

# Clinical implication of mitral annular plane systolic excursion for patients with cardiovascular disease

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Mitral annular plane systolic excursion (MAPSE) has been suggested as a parameter for left ventricular (LV) function. This review describes the current clinical application and potential implications of routinely using MAPSE in patients with various cardiovascular diseases. Reduced MAPSE reflects impaired longitudinal function and thus provides complementary information to ejection fraction (EF), which represents the global result of both longitudinal and circumferential contraction. Reduced long-axis deformation results from dysfunctional or stressed longitudinal myofibres due to endo- (and potentially epi-) cardiac ischaemia, fibrosis, or increased wall stress. In patients with aortic stenosis, reduced MAPSE is suggestive of subendocardial fibrosis. Moreover, reduced MAPSE could be used as a sensitive early marker of LV systolic dysfunction in hypertensive patients with normal EF, where compensatory increased circumferential deformation might mask the reduced longitudinal deformation. In addition, reduced MAPSE was associated with poor prognosis in patients with heart failure, atrial fibrillation and post-myocardial infarction as well as in patients with severe aortic stenosis undergoing aortic valve replacement. Despite of the routine use of newer and more refined echocardiographic technologies nowadays, such as strain-rate imaging, speckle-tracking imaging, and 3D echocardiography, the use of MAPSE measurement is still especially helpful to evaluate LV systolic function in case of poor sonographic windows, since good imaging quality is required for most of the modern echocardiographic techniques with the exception of tissue Doppler imaging.

## Keywords

Mitral annular plane systolic excursion • Clinical implication

## Introduction

Left ventricular (LV) longitudinal shortening plays an important role in cardiac pump function<sup>1,2</sup> and can be evaluated by measuring long-axis, M-mode-derived, mitral annular plane systolic excursion (MAPSE),<sup>3</sup> also referred to as mitral annulus excursion (MAE), mitral annulus motion, left atrioventricular plane displacement, or mitral ring displacement. Nowadays, newer and more refined echocardiographic technologies, such as strain-rate imaging, tissue Doppler imaging (TDI) and three-dimensional echocardiography are used for interrogating LV function. Although good imaging quality is required for most of the modern echocardiographic techniques for reasonable interpretation of LV systolic function, TDI and MAPSE are measurable in the majority of patients quiet independent

of imaging quality. Thus, use of MAPSE and TDI measurement is still helpful to evaluate LV systolic function in case of poor sonographic windows. MAPSE has been proposed as a well-established clinically useful echocardiographic parameter for the assessment of LV longitudinal function and correlates with global systolic function of the LV.<sup>4,5</sup> Previous clinical studies showed that, MAPSE, which reflects the mitral ring displacement at systole, can be used to assess cardiac global longitudinal function and is a sensitive parameter to define slight abnormalities in various patients with cardiovascular diseases at early stage where longitudinal function is affected before other components (which can even be increased in compensation).<sup>3,6–9</sup> The goal of this review is to summarize the current clinical applications of MAPSE in the context of different cardiovascular pathologies.

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## Measurement of MAPSE

Mitral annular displacement should be measured by the use of M-mode echocardiography in an apical view (Figure 1). Since the apex of the LV remains almost immobile, LV longitudinal pump function is mainly generated via the atrioventricular plane motion towards the apex.<sup>10</sup> Contraction of LV longitudinal fibres during cardiac systole results mainly in the atrioventricular plane movement towards the apex.<sup>10,11</sup>

MAPSE could be measured from four sites of the atrioventricular plane corresponding to the septal, lateral, anterior, and posterior walls using the apical four- and two-chamber views by M-mode echocardiography. In normal hearts, usually the values of lateral MAPSE are somewhat higher than septal MAPSE.<sup>12</sup> The M-mode cursor should always be aligned parallel to the LV walls. The systolic excursion of mitral annulus should be measured from the lowest point at end-diastole to aortic valve closure (end of the T-wave on the electrocardiogram) (Figure 2). The post-systolic motion towards the apex during the isovolumetric relaxation period, which is sometimes linked with ischaemia, fibrosis, or pressure overload,<sup>13</sup> should not be included in the measurement. In general, MAPSE should be extracted from the septal and lateral mitral annulus.

