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Intramyocardial Pulsed Doppler Echocardiography as a New Modality for Evaluation of Left Ventricular Wall Motion : Assessment in Normal Subjects

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Abstract

Doppler tissue imaging-guided pulsed Doppler echocardiography can record velocities of the regional ventricular wall, but the potential clinical applications have not yet been investigated. To propose a new modality for assessment of left ventricular wall dynamics, we investigated the longitudinal and latitudinal motions of the normal left ventricular wall with intramyocardial pulsed Doppler echocardiography under tissue imaging guidance, and characterized the velocity patterns in 31 normal subjects or normal volunteers (mean age 38 ± 18 years old).

Velocity patterns of the septal and posterior walls were recorded and compared using the parasternal and apical approaches. The apical approach showed that the entire left ventricle moved, coded in red, toward the transducer during systole, and moved away, coded in blue, during diastole. Pulsed Doppler echocardiography recorded the systolic S, early diastolic E and presystolic A waves from both windows. All three waves had higher velocities in the apical compared to the parasternal approach, and the velocities of S and E waves were increased more in the posterior wall than in the septum. Thus, the A/E ratio was significantly lower in the posterior compared to the septal wall (0.63 ± 0.3 and 0.77 ± 0.3, respectively, in the apical approach) and the A/E ratio of transmitral inflow was between those of the walls.

Apical intramyocardial pulsed Doppler echocardiography can accurately evaluate septal and posterior wall dynamics. The present study provides important basic data for assessing regional myocardial function.

Key Words

Doppler ultrasound (tissue imaging), Ultrasonic diagnosis (intramyocardial pulsed Doppler), Echocardiography (wall motion velocity), Diastole (relaxation)

INTRODUCTION

Doppler tissue imaging is a new technology that was developed to avoid Doppler signals from blood flow, and to provide a velocity map of myocardial motion[1,2]. Doppler tissue imaging-guided intramyocardial pulsed Doppler echocardiography has the potential for accurate measurement of localized wall motion velocities. However, clinical application of this method has not been fully studied. Recently, Garcia *et al.* recorded ventricular wall motion velocities parasternally in normal subjects[3]. In the previous report[4], we determined the velocities of several points of the normal left ventricular wall

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Selected abbreviations and acronyms

LV=left ventricle
MV=mitral valve
PW=posterior wall
VS=ventricular septum

with intramyocardial pulsed Doppler echocardiography from the apical window. The motion of the left ventricular posterior wall or the cardiac base using conventional pulsed Doppler echocardiography has already been described[5,6].

In the present study, we analyzed the two-dimensional left ventricular wall motion with this new method from both the apical and parasternal approaches, and characterized the septal and posterior wall dynamics.

METHODS

Subject characteristics

The study group included 11 normal subjects and 20 normal volunteers employed in our hospital, with a mean age of 38±18 (standard deviation) years. Normal subjects were patients who were referred for Doppler echocardiography because of chest pain, palpitation, arrhythmia, shortness of breath, *etc.*, but were found to be normal. All patients showed sinus rhythm without electrocardiographic evidence of conduction disturbance. Patients with cardiomegaly, hypertension, ischemic heart disease or serious abnormalities in laboratory data were excluded from the study. No volunteer had a history of cardiac symptoms or disease. All were normal on physical examination.

Doppler echocardiographic examination

Echocardiography and Doppler echocardiography used an Acuson 128XP/10ART (Acuson, Inc.) interfaced with a MultiHerz transducer (2.5–4 MHz). Studies were performed with the subjects in the left lateral decubitus position. Routine examinations including mitral inflow velocities confirmed normal findings. Then Doppler tissue imaging and intramyocardial pulsed Doppler echocardiography were performed. The career frequency of the transducer was 2.5 MHz, and the sample volume was adjusted to a minimal size of 1.5 mm in depth. In this method, forward Doppler signals were encoded in red, and backward signals in blue.

