Mitral Annular Plane Systolic Excursion as a predictor of Left Ventricular Ejection Fraction in mechanically ventilated patients

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Abstract

Introduction: The accurate measurement of Left Ventricular Ejection Fraction (LVEF) requires high-quality images and echocardiography expertise. Critically ill patients can present challenges in obtaining good acoustic windows for ultrasound, particularly for ICU trainees early in their ultrasound learning. Mitral Annular Plane Systolic Excursion (MAPSE), a simple measurement, may be useful in this context to estimate LV systolic function.

Materials and Methods: All adult patients admitted to the Alfred ICU between August 2012 and February 2013 who were on mechanical ventilation and needed an echocardiography examination were eligible to be included in the study. An ICU trainee in their first year of echocardiography training performed MAPSE measurements. An advanced echocardiographer classified LV systolic function into normal, mild, moderate or severe categories based on the visual estimation of LVEF. The relationship between the MAPSE measurements and the range of LV systolic function was assessed.

Results: Amongst 39 patients, the mean (SD) age was 55 (18.6) years, 20 (50%) were males, 36 (90%) were in sinus rhythm, 19 (48%) were on vasopressors, 12 (30%) were on inotropes and 23 (58%) were on mandatory mode mechanical ventilation. The mean (SD) MAPSE was 12.2 (5.28) mm. 28 (70%) of the patients had normal or mildly reduced LVEF. The ROC analysis showed that a MAPSE cut-off point of ≥ 12.5 mm diagnosed normal or mildly reduced LVEF with 82.14% sensitivity and 91.67% specificity. The area under ROC curve was 0.91 (95% CI 0.82–1.00).

Conclusion: MAPSE is useful as a surrogate for LVEF in mechanically ventilated patients. In early critical care echocardiography training, a novice learner can perform MAPSE easily, accurately, and find it helpful for assessment of LVEF.

Keywords: echocardiography, ICU, Mitral Annular Plane Systolic Excursion, ventilation.

Introduction

Cardiac function assessment is essential in the management of critically ill patients. The associated morbidity of invasive methods of assessment such as the pulmonary artery catheter has led to safer techniques like echocardiography being favoured.^{1,2} As a result, echocardiography has become a core skill for intensive care physicians.³ Education and training for ICU physicians are therefore essential for interpretation, interventions and patient safety. The World Interactive Network Focused on Critical Ultrasound (WINFOCUS) group published a document in 2008 for echocardiography practice, training and education.⁴ The document proposed the levels of competence of echocardiography in the intensive care unit (ICU). The College of

Intensive Care Medicine in Australia and New Zealand has mandated basic competency in critical care echocardiography (BCCE) for all of its trainees since 2014.⁵ It stipulates at least thirty studies before the completion of a basic critical care echocardiography module, consistent with observational studies and an International Expert Statement on critical care ultrasound.^{6–8}

In mechanically ventilated patients, acoustic windows can be particularly challenging with drains, tubes, dressings and positioning restrictions presenting difficulties.⁹ Patients on high positive end-expiratory pressure (PEEP) with hyperinflated lungs, surgical emphysema, pneumothorax or pneumomediastinum offer further difficulties to imaging. Also, inability of the patient to co-operate, for example by holding their breath at a specific point in the respiratory cycle and their positioning restrictions also offer challenges for good image acquisition.

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Left ventricular systolic function can be estimated by changes in dimensions and volumes between systole and diastole, systolic index of contractility, global longitudinal strain and M-mode. Left Ventricular Ejection Fraction (LVEF) is the percentage of end-diastolic blood volume ejected from the left ventricle during systole and is widely recognised as a measurement for left ventricular systolic function. Stroke volume (SV) is the volume of blood ejected and multiplied by the heart rate gives the CO. The various methods used to assess left ventricular systolic function with TTE include Simpson's Biplane method, the velocity time integral (VTi) of the blood flow through the left ventricular outflow tract (LVOT) multiplied by the LVOT area, mitral regurgitant jet dP/dT , two-dimensional and three-dimensional speckle tracking, tissue Doppler imaging at the mitral annulus, three-dimensional volumetry and Mitral Annular Plane Systolic Excursion (MAPSE) using M-mode.¹⁰ However, most of these measurements are beyond the scope of basic critical care echocardiography.