## MAPSE and ejection fraction

MAPSE represents the amount of displacement of the mitral annular plane towards the apex and thus assesses the global change in size of the LV cavity (in the long-axis direction). Thus, it can be interpreted as the volume change during ejection and

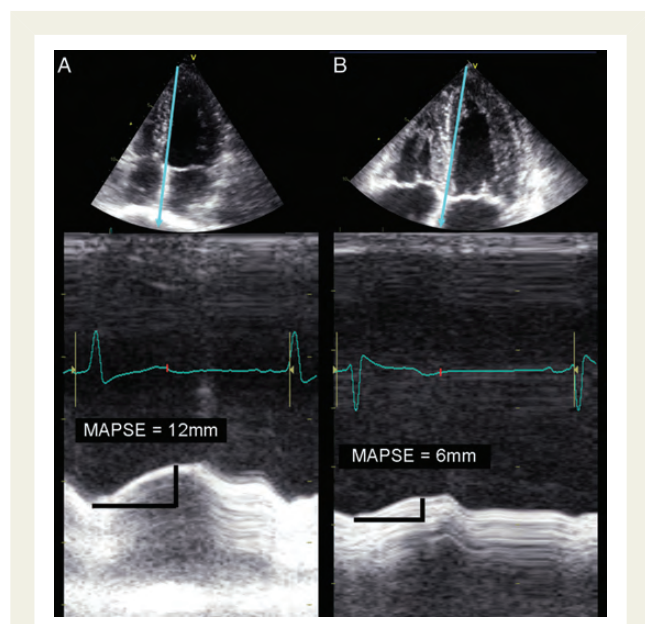
therefore a close association between the long-axis shortening and ejection fraction (EF) has been suggested in different patient groups with normal or reduced LV function.<sup>3,6,8,9,11,14–18</sup> The average normal value of MAPSE derived from previous studies for the four annular regions (septal, anterior, lateral, and posterior) ranged between 12 and 15 mm<sup>3,14</sup> and a value of MAPSE <8 mm was associated with a depressed LV EF (<50%) with a specificity of 82% and a sensitivity of 98%.<sup>3</sup> A mean value for MAPSE of  $\geq 10$  mm was linked with preserved EF ( $\geq 55\%$ ) with a sensitivity of 90–92% and a specificity of 87%.<sup>16,19</sup> In addition, a mean value for MAPSE of <7 mm could be used to detect an EF <30% with a sensitivity of 92% and a specificity of 67% in dilated cardiomyopathy patients with severe congestive heart failure.<sup>14</sup>

It is of note that the association between MAPSE and EF is only valid in case of normal or dilated left ventricles,<sup>20,21</sup> while the correlation is rather poor in patients with LV hypertrophy.<sup>22</sup> Thus, a reduced MAPSE was documented in patients with concentric hypertrophy despite normal EF and fractional shortening.<sup>23</sup> This is because in hypertrophic myocardium, longitudinal function is usually already reduced while radial function (being responsible for EF) is still preserved or even increased. Moreover, with increasing age, it was shown that EF remained unchanged or slightly increased while MAPSE was reduced.<sup>24,25</sup>

