Mitral Annular Plane Systolic Excursion as a Surrogate for Left Ventricular Ejection Fraction

Jason Matos, MD, Itzhak Kronzon, MD, Georgia Panagopoulos, PhD, and Gila Perk, MD, *New York, New York*

Background: Assessing left ventricular function is a common indication for echocardiography. It generally requires expert echocardiographer estimation and is somewhat subjective and prone to reader discordance. Mitral annular plane systolic excursion (MAPSE) has been suggested as a surrogate measurement for left ventricular function. The aim of this study was to examine the accuracy of MAPSE for predicting left ventricular ejection fraction (EF) on the basis of a large cohort of consecutive echocardiograms.

Methods: The study design was a retrospective analysis of 600 two-dimensional echocardiographic studies performed in a single laboratory. MAPSE measurement was performed by an untrained observer and compared with the EF as determined by an expert echocardiographer. The first 300 studies served as a calibration cohort to establish an algorithm for predicting EF on the basis of MAPSE measurement. The following 300 studies served as a verification cohort to test the accuracy of the established algorithm.

Results: Using the first 300 studies, an algorithm was developed to predict EF. Cutoff values for normal EF ($\geq$11 mm for women and $\geq$13 mm for men) and severely reduced EF (<6 mm for men and women) were identified. For the intermediate-range MAPSE values, a gender-specific regression equation was calculated to generate a predicted EF. Using this algorithm, predicted EFs were determined for the 300 patients in the verification cohort. By comparing the predicted EF and the expert-reported EF, positive and negative predictive values, sensitivity (73%–92%), specificity (81%–100%), and accuracy (82%–86%) of MAPSE for predicting EF were calculated.

Conclusions: MAPSE measurement by an untrained observer was found to be a highly accurate predictor of EF. (J Am Soc Echocardiogr 2012;25:969-74.)

Keywords: Ejection fraction, MAPSE

Assessing left ventricular systolic function is a common indication for transthoracic echocardiography. Stroke volume determination via echocardiography has been clinically relevant since the 1960s.[1] Left ventricular function is often expressed as an assessment of left ventricular ejection fraction (EF), which over time has been determined using numerous methods. Each of these requires an expert physician echocardiographer and is somewhat subjective and prone to reader discordance and variability. Also, assessing left ventricular EF using currently available techniques is highly dependent on adequate endocardial resolution and the technical quality of the echocardiographic study.[2]

During systole, both longitudinal and circumferential fibers contribute to myocardial contraction. Gibson and colleagues have done extensive work studying the importance of longitudinal fiber shortening and its relationship to left ventricular function. He and others

demonstrated that the movement of the mitral annulus toward the apex is a result of long-fiber contraction.[3] During diastole, the annulus moves back away from the apex. Left ventricular apical motion is limited throughout the cardiac cycle, such that the distance between the apex of the heart and the chest surface is almost constant during contraction. The magnitude of the displacement of the mitral annulus during myocardial contraction can be measured from M-mode images of the mitral annulus[4] (Figure 1).

Mitral annular plane systolic excursion (MAPSE), also referred to as mitral annular motion or atrioventricular displacement, was measured as early as 1967, when Zaky et al.[5] described a "curve contour" using M-mode echocardiography through the mitral ring, which measured 1.6 ± 0.4 cm. They found "deviations" from this normal value in the movement of the mitral ring in patients with heart disease. MAPSE more recently has been suggested as a surrogate measurement for left ventricular function.[6-8] Some have shown linear correlations between expert-measured EF and MAPSE; one study showed that a MAPSE value of <7 mm had sensitivity of 92% and specificity of 67% for detecting severe left ventricular dysfunction. A separate study demonstrated that a MAPSE value of <12 mm had 90% sensitivity and 88% specificity for the detection of EF<50%.[9] Others have shown that MAPSE measurements correlate well with other techniques for left ventricular functional assessment, including three-dimensional echocardiography and cardiac magnetic resonance imaging (MRI).[10,11] Tsang et al.[12] studied the correlation of MAPSE, as derived from

speckle-tracking echocardiography, with MRI-determined EF. They found a very strong correlation using this alternative MAPSE technique, suggesting a true inherent strong relation between mitral annular motion and global left ventricular systolic function.[12]

Multiple studies have shown that a decrease in MAPSE correlates with many factors affecting left ventricular function, including atrial fibrillation, myocardial infarction, dilated cardiomyopathy, and age.[13-15]

The major benefit of using MAPSE for left ventricular function assessment is in the simplicity of the measurement. It is a simple, one-dimensional measurement that can be easily performed by even novice practitioners with little training in echocardiography. Also, MAPSE measurement is much less dependent on endocardial resolution and can be performed even in technically challenging studies. Our hypothesis was that MAPSE, measured by an untrained observer, can accurately predict EF.