First, color-coded left ventricle movement was observed throughout the cardiac cycle in the apical long-axis view, and the velocities of two positions were recorded by spectrum analysis with the sample volume at the level of the mitral valve tip of the interventricular septum and posterior wall (**Fig. 1**). The velocities at the same positions were then recorded in the parasternal long-axis view after moving the probe to the parasternal area. This level corresponds to the standard position for making M-mode echocardiographic measurements. Under the guidance of Doppler tissue imaging, sampling volumes were carefully positioned to record the highest velocities with a clearly demarcated envelope. We manipulated the probe to keep the sample volume within the myocardium throughout the cardiac cycle during recording.

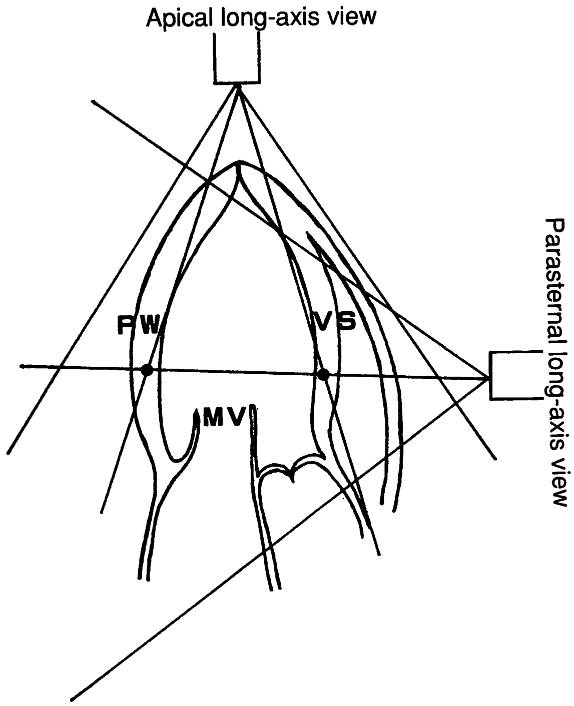

Fig. 1 Diagram showing approaches and sampling positions
Wall motion velocities were recorded at two positions of the midseptal and posterior walls from apical and parasternal windows with intramyocardial pulsed Doppler echocardiography under Doppler tissue imaging guidance.

All images were recorded on S-VHS videotape for subsequent analysis. Wall motion velocities were recorded and measured at a paper speed of 10 cm/sec by a strip chart recorder, with a simultaneous phonocardiogram. All recordings were made during expiratory apnea, and measurements were averaged over several cycles. We analyzed and compared velocity patterns both between ventricu-