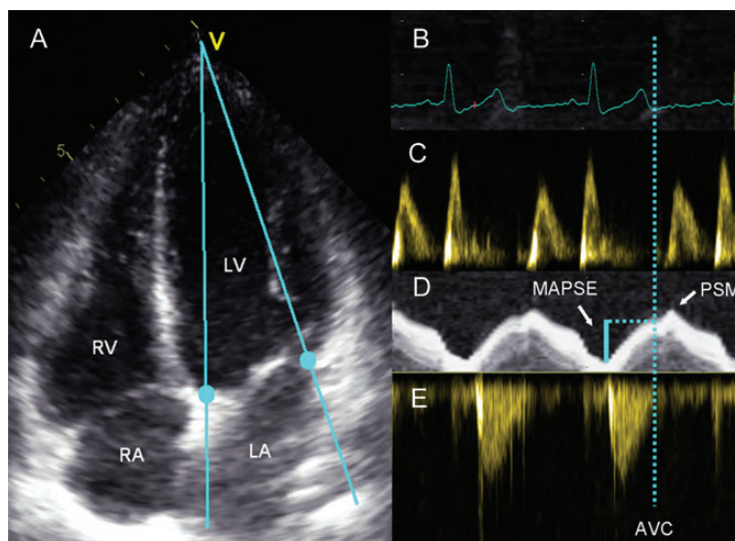
Histological studies revealed the complexity of myocardial fibre orientation with longitudinal and circumferential fibres with a continuous variation in fibre angulations across the LV wall in humans.<sup>26,27</sup> Cardiac pump function is the result of the contraction of all of these fibres. Basically, MAPSE is the result of the contraction of the (subendocardial and subepicardial) longitudinal fibres,<sup>28</sup> and represents the total longitudinal shortening within one wall. In contrast, and depending on how it is assessed, EF reflects function in the radial/circumferential direction (when using the Teichholz formula from a parasternal long-axis view) or represents the result of all components (when measured using a Simpson's approach) but never specifically assesses longitudinal function. It is known that in various cardiac pathologies, longitudinal function is already altered before radial/circumferential indices change.<sup>23</sup> MAPSE could be used as a simple and sensitive echocardiographic index to assess myocardial abnormalities involving predominantly longitudinal changes, especially in early disease stages. Additionally, Willenheimer et al.<sup>17</sup> found that patients with advanced LV diastolic filling abnormalities had lower MAPSE than patients with preserved diastolic filling despite similar fractional shortening, and suggested MAPSE could as well reflect LV diastolic function. However, this abnormal MAPSE in patients with diastolic abnormalities is most likely related to the reduced systolic function since diastolic and systolic function is intimately interlinked.

## MAPSE and tissue Doppler imaging

Tissue Doppler imaging enables measurements of atrioventricular annular and regional myocardial velocities, and may be more sensitive than conventional echocardiography in detecting abnormalities of LV systolic and diastolic function.<sup>29</sup> Unlike M-mode



**Figure 1** Examples of normal and reduced septal mitral annular plane systolic excursion (MAPSE) by M-mode images. (A) A normal subject with normal MAPSE. (B) A patient with reduced MAPSE.



**Figure 2** Example for correct measurement of mitral annular plane systolic excursion (MAPSE). (A) MAPSE is measured by M-mode echocardiography in apical four-chamber view; (B) electrocardiography; (C) pulsed Doppler recording of mitral inflow; (D) MAPSE. Note that the MAPSE should be measured from the lowest point to the highest point during systole. The post-systolic motion (PSM) towards the apex during the isovolumetric relaxation period should not be included in the measurement. (E) Pulsed Doppler recording of aortic outflow. AVC, aortic valve closure.

echocardiography, DTI allows not only the calculation of amplitude, but also the systolic ( $S_m$ ) and diastolic velocity ( $E_m$ ) and acceleration of mitral annular motion.<sup>30</sup> Strong negative correlation was found between brain natriuretic peptide (BNP) and  $S_m$  ( $r = -0.7$ ,  $P < 0.001$ ), and significant negative correlation was observed between BNP and MAPSE ( $r = -0.54$ ,  $P < 0.001$ ).<sup>31</sup> Two previous studies showed that there was a close correlation between systolic annular displacement directly measured by M-mode and that indirectly estimated by temporal integration of velocities measured by either pulsed tissue Doppler or colour Doppler in healthy subjects.<sup>32,33</sup> Another recent study showed that  $S_m$  significantly correlated with MAPSE both at rest and during exercise in heart failure patients with preserved LVEF.<sup>34</sup>