METHODS

The study design was a retrospective analysis of echocardiograms obtained for clinical indications. Six hundred consecutive two-dimensional (2D) echocardiographic studies done in the echocardiography laboratory at Lenox Hill Hospital (an urban teaching hospital) were included in our study (Philips iE33 xMATRIX Ultrasound System; Philips Medical Systems, Andover, MA). M-mode echocardiography through the mitral valve annulus, from the apical four-chamber view at both the septal and lateral annuli, is routinely performed and recorded in all studies in our laboratory. No specific image orientation was used for the purpose of MAPSE measurement; the images were optimized for routine four-chamber view evaluation. The M-line was positioned through the medial and lateral annulus and included the tissue-blood border for easy identification of the motion of the annulus. The trough of the motion was defined as the end-diastolic position of the annulus, measured at the tip of the QRS complex. The peak was defined as the maximal systolic excursion point. MAPSE measurement was performed by a fourth-year medical student, blinded to the official report of the echocardiogram. The student was initially trained by the attending echocardiographer to accurately measure MAPSE, identifying the required images and the trough and peak of annular motion, and using the calipers on the digitized system. Once the student demonstrated adequate skill at performing these measurements, the student's independent MAPSE measurements began for the study purpose.

The average MAPSE value (mean of septal and lateral values) was obtained for each patient and used in the analysis. Each study was interpreted (clinically) by an expert echocardiographer, providing an expert estimation of the EF that was based on "eyeballing," with or without the use of Simpson's method of disks. Because the purpose of the study was to assess how MAPSE measurement performs relative to an expert interpretation of an echocardiogram, there was no prerequisite requirement for the readers as to how to determine the EF.

Baseline patient characteristics were collected for all studies; these included age, gender, height, weight, body surface area, and the technical quality of the study. Technical quality was graded on a numeric scale (1 = poor, 2 = fair, 3 = good, and 4 = excellent).
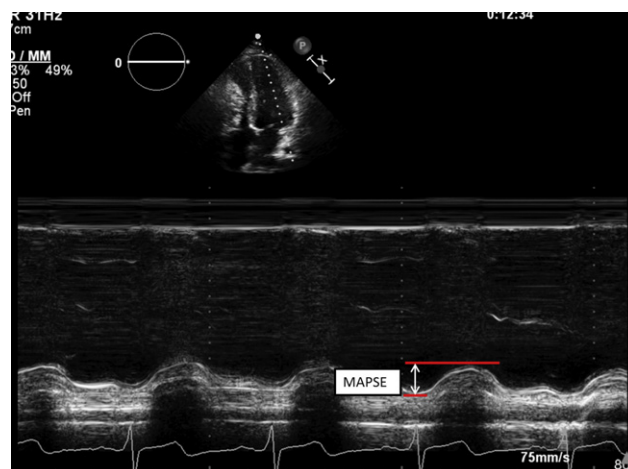
Figure 1 Measuring MAPSE. To measure MAPSE, M-mode echocardiography across the mitral annulus is acquired. The longitudinal motion of the mitral annulus is depicted over time as a sine wave. The nadir of the sine wave corresponds to the mitral annular position at end-diastole, and the peak occurs at end-systole. The height of the peak relative to the nadir is MAPSE. In our study, medial and lateral MAPSE measurements were taken and averaged for each patient (in both the calibration cohort and the verification cohort). All studies that had M-mode analysis were included, regardless of image quality.

The first 300 echocardiograms served as a calibration cohort to help establish MAPSE's correlation with EF in our laboratory. These studies were analyzed to determine appropriate MAPSE cutoff values for varying tiers of EF.

The following 300 echocardiograms served as a validation cohort. Using the algorithm we developed from the calibration cohort, MAPSE measurement was used by the medical student to predict left ventricular EF. The predicted EF was then compared with the expert-reported assessment. On the basis of this comparison, the sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of MAPSE measurements for EF were determined.