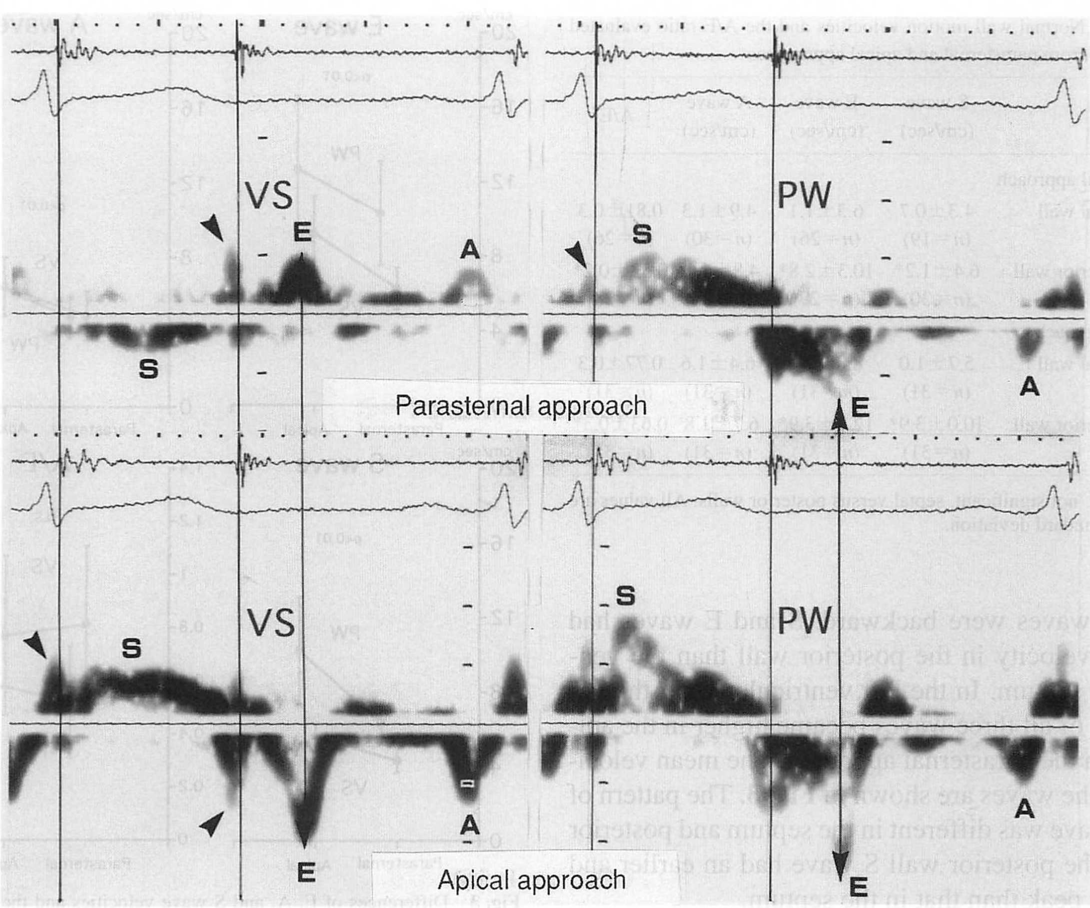

Fig. 2 Representative pulsed Doppler echocardiograms from a 27-year-old normal subject
The systolic S, early diastolic E, and presystolic A waves are shown in both ventricular walls from the apical and parasternal approaches. The patterns of the three wave velocities are basically similar. Septal and posterior walls are mirror images parasternally. Each wave becomes higher in velocity from the apical approach in each wall. The left ventricular walls move toward the apex and inward during systole, and toward the annulus and outward during diastole. Arrowheads show brief velocity components occurring just before the first heart sound and at the second heart sound.
Dot intervals are 5 cm/sec.

lar walls and mitral inflow, and between the two approaches.

Time analysis

The apexcardiogram or carotid artery pulse was also recorded simultaneously with wall motion velocities in seven subjects, and its timing was correlated with the patterns of velocities.

Statistical methods

Data are presented as mean ± standard deviation. We used the paired Student's t-test for comparisons between velocities from both approaches and septal and posterior wall velocities. Differences were considered significant at $p < 0.05$.

RESULTS

Intramyocardial pulsed Doppler findings

Intramyocardial pulsed Doppler echocardiography showed basically similar velocity patterns for both ventricular walls. The systolic S, early diastolic E and presystolic A waves were recorded in the interventricular septum and posterior wall from the apical and parasternal windows (**Fig. 2**). Parasternally, velocity patterns of the septal and posterior walls were mirror images. In the septum, three waves could not be parasternally identified in all subjects (**Table 1**) because of their lower, especially S, wave velocities.

Normal values for the three waves are shown in **Table 1**. The S wave was recorded upward, and E

Table 1 Normal wall motion velocities and the A/E ratio evaluated from parasternal and apical approaches

	S wave (cm/sec)	E wave (cm/sec)	A wave (cm/sec)	A/E
Parasternal approach				
Septal wall	4.3±0.7 (n=19)	6.3±1.1 (n=26)	4.9±1.3 (n=30)	0.81±0.3 (n=26)
Posterior wall	6.4±1.2* (n=30)	10.3±2.8* (n=29)	4.8±1.1† (n=28)	0.52±0.2* (n=28)
Apical approach				
Septal wall	5.7±1.0 (n=31)	8.8±2.0 (n=31)	6.4±1.6 (n=31)	0.77±0.3 (n=31)
Posterior wall	10.0±3.9* (n=31)	12.7±3.9* (n=31)	6.7±1.8† (n=31)	0.63±0.3* (n=31)

*$p<0.01$, †not significant, septal versus posterior walls. All values are mean±standard deviation.