## MAPSE and deformation by strain

Strain was introduced as an approach for measuring myocardial deformation in 1973.<sup>35</sup> Regional strain of the left ventricle can be quantified using both Doppler based and speckle-tracking-based technique.<sup>36–40</sup> Myocardial strain contains three main components directionally: longitudinal, circumferential, and radial strain.<sup>41</sup> The total LV systolic shortening relative to LV length can represent global systolic longitudinal strain of the interrogated wall. MAPSE can be used to assess global longitudinal wall function, but is not suitable for regional myocardial functional assessment which can only be quantified by strain-rate imaging. Longitudinal strain assessment using 2D speckle tracking offers angle-independent measurements which are normalized to cardiac length, can distinguish between myocyte tethering and true systolic shortening, and is useful for regional as well as global ventricular assessment.<sup>18</sup> Both longitudinal deformation by global strain and by MAPSE correlated well with

myocardial infarct size and could discriminate between different extents of myocardial infarctions.<sup>42</sup> In addition, Tsang *et al.*<sup>43</sup> recently propose that speckle-tracking-derived mitral annular displacement is a clinically useful tool for rapid, accurate, and robust estimates of LVEF irrespective of LV endocardial definition. A good correlation between MAPSE and longitudinal strain at rest has also been shown in heart failure patients with normal or preserved LVEF.<sup>34</sup> A full longitudinal LV speckle-tracking study is only slightly more time consuming than bi-annular MAPSE, and the resultant bulls-eye display readily details of both global and regional longitudinal function, which makes it a more attractive choice in many cases. However, good imaging quality is an essential prerequisite for LV speckle-tracking study, while in case of poor imaging quality, MAPSE could still be a suitable choice for assessing longitudinal systolic function. It is of note that MAPSE reflects the total shortening of the ventricular wall, and is thus a measurement of global longitudinal function. If MAPSE is divided by the end-diastolic length of the ventricular wall, it theoretically gives a measurement of the regional deformation (strain) of the wall. MAPSE and deformation (strain and strain rate) both should also be normalized for heart size.<sup>44,45</sup> The major differences between MAPSE and deformation imaging are as follows: first, MAPSE is a parameter of motion (displacement and velocity) which reflects global function. Deformation imaging (strain and strain rate) is able to extract regional myocardial function being independent of motion due to the effects of tethering from neighbouring segments.<sup>46</sup> Therefore, deformation imaging can show the true extent of pathology and regional function within the myocardium. In contrast, MAPSE is less dependent on image quality, whereas good image quality is essential for correct determination of deformation values derived from strain-rate imaging and speckle-tracking techniques.

# MAPSE and three-dimensional echocardiograph

The recently developed three-dimensional (3D) echocardiography has already provided important insight regarding the normal saddle-like mitral annular conformation. Little *et al.*<sup>47</sup> used 3D tracking software to identify 16 circumferential equidistant mitral annular points and to track changes in mitral annular area and apical descent from end-diastole to end-systole in patients with mitral regurgitation (MR). 3D echocardiography with mitral annular tracking demonstrated important differences in annular function between functional MR and prolapse MR, and these differences may have implications for surgical repair. Though the LV systolic function could be fairly analysed by this novel modality, it should be mentioned that they are mostly not easy to be performed in patients with bad imaging. Table 1 summarizes the advantages and disadvantages of MAPSE, tissue velocity, and strain techniques on assessing LV function.

