Original Article

Shape and Movement of the Interatrial Septum Predicts Change in Pulmonary Capillary Wedge Pressure

Colin F. Royse, MBBS, MD, FANZCA,[1] Alistair G. Royse, MD, MBBS, FRACS,[2]
Paul F. Soeding, MBBS, FANZCA,[1]
and Duncan W. Blake, MBBS, B Med Sci, PhD, FANZCA[1]

We aimed to assess whether movement of the interatrial septum predicts change in pulmonary capillary wedge pressure (PCWP). In 71 patients undergoing cardiac surgery, the interatrial septum was categorised by its shape and movement using transesophageal echocardiography (TEE). Fixed curvature (FC) was identified by bowing of the interatrial septum from left to right throughout the cardiac cycle, mid-systolic reversal (MSR) by minimal septal movement and transient reversal (right to left) during mid-systole, and mid-systolic buckling (MSB) by marked movement and buckling of the septum during mid-systole. These were compared with PCWP. Sensitivity and interobserver reliability was studied with continuous PCWP and TEE measurement during a period of acute volume alteration in 10 additional patients. Interatrial septal movement predicted PCWP, with mean PCWP (95% confidence intervals) for FC, 18.1 mmHg (16.7 to 19.6), MSR 13.2 mmHg (12.5 to 13.8) and MSB, 9.9 mmHg (9.0 to 10.7) mmHg. The mean PCWP at which a change in pattern occurred was 8.9 mmHg (8.3 to 9.6) for MSR to MSB, and 10.9 mmHg (10.1 to 11.8) for MSR to FC ($p<0.001$). There was no significant difference in mean values for all three observers.

Movement of the interatrial septum predicts change in PCWP. (Ann Thorac Cardiovasc Surg 2001; 7: 79–83)

Key words: pulmonary capillary wedge pressure, interatrial septum, transesophageal echocardiography

Introduction

In patients undergoing cardiac surgery, left atrial pressure (LAP) is commonly estimated by measuring the pulmonary capillary wedge pressure (PCWP) using a balloon-tipped pulmonary artery catheter. Less invasive measurement of PCWP by means of transesophageal echocardiography (TEE) remains a desirable but elusive goal. Although several groups have shown reliable estimation of high PCWP with TEE, quantification of normal or low PCWP states is less accurate.[1-4] In order to reduce reliance on the pulmonary artery catheter for LAP estimation, echocardiography methods must be easy to perform and at least semi-quantifiable. For clinical use it is important to discriminate between high, normal and low PCWP, and that this index is sufficiently sensitive to detect a change in pressure.

Estimation of PCWP is an important component in the evaluation of left ventricular diastolic function. Echocardiography allows direct visualisation of left ventricular volume, but when combined with PCWP estimation, left ventricular stiffness can be estimated. A hypovolemic ventricle operating at high PCWP for example indicates a stiff ventricle, whereas a normovolemic ventricle operating at low PCWP indicates a compliant ven-

From the [1]Department of Anaesthesia and Pain Management, and [2]Department of Cardiothoracic Surgery, the Royal Melbourne Hospital, Australia

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Address reprint requests to Colin F. Royse, MBBS: P.O.Box 1022, Research, Victoria 3095, Australia.

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tricle. Estimation of high PCWP is also useful in discriminating between the “normal” and “pseudonormal” mitral inflow Doppler patterns.

In this study we have investigated the shape and movement characteristics of the interatrial septum using TEE, and compared them with simultaneously measured pulmonary capillary wedge pressure in patients undergoing cardiac surgery.

Methods

Eighty-one patients undergoing cardiac surgery were studied. The Royal Melbourne Hospital Human Ethics committee gave approval for the study, and written informed consent was obtained from the patients. The study was conducted in two stages. In stage 1 we performed a prospective observational study in 71 patients to determine three patterns of interatrial septal motion and their corresponding PCWP. In stage 2, we performed an acute volume alteration procedure in 10 patients whilst simultaneously recording TEE images, PCWP and right atrial pressure. This allowed us to determine when the change in interatrial septal movement occurs, and to assess interobserver reliability.