Data were examined for normality; statistical tests and presentation of results were chosen accordingly. Continuous normally distributed data were analyzed using unpaired t tests and are presented as mean $\pm$ SD. A simple linear regression procedure was undertaken using MAPSE values as the predictor and EF values as the criterion variable. Diagnostic properties (sensitivity, specificity, positive predictive value, negative predictive values, and total accuracy) were calculated for MAPSE cutoff values on the basis of the performance of these values in the verification cohort. Two-tailed tests of significance are reported, and P values $<$ .05 were considered a priori to indicate statistical significance. Statistical analyses were performed using SPSS version 20 (SPSS, Inc., Chicago, IL).

Interobserver and intraobserver variability in MAPSE measurements were tested by having 20 random studies read by an independent observer, as well as remeasuring MAPSE by a single observer. Interobserver variability was calculated by averaging the values obtained and then dividing the absolute difference between the two observers' measurements by the mean of the two measurements for every single patient from the randomly selected group. Similarly, intraobserver variability was calculated from the difference between the two measurements by the same reader.

This study was approved by the institutional review board for human research.

RESULTS

Calibration Cohort

Three hundred consecutive 2D echocardiographic studies were reviewed by the medical student, and MAPSE values were measured in all 300 patients. No patients were excluded from data analysis. Data recorded for each patient are listed in Table 1. Of all the patient characteristics documented, gender had the greatest correlation with EF. Although MAPSE values were similar between genders, we found that on average, a given MAPSE value correlated with a higher EF in women. Given this observation, for establishing an algorithm for determining EF from MAPSE, men and women were analyzed separately.

Our initial analysis of the 300 studies in the calibration cohort (in accordance with data from previous research[9]) showed that MAPSE values ≥ 13 mm in men consistently predicted a normal or increased EF. Similarly, we found that in women, MAPSE values ≥ 11 mm consistently predicted a normal or increased EF. Likewise, we found that a MAPSE value < 6 mm (for both men and women) served as an appropriate cutoff for predicting severely depressed EF (≥30%).

Gender-specific scatterplots were constructed to evaluate MAPSE versus EF for those patients who had MAPSE measurements between the previously mentioned cutoff values (Figure 2). A regression line was obtained from each scatterplot; for men, $4.8 \times$ MAPSE (mm) + 5.8 ($R = 0.644$), and for women, $4.2 \times$ MAPSE (mm) + 20 ($R = 0.470$).

Given these data, we created an algorithm for predicting EF on the basis of MAPSE measurement. For women, a MAPSE value ≥ 11 mm determined a normal EF (≥55%), while in men, this value was 13 mm. A MAPSE value < 6 mm in either gender was considered to reflect a severely depressed EF (≤30%). A MAPSE measurement between these cutoff values was used in the gender-specific regression equation, and a predicted EF was calculated.

Verification Cohort

Another cohort of 300 consecutive 2D echocardiographic studies was reviewed by the medical student. Baseline patient characteristics, as well as general quantitative and qualitative data for the verification cohort, are listed in Table 2. There were no significant differences between the calibration cohort and the verification cohort. Similarly to the calibration cohort, a difference in average EF between men and women despite lack of difference in average MAPSE was noted in the verification cohort (Table 3). MAPSE values were measured by the medical student, blinded to the expert report. Using this measurement, a predicted EF was determined on the basis of the algorithm established in the calibration cohort.

To determine the accuracy of our algorithm, absolute variation from expert-reported EF was calculated for each patient. If a patient had a MAPSE value < 6 mm and an EF ≤ 30%, this was considered a concordant event. In addition, if a female patient had a MAPSE value ≥ 11 mm or a male patient had a value ≥ 13 mm and the expert-reported EF was normal or increased, this was also considered a concordant event. Concordant events were determined to have variation from expert-reported EFs of zero.

For patients with MAPSE above the normal threshold with expert-reported EFs below normal, variation was calculated by assigning a predicted EF of 60%. For patients with MAPSE values < 6 mm and expert-reported normal EFs, variation was calculated by assigning a predicted EF of 30%.