## Clinical applications

### Hypertensive heart disease

Total longitudinal systolic excursion in both the LV lateral wall and the interventricular septum were significantly reduced in treated hypertensive patients with normal EF and fractional shortening

with or without LV hypertrophy (Figure 3).<sup>48</sup> The possible mechanism of longitudinal dysfunction in hypertensive patients might be associated with the microcirculatory disturbances in the subendocardium of the left ventricle, resulting in a reduction of longitudinal myocardial contraction force<sup>49,50</sup> and subsequently reduction of MAPSE. Additionally, the larger radius of curvature of the longitudinally directed fibres results in a disproportionate increase in their stress with increasing cavity pressure<sup>51,52</sup> and therefore additionally decreases longitudinal deformation.

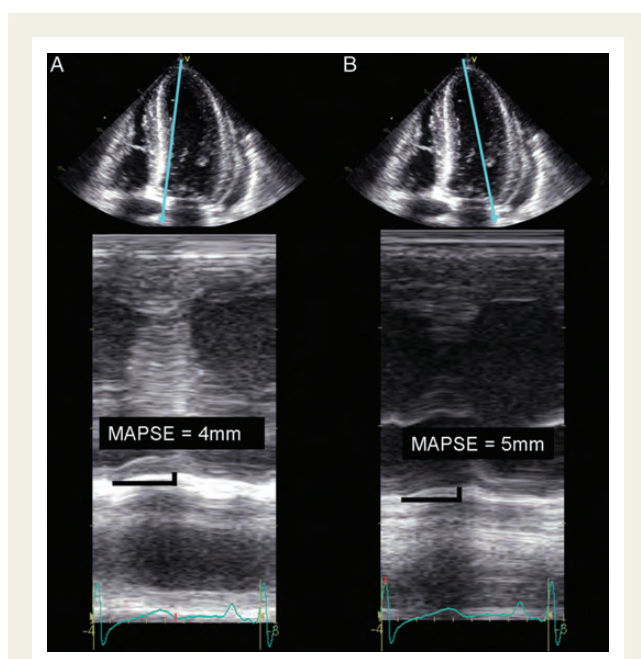
Therefore, the impairment in the contractile function of LV longitudinal fibres may substantially precede that of LV circumferential fibres in patients with hypertension because of LV hypertrophy, geometry, and wall stress.<sup>5</sup> This might explain the ‘early’ reduced longitudinal function (= MAPSE) in contrast to the long time preserved circumferential and radial function (= EF). Thus, reduced MAPSE can be used as a sensitive early marker of LV systolic dysfunction in hypertensive patients.<sup>48</sup>

### Coronary artery disease

Alam *et al.* observed an association between MAPSE and LV systolic function in 37 patients with first-time acute myocardial infarction (AMI). They showed a decreased MAPSE in AMI patients compared with controls and a more pronounced reduction at the sites of infarction. Moreover, a close correlation was found in patients with coronary artery disease between LV wall motion index and MAPSE.<sup>53</sup> A study of 159 consecutive patients, with

**Table 1** Advantages and disadvantages comparison of MAPSE, tissue velocity, and strain techniques

	MAPSE	Tissue velocity	Strain
Technique	M-mode	Tissue Doppler imaging	Strain-rate imaging derived from 2D/3D speckle-tracking imaging
Advantages	Measure mitral annular displacement	Measure mitral annular motion velocity	Measure myocardial deformation
	Assess global longitudinal function	Assess global longitudinal function and ventricular synchrony	Assess regional and global longitudinal/radial/circumferential function, rotation/torsion, and ventricular synchrony
	Less dependent on 2D imaging quality	Less dependent on 2D imaging quality	Less angle dependent
	Good correlation with left ventricular ejection fraction	Good correlation with left ventricular ejection fraction	Assess regional and multiple directional function
	Easy to apply	Easy to apply	Good correlation with left ventricular ejection fraction
Disadvantages	High temporal resolution	High temporal resolution	
	Good reproducibility	Good reproducibility	
	Pre- and afterload dependent	Pre- and afterload dependent	Pre- and afterload dependent
	Angle dependent	Angle dependent	2D imaging quality dependent
	Unable to detect regional myocardial abnormalities	Unable to detect regional myocardial abnormalities	Prone to stationary artifacts error (such as reverberations)
	Variation due to cardiac size (especially in children)	Confounding influence of ventricular translational, rotational movement, and tethering effect from the adjacent segment	Depend on frame rate of the cine-loop (40–80 frame per second)
	Influenced by mobile apex (in case of moderate/large pericardial effusion)		Relatively time consuming
			Analyser experience-dependent