All patients were instrumented with a pulmonary artery catheter (834HF75, Baxter Healthcare Corporation, Irvine, CA) and TEE (Hewlett-Packard Co., Andover, MA) as a routine part of their procedure. Echocardiography transducers were 5 MHz or 6.2 MHz Omniplane or Biplane. Patients were excluded from the study if they had moderate or severe mitral valve regurgitation or stenosis, were in atrial fibrillation, or if there was inadequate imaging of the interatrial septum.

Measurements

Pulmonary capillary wedge pressure

Pulmonary capillary wedge pressure was used to estimate left atrial pressure. The pulmonary artery catheter was inserted to wedge position prior to induction of anaesthesia and the balloon deflated. The balloon was inflated for repeated measures of PCWP. Measurements were made at end expiration using a disposable pressure transducer (Transpac IV. Abbott Critical Care Systems, Sligo Ireland). The zero pressure reference point was at the level of the mid-axillary line.

Interatrial septal movement

The interatrial septum was viewed in the mid-esophageal short axis (30-50°). Three patterns of interatrial septal movement were identified by the degree of curvature and movement with each cardiac cycle and coded as fixed curvature (FC), mid-systolic reversal (MSR) and mid-systolic buckling (MSB) (Fig. 1). FC is identified by the interatrial septum bowing from left to right throughout the cardiac cycle. MSR is identified by minimal movement of the interatrial septum during the cardiac cycle with reversal of curvature during mid-systole (right to left), returning to a left to right curvature during diastole. MSB is identified by marked movement of the interatrial septum, with mid-systolic reversal, but differing by the appearance of buckling of the interatrial septum at this point.

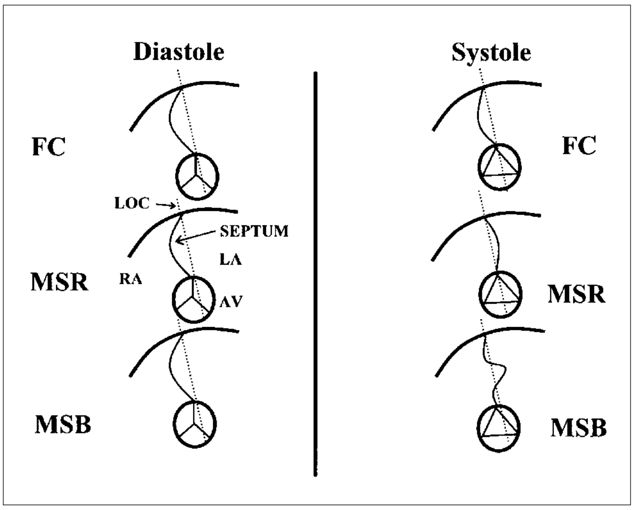

Fig. 1. Interatrial septal curvature viewed from mid-esophageal short axis view, during systole and diastole. See text for definitions. LOC is line of curvature, SEPTUM is interatrial septum, LA is left atrium, RA is right atrium and AV is aortic valve.

Stage 1

The interatrial septal movement was determined by a single observer and was immediately followed by PCWP measurement. Measurements were performed at three time periods: before cardiopulmonary bypass (preCPB), immediately after cardiopulmonary bypass (postCPB), and again 30 minutes later (post30).

Stage 2

Continuous measurement of PCWP and right atrial pressure (RAP), and interatrial septal movement was performed by separate observers during an acute volume alteration manoeuvre. The pressures were recorded in digital format (JRAK Biosignals Pty. Ltd., NY, USA). TEE images were simultaneously recorded on videotape. Measurements were performed during an apnoeic period. Acute volume alteration was achieved by draining blood from the aortic cannula into the cardiopulmonary bypass reservoir at approximately 2 l/min and then reinfusing it through the aortic cannula to restore and then increase volume. We aimed to produce a wide range of filling pressures. Each measurement period lasted for 60-90 seconds, and measurements were performed immediately pre and post cardiopulmonary bypass.