Mitral Annular Plane Systolic Excursion is a measurement of the displacement of the mitral annulus towards the apex and thus relates to the longitudinal contractility of the myocardium. It is easy to obtain by a single M-mode measurement and has been demonstrated in many studies in non-critically ill patients to correlate well with LVEF.⁸ Unlike all other echocardiography methods to measure LVEF described above that require good acoustic windows and a certain level of expertise, MAPSE values can be obtained accurately even with poor windows as often seen in mechanically ventilated patients, because of the high echogenicity of the atrioventricular annulus, and by little experience.

We hypothesised that MAPSE values obtained by a novice critical care trainee in mechanically ventilated patients would correlate well with visual estimation of LVEF. This would be particularly useful during the early period of training when the new trainee has not had enough experience to visually estimate LVEF.

Materials and methods

This was a prospective observational study set in a large 45-bed teaching hospital intensive care unit from August 2012 to February 2013. A study size of forty studies was chosen as a sample of convenience. Patients on mechanical ventilation in whom an echocardiogram was requested by the treating intensivist were eligible for inclusion in the study. Patients on mechanical cardiac assist devices like an intra-aortic balloon pump, extracorporeal membrane oxygenation and ventricular assist devices were excluded. Patient demographic data, diagnosis, ventilator settings, haemodynamic parameters and vasoconstrictor/inotrope support were collected at the time of echocardiography examination.

We trained the ICU echocardiography fellow, who had no previous ultrasound experience, to perform MAPSE measurements. To prevent inter-individual variation, the ICU echocardiography

fellow performed all the MAPSE measurements. The echocardiography machine used was a Siemens Acuson SC2000 with standard local ICU settings. Every patient had a 2D echocardiography examination with standard views. The apical four-chamber (A4C) view was used for the MAPSE measurement. The M-mode cursor was aligned parallel with the lateral wall of the left ventricle, and a continuous line of systolic excursion was identified and interrogated from the lateral annulus of the mitral valve to the apex of the left ventricle. On the M-mode image, the waveform was reviewed and the vertical distance between the peak and nadir measured in millimetres – the nadir represents end-diastole and the peak closure of the aortic valve.

Visual estimation of LVEF was performed by two senior intensivists who held the Diploma of Diagnostic Ultrasound (Critical Care) qualification from the Australasian Society for Ultrasound in Medicine. They were blinded to the trainee's assessment and also to each other's assessment. They used the European Heart Association's categorisation for LVEF. An adjudicator resolved any discrepancy in assessment by reviewing the images independently.

Ethics approval

The Alfred Hospital Human Research Ethics Committee provided ethics approval for the study, and the patient's next of kin provided written informed consent prior to the recruitment of patients.

Statistical analysis

Continuous variables were summarised using means and standard deviation (SD), or median with 25th and 75th quartiles. Discrete variables were summarised as percentages. Kappa statistics were used to compare the inter-observer variation between the two expert assessors who evaluated LV systolic function. Spearman's rank correlation coefficient was calculated to assess the relationship between MAPSE and various EF categories. We used the receiver operating characteristic (ROC) curve analysis to determine the optimal cut-off point to separate normal or low LV systolic dysfunction from moderate or severe LV systolic dysfunction. In the ROC analysis, sensitivity is plotted against (1-specificity) for a range of different cut-off points. The area under the ROC curve measures the ability of the test to correctly classify those with and without the disease. An area of 1 represents a perfect test, and an area of 0.5 represents a poor test. We used Youden's index to determine the optimal cut-off point to separate normal/mild LV dysfunction from moderate/severe LV dysfunction. Youden's index (J point) is calculated by determining sensitivity + (specificity – 1) at each cut-off point, and the values range from 0 to 1. A value approaching 1 indicates a better test and vice versa. This allows finding an optimal cut-off point independently from the outcome prevalence. All statistical analyses were performed using Stata 11.2 (StataCorp, College Station, TX, USA).

Results

We recruited 39 patients in this study. One patient had two echocardiography studies performed during two different ICU admissions. Hence, we had 40 studies from 39 patients included in the analysis. Patient characteristics and diagnostic categories are summarised in Table 1. The mean (SD) age was 54.8 (18.54) years with equal sex distribution. Most of the patients had sinus tachycardia and vasopressor or inotrope infusions at the time of echocardiography. Trauma was the most common diagnostic group followed by cardiac diagnostic groups: cardiac surgery, cardiac arrest and heart failure.