**Figure 3** Reduced septal and lateral mitral annular plane systolic excursion (MAPSE) in a 45-year-old male hypertensive patient with left ventricular hypertrophy and preserved left ventricular ejection fraction. Septum and posterior wall thickness was 18 mm; ejection fraction was 56%; septal and lateral MAPSE were both significantly reduced.

significant stenosis at coronary angiography, also showed that MAPSE was significantly decreased compared with controls, and was further decreased with increasing extent of coronary atherosclerosis.<sup>54</sup> However, MAPSE could not be used to identify regions of hypoperfusion due to coronary stenosis.<sup>54</sup> Willenheimer *et al.*<sup>55</sup> demonstrated that MAPSE was reduced in 88 out of 1350 consecutive patients with visual evaluated normal LV regional wall motion and these patients with reduced MAPSE had either prior myocardial infarction (60%) or coronary artery disease without infarction (33%), or uncontrolled hypertension (2%) while definitive evidence for cardiovascular diseases was absent in only 4% patients with reduced MAPSE. This suggests that decreased MAPSE, in the case of normal LV regional wall motion, could serve as a echocardiographic functional sign for myocardial abnormalities, predominantly indicating subendocardial dysfunction.<sup>55</sup>

## Aortic stenosis

In patients with aortic stenosis (AS), MAPSE is reduced even in the presence of normal LV fractional shortening or EF.<sup>56–59</sup> It is lower in patients with symptomatic, compared with asymptomatic, severe AS and may be of use in predicting the onset of symptoms.<sup>59</sup> Another study by Rydberg *et al.*<sup>58</sup> suggested that reduced MAPSE, but not LVEF, is an independent predictor for the degree of AS. MAPSE could therefore be used as an earlier and more sensitive marker than LVEF in patients with AS.<sup>57–59</sup> In line with the above findings, we showed that during clinical assessment

of the patient with severe AS, MAPSE emerged as a marker of structural abnormalities and a useful surrogate of myocardial fibrosis. The amount of myocardial fibrosis is closely associated with the long-term outcome of patients receiving aortic valve replacement operation. MAPSE could be used as a predictor of long-term prognosis for patients receiving aortic valve replacement operation and MAPSE >7 mm is linked with satisfactory functional improvement after aortic valve replacement.

In the clinical setting, it is sometimes difficult to distinguish between moderate AS with low gradient and severe AS with low gradient due to reduced stroke volume. A recent study found that MAPSE was useful to distinguish between these two entities.<sup>57</sup> In patients with an isolated low-gradient AS, a cut-off value of MAPSE <9 mm had an excellent sensitivity (100%) and specificity (100%) to distinguish between moderate and severe AS (Figure 4).<sup>57</sup>

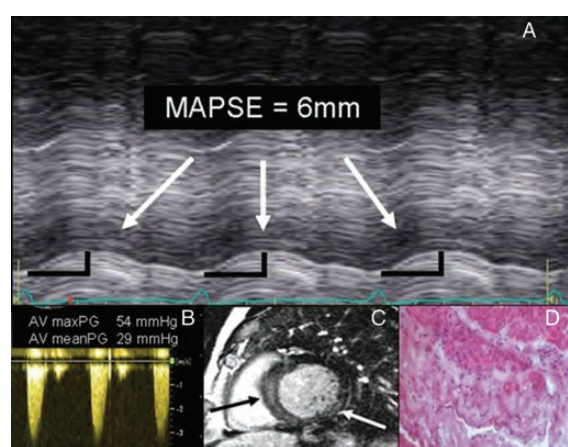
The underlying patho-mechanism for the significant reduction of MAPSE in patients with symptomatic severe AS is multifactorial. In patients with symptomatic severe AS, wall stress is significantly increased and increased wall stress results in decreased deformation and could also result in subendocardial ischaemia and later evolve to fibrosis. These changes are closely related to subendocardial longitudinal fibres function, which could be detected as a reduction of MAPSE. Additionally, although the increased afterload is offset by the development of concentric LV hypertrophy in AS,<sup>60</sup> the decrease of MAPSE in relation to the degree of aortic valve obstruction is independent of LV hypertrophy, suggesting a direct relation with the increased intraventricular pressure resulting from AS.<sup>58</sup>