Three blinded observers reviewed the TEE recordings and categorised the patterns of interatrial septal movement, recording the times at which a change in pattern occurred. A separate observer, blinded to the TEE data, measured the mean PCWP and RAP that occurred at the times recorded by the TEE observers from the digital recordings. This allowed us to determine the pressure at which changes in the interatrial septal movement occurs, and also to assess interobserver reliability. We also compared the PCWP-RAP difference with interatrial septal movement to determine whether the interatrial pressure difference was more important than the actual PCWP in determining the shape and movement of the interatrial septum.

Statistical methods

Stage 1. The comparison of PCWP and the pattern of interatrial septal movement was analysed by two-way ANOVA, the factors being interatrial septal movement (3 levels) and time in relation to cardiopulmonary bypass (3 levels).

Stage 2. The mean PCWP at which a change in interatrial septal pattern occurred was initially compared for direction (e.g. MSR to MSB versus MSB to MSR), using one-way ANOVA. The difference in mean values at which a change in pattern occurred, and the difference between observers was compared using one-way ANOVA. The prediction of PCWP and the PCWP-RAP difference by change in interatrial septal pattern was performed by three-factor ANOVA. The factors in the analysis were the interatrial septal pattern, the observer, pre or post cardiopulmonary bypass, and the pattern versus observer interaction.
All analyses were done using SYSTAT 7.01 (SPSS Inc, Chicago, USA).

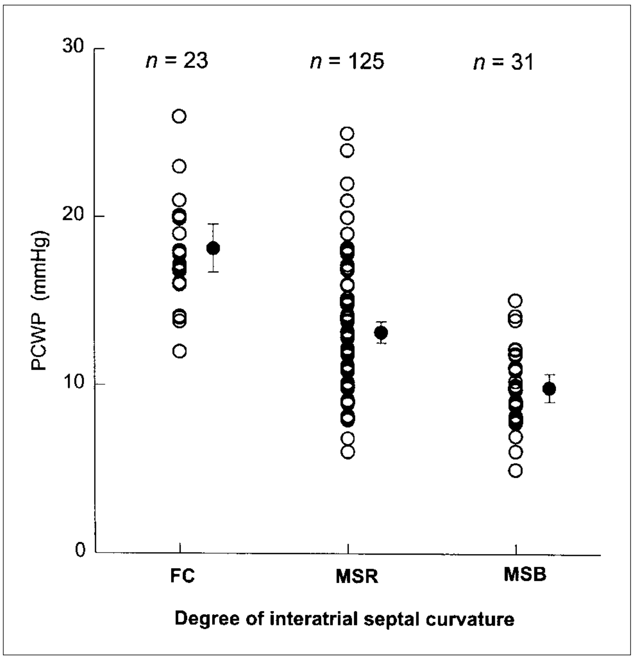

Fig. 2. Scattergram of pulmonary capillary wedge pressure (PCWP) according to the grade of interatrial septal curvature (see text and Fig. 1 for definitions). *n:* number of observations. Open circles, observed values. Closed circles, group means. Bars indicate 95% confidence intervals for the population means. Note absence of overlap of confidence intervals according to grade of interatrial septal motion.