The accuracy of MAPSE < 6 mm for predicting a severely depressed EF was calculated (Table 4). The positive predictive value

Table 1 Baseline characteristics for the initial 300 patients (calibration cohort)

Variable	Cohort (n = 300)	Men (n = 147)	Women (n = 153)	P
Age (y)	65.9 ± 17.4	63.2 ± 15.6	68.1 ± 18.8	.015
Age range (y)	18–100	20–100	18–100	—
Body surface area (m²)	1.86 ± .29	2.02 ± 0.26	1.71 ± 0.22	<.0001
Average MAPSE (mm)	10.9 ± 3.0	10.7 ± 3.4	10.9 ± 2.7	.53
Reported EF (%)	56.8 ± 13.4	53 ± 15	60 ± 10	<.0001
Average image quality*	2.82 ± 0.54	2.88 ± 0.60	2.80 ± 0.52	.223

Data are expressed as mean ± SD. Men and women were analyzed separately given our observation that for a given MAPSE value, men had lower EFs than women.

*Image quality was graded on four-point scale (1 = poor, 2 = fair, 3 = good, and 4 = excellent).

was 100% in men and 88% in women. Sensitivity was 73% in men and 100% in women.

The positive predictive value for MAPSE ≥ 11 mm in women to predict a normal EF was 94%. Sensitivity for this cutoff value was 92%. The positive predictive value for MAPSE ≥ 13 mm in men to predict a normal EF was 94%. The sensitivity of this cutoff value was the same as the value for women, 92%.

For each patient in the verification cohort, a ΔEF value was calculated. This was determined by calculating the absolute difference between the expert-reported EF and the algorithm-predicted EF. Eighty-six percent of men and 82% of women had ΔEF values ≤ 7 (i.e., the predicted EF and expert-reported EF differed by ≤7 percentage points). Differences between predicted EFs and expert-reported EFs of ≤5 percentage points were found in 75% of men and 76% of women (Table 4).

Image quality was not statistically different between the calibration and verification cohorts (Table 2). We evaluated separately the group of patients with fair-quality or poor-quality studies to assess the effect of image quality on the accuracy of MAPSE for predicting EF. There was no significant difference between these studies and those with good or excellent quality (Table 4). Eighty-five percent of cases with poor-quality or fair-quality images had ΔEF values ≤ 7 percentage points. Seventy-four percent of cases had ΔEF values ≤ 5 percentage points. This demonstrates that student-measured MAPSE is capable of predicting EF regardless of the image quality of the study.

The interobserver variability in the MAPSE measurement was 9.5 ± 8.1%, and the intraobserver variability was 9.3 ± 6.9%.

DISCUSSION

Our results demonstrate that MAPSE values, measured by an untrained reader, are accurate predictors of left ventricular EF. We verified this in a large cohort of consecutive patients (600) with no exclusion criteria, representative of what might be seen in any busy echocardiography laboratory. This is the largest study thus far to correlate MAPSE and EF.

We created a simple algorithm for the prediction of EF on the basis of MAPSE values; high and low cutoff values were defined to help quickly determine normal and severely reduced EF. For MAPSE
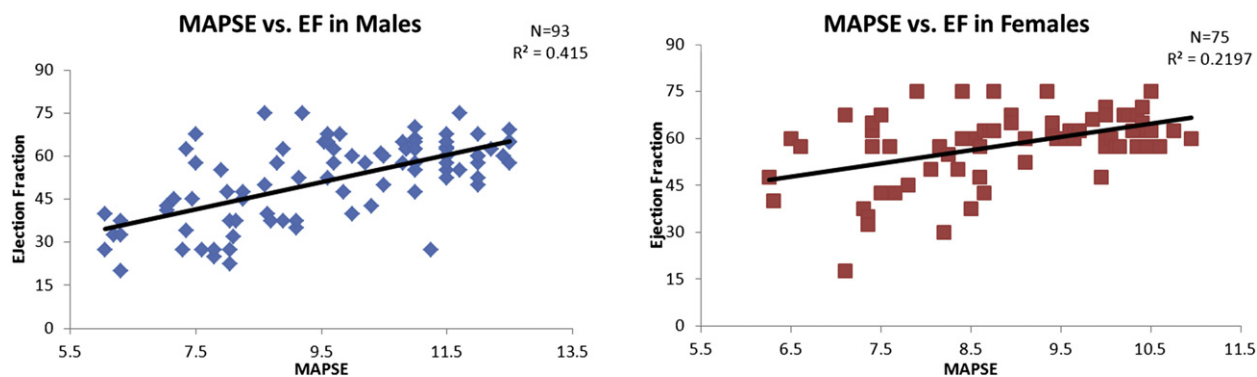
Figure 2 MAPSE correlation with EF. Scatterplots showing the correlation between MAPSE and EF, separated by gender. Included are all patients who had MAPSE values between the determined cutoff points (for men, 6–13mm; for women, 6–11 mm). (*Left*) Data for men show an *R* value of 0.644. Regression analysis provided a formula for calculating predicted EF on the basis of MAPSE as 4.8 × MAPSE (mm) + 5.8. (*Right*) Data for women show an *R* value of 0.470. Regression analysis provided a formula for calculating predicted EF on the basis of MAPSE as 4.2 × MAPSE (mm) + 20.