Twenty-two (55%) patients had normal LV systolic function, 6 (15%) had mild LV systolic dysfunction, 7 (17.5%) had moderate LV systolic dysfunction, and 5 (12.5%) patients had severe

Table 1: Baseline characteristics and diagnostic groups

Characteristic		Value
Age (years)	Mean (SD)	54.8 (18.54)
Sex		
Male	N (%)	20 (50%)
Female	N (%)	20 (50%)
Heart rate (per min)	Mean (SD)	92 (18.6)
MAP (mmHg)	Mean (SD)	77 (11.5)
Rhythm		
Sinus	N (%)	36 (90)
AF	N (%)	2 (5)
Paced	N (%)	2 (5)
Vasopressors	N (%)	19 (47.5)
Inotropes	N (%)	12 (30)
Mechanical ventilation		
PSV	N (%)	17 (42.5)
Mandatory mode	N (%)	23 (57.5)
Diagnostic groups		
Trauma	N (%)	11 (28)
Post-cardiac surgery	N (%)	5 (13)
Post-surgery	N (%)	3 (8)
Cardiac arrest	N (%)	4 (10)
Heart failure	N (%)	3 (8)
Sepsis	N (%)	5 (13)
Miscellaneous	N (%)	8 (23)

LV systolic dysfunction. Kappa statistics between the two observers was 77.5% with a Kappa value of 0.66 (95% CI 0.47–0.85, P-value < 0.001) suggesting good agreement between the two expert observers.

Figure 1 shows the distribution of MAPSE in various grades of LV systolic function in the patients. Patients with normal function or mild LV dysfunction had a higher median MAPSE compared to patients with moderate or severe LV systolic dysfunction: median (IQR) 15.6 (13–17.45) mm vs. 8.85 (7.35–12.15) mm (P < 0.01). Spearman's rank correlation coefficient between MAPSE and LVEF categories was -0.61 (P-value < 0.01).

Figure 2 shows the results of the ROC analysis. The area under the ROC curve was 0.91 (95% CI 0.82–1.00) which suggested that MAPSE had good predictability to differentiate normal or mildly abnormal LV systolic function from moderate or severely deranged LV systolic function. Using Youden's index, we found that a MAPSE value of 12.5 mm was the optimal cut-off point to predict normal or mild LV systolic function with high sensitivity and specificity (Sensitivity 82.1%, Specificity 91.7%).

Discussion

In this prospective observational study of critically ill patients on mechanical ventilation who had echocardiography performed by a novice echocardiographer, MAPSE had a strong correlation with LV systolic function. Furthermore, a MAPSE of ≥ 12.5 mm predicted normal or mildly abnormal LV systolic function with high sensitivity and specificity.

Cardiac contraction is a complex process involving four different processes which lead to deformation or strain of the myocardial fibres. These are myocardial contractility, cardiac chamber loading pressure and distension, interaction with neighbouring segments (and chambers) and tissue elasticity.

Figure 1: Distribution of Mitral Annular Plane Systolic Excursion Measurements by the Grade of Left Ventricular Systolic Dysfunction.

Figure 2: Receiver Operative Characteristic Curve Analysis to Separate Normal or Mild Left Ventricular Systolic Dysfunction from Moderate or Severe Dysfunction Using Mitral Annular Plane Systolic Excursion Measurement. *Mitral Annular Plane Systolic Excursion Value of ≥ 12.5 mm Diagnosed Normal or Mildly Reduced LVEF with 82.14% Sensitivity and 91.67% Specificity. Area Under ROC Curve 0.91 (95% CI 0.82–1.00).