Results

Interatrial septal curvature versus PCWP (Stage 1)

Observations were made in 71 patients. Incomplete recording of at least 1 time period occurred in 17 patients because of inadequate imaging or haemodynamic instability at the time, leaving 179 pairs of observations for analysis: 64 preCPB, 62 postCPB and 53 post30. The scattergram of the data is presented as Fig. 2. The mean values of PCWP for each interatrial septal movement

Table 1. Mean values of pulmonary capillary wedge pressure according to grade of interatrial septal curvature

Grade	*n*	Mean PCWP	95% CI
FC	23	18.1	16.7 to 19.6
MSR	125	13.2	12.5 to 13.8
MSB	31	9.9	9.0 to 10.7

FC, MSR, and MSB refer to left atrial pressure states identified by atrial septal movement (see text and Fig. 1 for details). *n*: number of pairs of observations, PCWP: pulmonary capillary wedge pressure (mmHg), CI: confidence intervals for population mean. Note that there is no overlap between confidence intervals according to grade.

category are presented in Table 1.

There was a powerful predictive effect of interatrial septal movement on PCWP (p<0.000001), with no confounding effects of TIME (p=0.231)

Mean PCWP at which a change in interatrial septal curvature occurs (Stage 2)

One patient was excluded because a pulmonary capillary wedge trace could not be obtained leaving 9 data sets for analysis. There was no significant effect on the relationship between interatrial septal pattern and the direction of volume change (for MSR to MSB versus MSB to MSR, p=0.257 and FC to MSR versus MSR to FC, p=0.215). We therefore combined the groups of measurements.

The mean (95% confidence interval) PCWP for the change between MSB and MSR was 8.9 mmHg (8.3 to 9.6), and between MSR and FC was 10.9 mmHg (10.1 to 11.8). The difference between the two change points was significant (p=0.0004). There was no significant difference in the mean values of PCWP between the three observers (p=0.956)

Prediction of PCWP by interatrial septal shape and movement

The change in pattern was a powerful predictor of PCWP (p=0.0047). The mean PCWP across all observations of interatrial septal motion did not differ according to observer (p=0.958), nor was there any interaction between the pattern and observer (p=0.964), indicating that there was no difference among the 3 observers in their capacity to predict PCWP. There was also no difference whether the observations were made before or after CPB (p=0.220).

The change in pattern, however, was not a predictor of interatrial pressure difference (p=0.128). The PCWP was greater that the RAP in all observations. This indicates that the PCWP is the important determinant of interatrial septal shape, rather than the interatrial pressure difference.

Discussion

Our study shows that the interatrial septal shape and movement can identify a range of pulmonary capillary wedge pressures in patients undergoing cardiac surgery. In general terms, mid-systolic buckling will predict normal to low PCWP, mid-systolic reversal will predict normal PCWP and fixed curvature will predict normal to high PCWP. Importantly the pattern will alter with a change in PCWP. The simplicity of the technique, its ability to detect a change or trend in PCWP, and interobserver reliability, will enhance its clinical utility.

There was considerable overlap of pressures for the 3 interatrial septal patterns. This reduces the power of our method to determine the exact PCWP for an individual patient. Differences in left atrial compliances could account for the overlap. Left atria that are chronically exposed to high pressures, for example, may show a change in pattern at a higher PCWP than a normal left atrium. The value of our technique however is in the ability of the shape and movement of the interatrial septum to detect a change in PCWP. For any patient, FC will occur at a higher PCWP than MSR, which will be higher than MSB. It is useful as a monitor of the trend in PCWP, whilst still broadly allowing prediction of PCWP.

The concept of interatrial septal movement for PCWP or left atrial pressure estimation is not new. Kusumoto and colleagues[3] measured the radius of curvature of the interatrial septum and its movement during the ventilatory cycle and correlated it with PCWP. They described that during early diastole and atrial contraction, the PCWP exceeds the right atrial pressure and the septum bows to the right. During systole, the right atrial pressure momentarily exceeds the left and the septum bows to the left and is accentuated during passive expiration. This is analogous to the MSR pattern. When the PWCP exceeded 15 mmHg, they found that the interatrial septum remained bowed to the right. Although they described this finding during passive expiration, we have found the same phenomenon occurs during each cardiac cycle and identifies a normal to high PCWP state (FC). When the left atrial pressure is low, the walls of the atrium are "slack." The normal movement changes that occur during the cardiac cycle are accentuated and the interatrial septum shows increased mobility, with the septum buckling during mid-systole (MSB).