Table 2 Comparison of calibration and verification cohorts

Variable	Training cohort (*n* = 300)	Verification cohort (*n* = 300)	*P*
Age (y)	65.87 ± 17.4	63.86 ± 17.17	.098
Age range (y)	18–100	22–94	—
Body surface area (m²)	1.86 ± .29	1.89 ± .27	.15
Average MAPSE (mm)	10.9 ± 3.0	11.3 ± 3.06	.051
Reported EF (%)	56.8 ± 13.4	56.47 ± 13.08	.378
Average image quality*	2.82 ± .54	2.82 ± .53	.316

Data are expressed as mean ± SD. Comparison of baseline characteristic of both patient cohorts was performed to ensure consistency between the two 300-patient groups. As shown, none of these characteristics showed a statistically significant difference.

*Image quality was graded on four-point scale (1 = poor, 2 = fair, 3 = good, and 4 = excellent).

Table 3 Gender differences in MAPSE and EF in the verification cohort

Variable	Men (*n* = 159)	Women (*n* = 141)	*P*
Average MAPSE (mm)	11.4 ± 3.1	11.4 ± 3.1	.33
Reported EF (%)	54 ± 14	59 ± 12	<.001

Data are expressed as mean ± SD. Verification cohort data separated by gender; for a given MAPSE value, men had lower EFs than women. No significant difference between MAPSE values of men and women was seen, but men had significantly lower EFs (*P* < .001).

values between these cutoff numbers, gender-specific linear equations were established.

MAPSE is a simple M-mode measurement that is almost independent of image quality for its accuracy. This was demonstrated in our study: poor image quality had no effect on the accuracy or precision of our measurements. Thus, measuring MAPSE may become an alternative way to assess left ventricular function if the echocardiographic study is performed during off hours by less experienced individuals (e.g., on-call house officers) and there is no expert reader immediately available for consultation.

All MAPSE measurements done in this study were performed by a medical student with no prior training in echocardiography. The student was blinded to all echocardiographic reports until after MAPSE measurements had been performed. Estimating EF via eyeballing is an imperfect science that can take years to master. A study by Hope *et al.*[16] looked at medical students' ability to estimate EF. Trained by a "template-matching" approach, students were successfully able to estimate EF compared with MRI reading, with an *R* value of approximately 0.8. However, excluded from that study were echocardiograms that were technically difficult or had isolated wall-motion abnormalities. We believe our model complements that study very well. There is a trend toward ultrasound's becoming more widely accessible and portable, including the use of handheld miniaturized devices.[16] As such, untrained professionals

can benefit from simple objective measurements to help guide clinical decision making. Clearly, there is no way to replace a comprehensive expert echocardiographic examination with a one-dimensional measurement that is a surrogate for left ventricular EF. However, in clinical settings, sometimes a rough estimate of EF is urgently required, and we believe that having the option to accurately estimate it with such a simple method can be very valuable. In these situations, this assessment should be regarded as a preliminary result, to be followed by a complete expert evaluation of the echocardiogram.

A new finding noted in our calibration and verification cohorts was the difference in MAPSE values between men and women. In both cohorts, we found that although average MAPSE values did not differ significantly between men and women, EFs did. For a given MAPSE value, the correlating EF was higher for women than for men. Otherwise stated, for a given EF, women had lower MAPSE values than men. No study to date has been published that evaluated gender specifically as a factor that affects the correlation between MAPSE and EF. Prior work suggested a gender difference in EF in the general population as well as in patients with certain heart conditions, for example, aortic stenosis.[17,18] Villari *et al.*[18] found that for a similar degree of aortic stenosis, women had higher EFs than men, while myocardial stiffness constant was found to be higher in men than women. In addition, previous work has shown that a larger heart size correlates with a larger MAPSE for a given EF.[15] Because women's hearts are typically smaller than men's, the mitral annulus has a shorter distance to travel toward the apex during systolic motion. This could account (at least partially) for the observed differences between men and

Table 4 Accuracy of MAPSE values from calibration cohort for predicting EF in verification cohort

