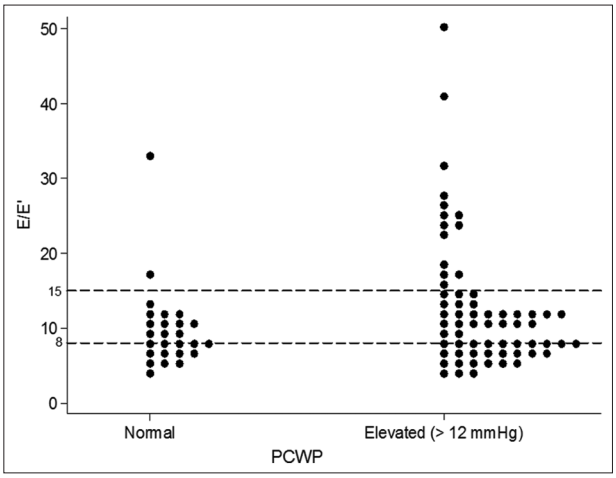

Figure 2: Dot plot of E/e' values in patients with normal pulmonary capillary wedge pressure (PCWP) and those with an elevated PCWP (over 12 mmHg). The two horizontal dashed reference lines at 8 and 15 represent two commonly cited E/e' cut-offs to predict PCWP over 12 mmHg

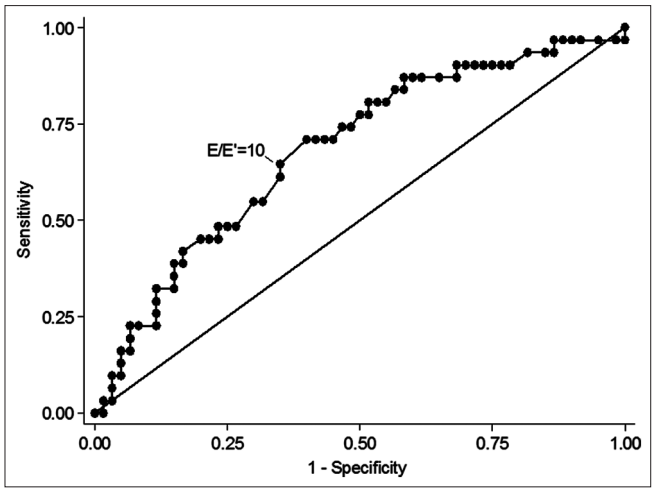

Figure 3: Receiver operating characteristic curve for the use of E/e' to predict pulmonary capillary wedge pressure ≥18 mmHg. Youden index (maximum sum of sensitivity and specificity) represented by point where E/e' = 10

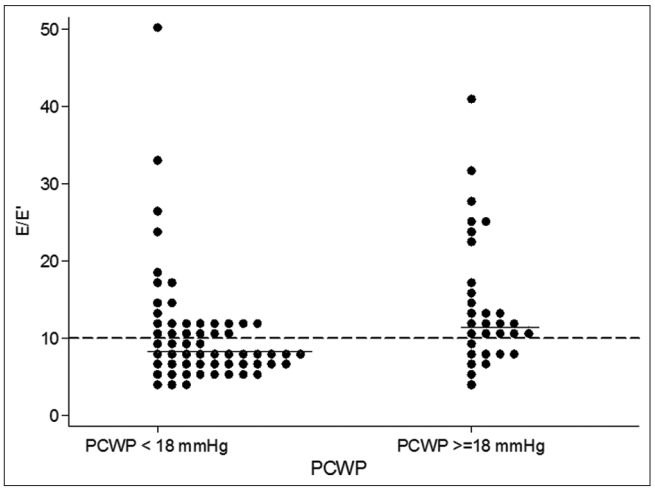

Figure 4: Dot plot of E/e' values in patients with pulmonary capillary wedge pressure (PCWP) <18 mmHg and those with PCWP ≥18 mmHg. The two small horizontal lines represent the medians of each group. The long dashed line represents the optimum threshold value of E/e'

had 71% sensitivity and 60% specificity to predict a PCWP ≥18 mmHg.

Figure 4 is a dot plot of the E/e' values in patients with PCWP <18 mmHg (median 8.2) and those with PCWP ≥18 mmHg (median 11.4). This was significantly different ($P = 0.004$, Mann–Whitney U-test).

DISCUSSION

There is a modest correlation of E/e' >10 and elevated PCWP >18 mmHg. However, the clinical utility of this is limited with many patients with elevated filling pressures having normal E/e' and many patients with elevated E/e' ratios having normal filling pressures.

In cardiology literature and TTE studies, E/e' is routinely measured to estimate left ventricular diastolic function and to estimate LAPs.[13] However, recent data suggest that there are significant limitations in this technique, particularly in patients with normal left ventricular structure and function, segmental wall motion abnormalities, and mitral valve disease.[13] This greatly limits the utility of this technique, in general, cardiac surgical patients and would exclude many, if not all patients.

Two recent publications post completion of our study also suggested a poor correlation of E/e' with PCWP in cardiac surgical patients undergoing general anesthesia.[16,17] In fact, correlations were poor in patients with normal and impaired left ventricular function under anesthesia.

Given the declining use of the PAC in cardiac anesthesia, noninvasive estimation of intracardiac pressures is required. However, we have shown that TOE is unable to reliably estimate PCWP in cardiac surgical patients. Nor is it able to reliably provide a cut-off value that rules in or out elevated PCWP. As yet, there is no noninvasive tool capable of reliably measuring this parameter and a PAC or direct catheter in the LA remains the clinical gold standard.

While TOE does not reliably estimate LAP with Doppler indices, it does accurately measure left ventricular volumes and ejection fraction with two-dimensional biplane and newer three dimensional techniques.[18] However, these are noncontinuous measurements at a specific time point, requiring repeating with changes in patient physiology.

LIMITATIONS

Our study includes using the lateral mitral annulus for e' measurements, which are different to septal e'. In general, lateral e' values are higher than septal, and these values seem to correlate better with LAP in patients with normal left ventricular function. Averaging septal and lateral e' values is recommended in some guidelines, but this adds additional time and complexity during a TOE study in the cardiac operating room, without clear benefit.[13]

We did not specifically evaluate the E/e' technique in patients with different cardiac pathologies and it may be

that in specific groups of patients this has some value. However, an echocardiographic technique that cannot be reliably used across a wide range of cardiac surgical patients, and only in small subgroups, has limited appeal.

Accurate line up for mitral annular motion is required for optimal tissue Doppler velocities, and when the lateral annulus moves in a nonparallel direction, tissue velocities can be underestimated.

CONCLUSION

Noninvasive measurements of E/e' with TOE, in general, cardiac surgical patients has only a modest correlation with PCWP, does not reliably estimate PCWP and has limited clinical utility.

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