## Chronic heart failure

Patients with chronic heart failure following dilated cardiomyopathy or myocardial infarction showed a significant reduction of MAPSE and there was a good correlation between MAPSE and EF.<sup>14</sup> Furthermore, MAPSE significantly correlated with Doppler variables of LV diastolic filling, especially deceleration time of early filling, indicating that a reduction in MAPSE may be a result of impaired LV filling, systolic dysfunction, or both.<sup>17</sup> MAPSE has recently been described as a useful and easily acquired measurement, especially on exercise, for the diagnosis of heart failure patients with preserved EF. In these patients MAPSE value correlated well with systolic mitral annular velocity, longitudinal strain, and LVEF.<sup>34</sup>

## Implication for prognosis and therapy

MAPSE is of prognostic importance in the risk stratification for patients with atrial fibrillation,<sup>61</sup> patients post-myocardial infarction,<sup>62</sup> and patients with heart failure.<sup>15,63,64</sup> Cardiac mortality was 44% in atrial fibrillation patients with an MAPSE <7 mm during 45 months follow-up.<sup>61</sup> In post-myocardial infarction patients with MAPSE <8 mm, the combined mortality/hospitalization incidence was 43.8%.<sup>62</sup> Sveälv *et al.*<sup>64</sup> showed that 10 years survival was significantly better in heart failure patients with highest MAPSE (>9 mm) than in heart failure patients with the

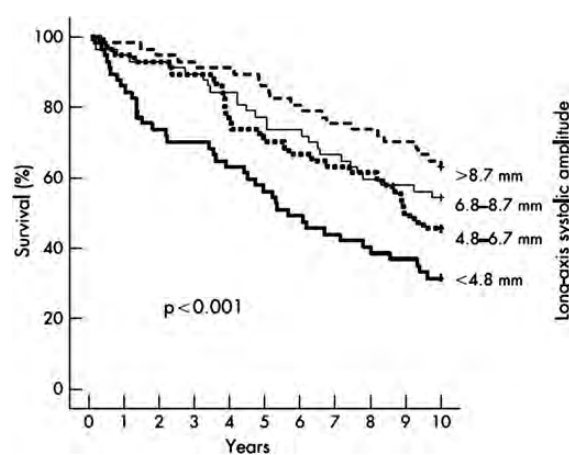


**Figure 4** Reduced mitral annular plane systolic excursion (MAPSE) in a patient with low-gradient aortic stenosis. A 78-year-old woman (ejection fraction >50%) presented with diastolic septal and posterior wall thickness of 13 mm, aortic valve area of 0.9 cm<sup>2</sup>. MAPSE (= 6 mm) was markedly reduced (A). Peak and mean transvalvular gradient were 54 and 29 mmHg, respectively (B). Typical basal septal and lateral late-enhancement on cardiac magnetic resonance imaging indicated myocardial replacement fibrosis (C). An endocardial biopsy showed large areas of fibrosis (D). AV maxPG = peak aortic gradient (mmHg); AV meanPG = mean aortic gradient (mmHg).

lowest MAPSE (<5 mm) (Figure 5). Interestingly, significant correlation was found between serum BNP levels and MAPSE ( $r = -0.54$ ,  $P < 0.001$ ).<sup>31</sup>