Variable	Men (n = 159)	Women (n = 141)	Image quality fair or poor (n = 53)
Normal EF			
Positive predictive value	104/111 = 94%	107/114 = 94%	35/39 = 90%
Negative predictive value	39/48 = 81%	18/27 = 67%	13/14 = 93%
Sensitivity	104/113 = 92%	107/116 = 92%	35/36 = 97%
Specificity	39/46 = 85%	18/25 = 72%	13/17 = 76%
Severe EF			
Positive predictive value	11/11 = 100%	7/8 = 88%	3/3 = 100%
Negative predictive value	144/148 = 97%	133/133 = 100%	0/0
Sensitivity	11/15 = 73%	7/7 = 100%	3/3 = 100%
Specificity	144/144 = 100%	133/134 = 99%	0/0
Accuracy, ΔEF < 7	136/159 = 86%	115/141 = 82%	45/53 = 85%
Accuracy, ΔEF < 5	119/159 = 75%	107/141 = 76%	39/53 = 74%

Positive predictive value, negative predictive value, sensitivity, and specificity were calculated to determine the accuracy of the MAPSE calibration cohort cutoff values to predict normal and severely depressed EFs in the verification cohort. For intermediate MAPSE values (between the cutoffs for predicting normal and severely reduced EFs), predicted EFs were calculated on the basis of gender-specific regression equations. Differences between predicted and reported EFs were calculated as ΔEF values. Analysis was performed separately for men, women, and the group of patients with suboptimal images (image quality scores of 1 and 2), and MAPSE accuracy for predicting EF was found to be similar in all these subgroups.

women and explain why the threshold for a normal MAPSE for women should be lower than that of men.

MAPSE, in addition to being a simple surrogate for EF, may have additional implications for patient outcomes. Willenheimer et al.[14] demonstrated that among patients with heart failure, those with decreased MAPSE levels had significantly higher mortality. Previous work done on tricuspid annular systolic excursion has also shown that a simple one-dimensional measurement can predict mortality in patients with heart failure.[19] MAPSE may also detect pathology other than a depressed EF. Wenzelburger et al.[20] demonstrated that MAPSE values are decreased in patients with heart failure with preserved EF versus normal controls.

Future work should be done in large patient populations to assess the correlation between serial MAPSE measurements and patient outcomes. A decrease in MAPSE may be a predictor of heart pathology and may aid in patients' risk stratification by an easily measured, bedside echocardiographic parameter.

Limitations

We examined the accuracy of student-measured MAPSE for predicting left ventricular EF. We compared the MAPSE-predicted EF with 2D-based expert-reported EF. We did not compare MAPSE with a non-echocardiography-based technique (i.e., cardiac MRI). Because our study sample was so large, it was not feasible to perform an extra imaging modality in all patients included. Although visual estimation of EF may be subjective and prone to interobserver and intraobserver variability, previous studies have shown that when performed by experienced echocardiographers, it is quite accurate compared with other techniques.[21] Furthermore, the goal of our study was to define a simple echocardiographic method that can be used (even by inexperienced observers) for a quick estimation of global EF, not to replace other, more sophisticated techniques.

We did not attempt to examine the effect of specific disease entities on MAPSE measurements. For example, localized wall motion abnormalities due to coronary artery disease, significant mitral annular calcifications, prosthetic valves, and more can definitely affect MAPSE values, irrespective of global EF. Although assessing all these issues is an important task of echocardiography, often there is urgent clinical need to obtain assessment of global EF to guide acute management decisions. As such, MAPSE may be very helpful in urgent, off-hours clinical decision making.

CONCLUSIONS

Our work has determined that MAPSE, measured by an untrained observer, is a viable surrogate for expert determined left ventricular EF. Our findings suggest that gender significantly affects this correlation. We have established upper and lower thresholds for normal and severely reduced EFs for each gender and a simple gender-specific equation to calculate EF from intermediate MAPSE values. We believe that MAPSE should be routinely acquired in all echocardiographic studies and used as a surrogate for global left ventricular EF.