The arrangement of myocardial fibres in longitudinal, radial and circumferential orientations results in a multidirectional but synchronised contraction. MAPSE specifically represents the longitudinal contractility of the heart. It is a measure of the global longitudinal displacement of the mitral annulus towards the relatively immobile apex. Several studies in the cardiology literature on non-ICU patients have shown a good correlation between MAPSE and LVEF. Elnoamany *et al.*¹¹ studied mitral annular motion and LVEF and found a MAPSE < 12 mm had a 90% sensitivity and 88% specificity for detection of LVEF $< 50\%$ (p -value < 0.001). Similar to this study, the large retrospective study by Matos *et al.* demonstrated that MAPSE was a highly accurate predictor of LVEF.⁸ However, the echocardiograms in this study were performed by expert echocardiographers and the MAPSE measured off-system (post-processing) by a medical student. In this study, a MAPSE > 11 mm for women and > 13 mm for men predicted an LVEF of $> 55\%$, with a sensitivity of 92%. As in our study, most of the patients had normal LVEF in that study. Adel *et al.*⁸ looked at the correlation between MAPSE and LVEF specifically in the group of patients with LVEF $< 50\%$. They found a significant positive correlation between MAPSE and LVEF measured by visual estimation. A cut-off value < 5 mm was able to predict LVEF $< 30\%$ with a sensitivity of 67.1% in that study.

Two previous studies have looked at the use of MAPSE in critically ill patients. In contrast to our study they both used expert echocardiographers. Our study demonstrates that MAPSE can be performed accurately by new ICU trainees in

patients on mechanical ventilation. The first study is by Bergenzaun *et al.* in which experienced echocardiographers imaged and performed MAPSE estimation. The results of this study are similar to our study with respect to the correlation between MAPSE and LVEF.¹² In contrast to our study, median MAPSE (16 (13–17.6)) mm was lower. However, they only looked at patients with shock and the number of patients with preserved LVEF was small ($n = 14$) which might have led to sampling error. Also, it is not clear how many of these patients were on mechanical ventilation.

In another study, Zidan *et al.*¹³ evaluated the role of MAPSE in the determination of LVEF in critically ill patients with obesity on mechanical ventilation. Similar to our study and that by Bergenzaun *et al.*, they demonstrated a strong correlation between MAPSE and LVEF by visual assessment. They also showed a strong correlation between MAPSE and Simpson's Biplane technique. The echocardiography examination for MAPSE and assessment of LVEF was performed by experienced echocardiographer intensivists. However, they did not provide a cut-off value for categorisation of LVEF. Their study did demonstrate that even in obese patients with difficult acoustic windows, MAPSE can be used to measure LVEF.

Our study showed some discrepancy between MAPSE and LVEF in the moderately impaired and severely impaired subgroups with the mean MAPSE being lower in the moderate subgroup (7.4 v 9.8). There could be several reasons for this. There were a number of outliers in the moderate subgroup. Longitudinal contractility can be impaired earlier in some patients with preserved LVEF and cardiac disease, with radial and circumferential contractility compensation to preserve the LVEF therefore giving an impression on visual assessment of a higher LVEF than one would normally expect with the MAPSE value.¹⁴ Other potential causes could be regional wall motion abnormalities, left ventricular hypertrophy, a calcified mitral ring and small localised areas of myocardial fibrosis. Increasing age can be a factor.¹⁵ The effect of inotropes and vasoconstrictors on longitudinal contractility is an interesting question that has not been studied so far. Finally, technical issues such as angle dependence and a new trainee might have influenced the estimation of MAPSE.

Overall we demonstrated that a new trainee can accurately obtain MAPSE values that correlate well with binary LVEF categories of normal/mildly impaired and moderate/severely impaired. Previous studies have shown that visual inspection is not accurate in trainees in their first thirty echocardiograms. We propose that MAPSE can be incorporated in early training programmes for ICU trainees learning echocardiography to guide them in developing visual assessment skills. The College of Intensive Care Medicine in Australia and New Zealand mandates thirty basic echocardiography studies for all trainees – MAPSE may be useful in this stage of training.

Limitations

Limitations in our study were the low number of moderately/severely impaired LVEF patients – we could have stratified patients at the beginning to enrol more low LVEF patients. Also, we only compared MAPSE with visual assessment and not Simpsons Biplane method, speckle tracking or 3D volumetry; this was to maintain fidelity for the use of a trainee as these images can only be obtained by an experienced operator.

Conclusion

MAPSE as measured in critically ill mechanically ventilated patients by a non-expert trainee correlates well with LVEF. We conclude that early in training MAPSE can be used accurately to differentiate between normal or mildly impaired LVEF and moderate to severely impaired LVEF. Future studies may compare MAPSE in this context with quantitative measures of LVEF.