After mitral valve repair, both tissue Doppler peak systolic annular velocity and MAPSE increased, while EF decreased. Thus, assessment of the velocity and the amplitude of LV long-axis motion by echocardiography is more sensitive than simple determination of LVEF for revealing the beneficial impact of mitral valve surgery on overall systolic function.<sup>65</sup> In a recent work, Kempny *et al.*<sup>66</sup> reported that longitudinal LV 2D strain is superior to EF in predicting myocardial recovery and symptomatic improvement after aortic valve implantation.

MAPSE could also be used to monitor the efficiency of thrombolytic agent in patients with AMI. An improvement in both global and regional myocardial function assessed by the changes of MAPSE following AMI was documented in patients with anterior AMI with successful thrombolytic therapy.<sup>67</sup> MAPSE might be used as a solid surrogate for observing therapy effects on LV systolic function. Palazzuoli *et al.*<sup>68</sup> showed that MAPSE and LVEF were significantly increased while B-type natriuretic peptide and hospitalization rate were significantly reduced after 4–12 months of beta-erythropoietin therapy in patients with chronic heart failure and anaemia. In another observation, Parissis *et al.*<sup>69</sup> demonstrated that recombinant human erythropoietin analogue darbepoetin alpha combined with oral iron significantly improved LV systolic function (improvements on LVEF, MAPSE, New York Heart Association class, 6-min walk test) and reduced plasma BNP in patients with chronic heart failure and anaemia.



**Figure 5** Survival curves of patients with heart failure are displayed for each quartile of left ventricular long-axis systolic function. There was an overall difference between the curves as assessed by the log-rank test ( $P < 0.001$ ). Survival between quartiles was estimated by Cox regression analysis, the fourth quartile being the reference. Q1: <4.8 mm; Q2: 4.8–6.7 mm; Q3: 6.8–8.7 mm; Q4: >8.7 mm. (Reproduced with permission of the copyright owner.)

## Limitation of MAPSE

Some of the variations of MAPSE are due to cardiac size. Theoretically, this means that the annular displacement should be normalized for heart size. This is definitely necessary in children, where the variation in cardiac size is great. The interpretation of MAPSE should be carefully applied in case of a mobile apex, such as large pericardial effusion. Also in patients with paradox septal motion, because of severe right heart dysfunction, septal MAPSE is not only reflecting LV function but rather RV abnormalities. Thus in these patients, the lateral MAPSE should be used. It is to be mentioned that MAPSE, as opposed to global longitudinal systolic strain assessment, cannot detect regional areas of dysfunction.

After cardiac surgery, septal MAPSE, together with RV function, might be more reduced compared with lateral MAPSE.

Sometimes in patients with mitral valve disease, the mitral ring is extremely calcified. In these patients, the direct MAPSE measurement at the mitral ring is not possible and longitudinal functional assessment should be done slightly more above in the myocardium.

Another limitation of this parameter is that small localized abnormalities (i.e. small areas of fibrosis) cannot be detected as it is only possible to assess longitudinal function of the complete wall.

## Conclusions

In summary, MAPSE, reflecting longitudinal myocardial shortening, is a simple and sensitive echocardiographic parameter for assessing global longitudinal LV wall function. Reduced MAPSE is mostly related to subendocardial ischaemia or to fibrosis in some extent. This parameter seems to be much more sensitive, compared with global EF, for detecting early abnormalities, especially

useful in patients with poor imaging qualities. Reduced MAPSE is also related to poor outcome in patients with various cardiovascular diseases. Despite the routine use of newer and more refined echocardiographic technologies, MAPSE measurement is still helpful to evaluate LV systolic function during daily routine echocardiography in case of poor sonographic windows as this measurement demands very little of image quality on account of the high echogenicity in the atrioventricular annulus while most advanced echocardiographic techniques (except TDI) require very good image quality.

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