Other groups have used a variety of Doppler approaches to estimate LAP or PCWP, including left atrial appendage flow velocity,[2] transit time of the left atrial pressure wave,[5] subtraction of mitral regurgitant pressure gradient from peak brachial systolic pressure,[6,7] left atrial systolic time intervals[1] or mitral inflow Doppler.[4] Although these methods show reasonable correlation with PCWP or can identify a high PCWP state, they are time consuming and require calculation. The advantage of observing interatrial septal curvature is that it is quick and easy to perform and does not involve calculation.

Our study has several possible limitations. We used PCWP to estimate left atrial pressure. PCWP has been shown to correlate with end-diastolic pressure over a wide range of conditions in patients undergoing cardiac surgery.[8] A single operator performed all measurements in stage 1, making blinding impossible. However, we performed the PCWP following echocardiography estimation to minimise this limitation. The subjective assessment of interatrial septal movement is a potential error, but despite this, the predictive value was good. This study has been validated in patients undergoing cardiac surgery whilst mechanically ventilated. Further studies in non-anesthetised patients using transthoracic echocardiography should be performed before extending its use to the outpatient setting. We attempted to overcome the limitations of stage 1 in the stage 2 protocol. We used separate observers for pressure and TEE recordings, analysed all recordings off-line and used 3 blinded observers to assess the TEE images. We found good interobserver reliability in the ability to determine the 3 patterns and the PCWP at which those patterns changed.

We were surprised that the interatrial pressure difference was not significant in determining the shape and movement of the interatrial septum. The lack of significance, however, reinforces our findings that the PCWP (estimating left atrial pressure) is the important determinant of the shape and movement of the interatrial septum.

Conclusion

The shape of interatrial septal shape and movement predicts change in pulmonary capillary wedge pressure in patients undergoing cardiac surgery, using transesophageal echocardiography.

Acknowledgments

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References

1. Okamoto M, Tsubokura T, Yokote Y, et al. Left atrial systolic time intervals: their relations to left atrial preload, afterload and acute left ventricular pressure loading. *J Cardiol* 1990; **20**: 177–83.
2. Tabata T, Oki T, Fukuda N, et al. Influence of left atrial pressure on left atrial appendage flow velocity patterns in patients in sinus rhythm. *J Am Soc Echocardiogr* 1996; **9**: 857–64.
3. Kusumoto F, Muhiudeen I, Kuecherer H, Cahalan M, Schiller N. Response of the interatrial septum to transatrial pressure gradients and its potential for predicting pulmonary capillary wedge pressure: an intraoperative study using transesophageal echocardiography in patients during mechanical ventilation. *J Am Coll Cardiol* 1993; **21**: 721–8.
4. Kuecherer H, Muhiudeen I, Kusumoto F, et al. Estimation of mean left atrial pressure from transesophageal pulsed Doppler echocardiography of pulmonary venous flow. *Circulation* 1990; **82**: 1127–39.
5. Brennan E, O'Hare N, Walsh M. Correlation of end-diastolic pressure and myocardial elasticity with the transit time of the left atrial pressure wave (A-Ar interval). *J Am Soc Echocardiogr* 1997; **10**: 293–9.
6. Gorcsan III J, Snow F, Paulsen W, Nixon J. Noninvasive estimation of left atrial pressure in patients with congestive heart failure and mitral regurgitation by Doppler echocardiography. *Am Heart J* 1991; **121**: 858–63.
7. Ge Z, Zhang Y, Fan D, Zhang M, Duran C. Simultaneous measurement of left atrial pressure by Doppler echocardiography and catheterization. *Int J Cardiol* 1992; **37**: 243–51.
8. Greene E, Gerson J. One versus two MAC halothane anesthesia does not alter the left ventricular diastolic pressure-volume relationship. *Anesthesiology* 1986; **64**: 230–7.