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Disclosure

The authors have no conflict of interests to declare.

Authorship declaration

The authors certify that this manuscript is original, has been written by the stated authors, has not been published previously and is not under consideration for publication by another journal. Moreover, each author certifies that they have participated to a sufficient degree to take public responsibility for the work and believes that the manuscript describes truthful facts. They declare that they shall produce the data on which the manuscript is based for examination by the editors or their assignees, should it be requested.

References

- 1 Tuman KJ. Debate: the pulmonary artery catheter, is it safe? To use or not to use. Pro: a moratorium on PAC is unjustified *J Clin Monit* 1997;13(5):337–8.
- 2 Mercado P, Maizel J, Beyls C, Titeca-Beauport D, Joris M, Kontar L, et al. Transthoracic echocardiography: an accurate and precise method for estimating cardiac output in the critically ill patient. *Crit Care* 2017; 21(1): 136.
- 3 Price S, Nicol E, Gibson D, Evans T. Echocardiography in the critically ill: current and potential roles. *Intensive Care Med* 2005; 32(1): 48–59.
- 4 Price S, Via G, Sloth E, Guarracino F, Breitzkreutz R, Catena E, et al. Echocardiography practice, training and accreditation in the intensive care: document for the World Interactive Network Focused on Critical Ultrasound (WINFOCUS). *Cardiovasc Ultrasound* 2008; 6(1): 49.
- 5 Cicm.org.au. 2018 [Internet] [cited 2 September 2018]. Available from: [https://www.cicm.org.au/CICM_Media/CICMSite/CICM-Website/Resources/Trainee%20Resources/T-35-\(2014\)-Focused-Cardiac-Ultrasound-in-Intensive-Care-Syllabus.pdf](https://www.cicm.org.au/CICM_Media/CICMSite/CICM-Website/Resources/Trainee%20Resources/T-35-(2014)-Focused-Cardiac-Ultrasound-in-Intensive-Care-Syllabus.pdf) (accessed 19/04/2018).
- 6 Expert Round Table on Ultrasound in ICU. International expert statement on training standards for critical care ultrasonography. *Intensive Care Med* 2011;37(7):1077–83.
- 7 See K, Ong V, Ng J, Tan R, Phua J. Basic critical care echocardiography by pulmonary fellows. *Crit Care Med* 2014; 42(10): 2169–77.
- 8 Adel W, Roushdy A, Nabil M. Mitral annular plane systolic excursion-derived ejection fraction: a simple and valid tool in adult males with left ventricular systolic dysfunction. *Echocardiography* 2015; 33(2): 179–84.
- 9 Orde S, Slama M, Hilton A, Yastrebov K, McLean A. Pearls and pitfalls in comprehensive critical care echocardiography. *Crit Care* 2017; 21(1): 279.
- 10 Matos J, Kronzon I, Panagopoulos G, Perk G. Mitral annular plane systolic excursion as a surrogate for left ventricular ejection fraction. *J Am Soc Echocardiogr* 2012; 25(9): 969–74.
- 11 Elnoamany M, Abdelhameed A. Mitral annular motion as a surrogate for left ventricular function: correlation with brain natriuretic peptide levels. *Eur J Echocardiogr* 2006; 7(3): 187–98.
- 12 Bergenzaun L, Öhlin H, Gudmundsson P, Willenheimer R, Chew M. Mitral annular plane systolic excursion (MAPSE) in shock: a valuable echocardiographic parameter in intensive care patients. *Cardiovasc Ultrasound* 2013; 11(1): 16.
- 13 Zidan D, Helmy T. Usefulness of mitral annular plane systolic excursion in assessment of left ventricular systolic function in mechanically ventilated obese patients. *J Crit Care* 2016; 34: 74–6.
- 14 Tan Y, Wenzelburger F, Lee E, Heatlie G, Leyva F, Patel K, et al. The pathophysiology of heart failure with normal ejection fraction. *J Am Coll Cardiol* 2009; 54(1): 36–46.
- 15 Gelzinsis T. New insights into diastolic dysfunction and heart failure with preserved ejection fraction. *Semin Cardiothorac Vasc Anesth* 2013; 18: 208–17.