REFERENCES

1. Feigenbaum H, Zaky A, Nasser WK. Use of ultrasound to measure left ventricular stroke volume. Circulation 1967;35:1092-9.
2. Johri AM, Picard MH, Newell J, Marshall JE, King ME, Hung J. Can a teaching intervention reduce interobserver variability in LVEF assessment: a quality control exercise in the echocardiography lab. JACC Cardiovasc Imaging 2011;4:821-9.
3. Jones CJH, Raposo L, Gibson DG. Functional importance of the long axis dynamics of the human left ventricle. Br Heart J 1990;63:215-20.
4. Keren G, Sonnenblick E, Le Jemtel T. Mitral annulus motion: relation to pulmonary venous and transmitral flows in normal subjects and in patients with dilated cardiomyopathy. Circulation 1988;78:621-9.
5. Zaky A, Grabhorn L, Feigenbaum H. Movement of the mitral ring: a study in ultrasoundcardiography. Cardiovasc Res 1967;1:121-31.
6. Simonson JS, Schiller NB. Descent of the base of the left ventricle: an echocardiographic index of left ventricular function. J Am Soc Echocardiogr 1989;2:25-35.
7. Alam M, Hoglund C, Thorstrand C, Philip A. Atrioventricular plane displacement in severe congestive heart failure following dilated cardiomyopathy or myocardial infarction. J Intern Med 1990;228:569-75.
8. Alam M, Thorstrand C. Effects of acute myocardial infarction on the displacement of the atrioventricular plane: an echocardiographic study. J Intern Med 1989;226:251-6.

9. Elnoamany MF, Abdelhameed AK. Mitral annular motion as a surrogate for left ventricular function: correlation with brain natiuretic peptide levels. Eur J Echocardiogr 2006;7:187-98.

10. Qin JX, Shiota T, Tsujino H, Saracino G, White RD, Greenberg NL, et al. Mitral annular motion as a surrogate for left ventricular ejection fraction: real-time three-dimensional echocardiography and magnetic resonance imaging studies. Eur J Echocardiogr 2004;5:407-15.

11. Soeki T, Fukuda H, Shinohara H, Sakabe K, Onose Y, Sawada Y, Tamura Y. Mitral inflow and mitral annular motion velocities in patients with mitral annular calcification: evaluation by pulsed Doppler echocardiography and pulsed Doppler tissue imaging. Eur J Echocardiogr 2002;3:128-34.

12. Tsang W, Ahmad H, Patel AR, Sugeng L, Salgo IS, Weinert L, et al. Rapid estimation of left ventricular function using echocardiographic speckle-tracking of mitral annular displacement. J Am Soc Echocardiogr 2010;23: 511-5.

13. Alam M. The atrioventricular plane displacement as a means of evaluating left ventricular systolic function in acute myocardial infarction. Clin Cardiol 1991;14:588-94.

14. Willenheimer R, Cline C, Erhardt L, Israelsson B. Left ventricular atrioventricular plane displacement: an echocardiographic technique for rapid assessment of prognosis in heart failure. Heart 1997;78:230-6.

15. Emilsson K, Wandt B. The relation between mitral annulus motion and ejection fraction changes with age and heart size. Clin Physiol 2000;20:38-43.

16. Hope MD, de la Pena E, Yang PC, Liang DH, McConnell MV, Rosenthal DN. A visual approach for the accurate determination of echocardiographic left ventricular ejection fraction by medical students. J Am Soc Echocardiogr 2003;16:824-31.

17. Chung AK, Das SR, Leonard D, Peshock RM, Kazi F, Abdullah SM, et al. Women have higher left ventricular ejection fractions than men independent of differences in left ventricular volume: the Dallas Heart Study. Circulation 2006;113:1597-604.

18. Villari B, Campbell SE, Schneider J, Vassalli G, Chiariello M, Hess OM. Sex-dependent differences in left ventricular function and structure in chronic pressure overload. Eur Heart J 1995;16:1410-9.

19. Ghio S, Recusani F, Klersy C, Sebastiani R, Laudisa ML, Campana C, et al. Prognostic usefulness of the tricuspid annular plane systolic excursion in patients with congestive heart failure secondary to idiopathic or ischemic dilated cardiomyopathy. Am J Cardiol 2000;85:837-42.

20. Wenzelburger FWG, Tan YT, Choudhary FJ, Lee ES, Leyva F, Sanderson JE. Mitral annular plane systolic excursion on exercise: a simple diagnostic tool for heart failure with preserved ejection fraction. Eur J Heart Fail 2011;13:953-60.

21. Gudmundsson P, Rydberg E, Winter R, Willenheimer R. Visually estimated left ventricular ejection fraction by echocardiography is closely correlated with formal quantitative methods. Int J Cardiol 2005;101: 209-12.