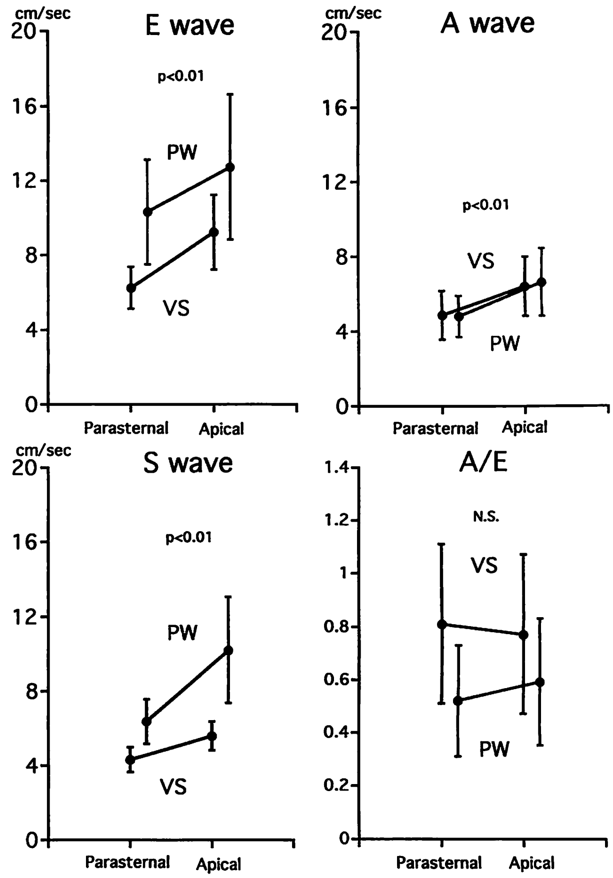

Fig. 3 Differences of E, A, and S wave velocities and the A/E ratio both between the two ventricular walls and the two approaches

Velocities of E, A and S waves became higher in the apical than the parasternal approach, but the A/E ratio was not different between the two approaches. The A/E ratio of the septum is higher than that of the posterior wall.

and A waves were backward. S and E waves had higher velocity in the posterior wall than the ventricular septum. In the left ventricular wall, the velocities of all three waves became higher in the apical than the parasternal approach. The mean velocities of the waves are shown in **Fig. 3**. The pattern of the S wave was different in the septum and posterior wall. The posterior wall S wave had an earlier and sharper peak than that in the septum.

Relationship of the A/E ratio in the ventricular wall and mitral inflow

Although the A/E ratio did not change between the approaches in each wall, it was lower in the posterior wall than the ventricular septum because of the higher E wave recorded in the former. The apical approach showed a mean A/E ratio for the mitral inflow of 0.68±0.3 (mean±standard deviation) in 31 normal subjects. This value was significantly smaller than 0.77±0.3 of the A/E ratio in the ventricular septum and larger than 0.63±0.3 of A/E ratio in the posterior wall (**Figs. 4, 5**).

Time analysis of brief velocity components

Just before the first heart sound and at the timing of the second heart sound, sharp and brief deflections were recorded at both walls, more clearly from the apical approach (arrowheads in **Figs. 2, 6**). The first component was observed in 29 subjects and the second component in 25 subjects. Upstroke of the apexcardiogram started with the beginning of an abrupt and sharp anterior or biphasic velocity component occurring immediately before the first heart sound (**Fig. 6–left**). Comparison of the carotid pulse tracing with pulsed Doppler recordings shows the peak of the S wave of the posterior wall coincided with the beginning of the upstroke of the carotid pulse (**Fig. 6–right**).

DISCUSSION

Long-axis and short-axis motion of the left ventricle

The major finding of this study is that the left ventricle moves with a more rapid motion longitudinally than latitudinally throughout systole and diastole. The velocity patterns of the three waves recorded in the septal and posterior walls were basically similar, although the velocities in each wall were higher from the apical approach. Considering these findings and our experiences of observing conventional short-axis views and M-mode echo-

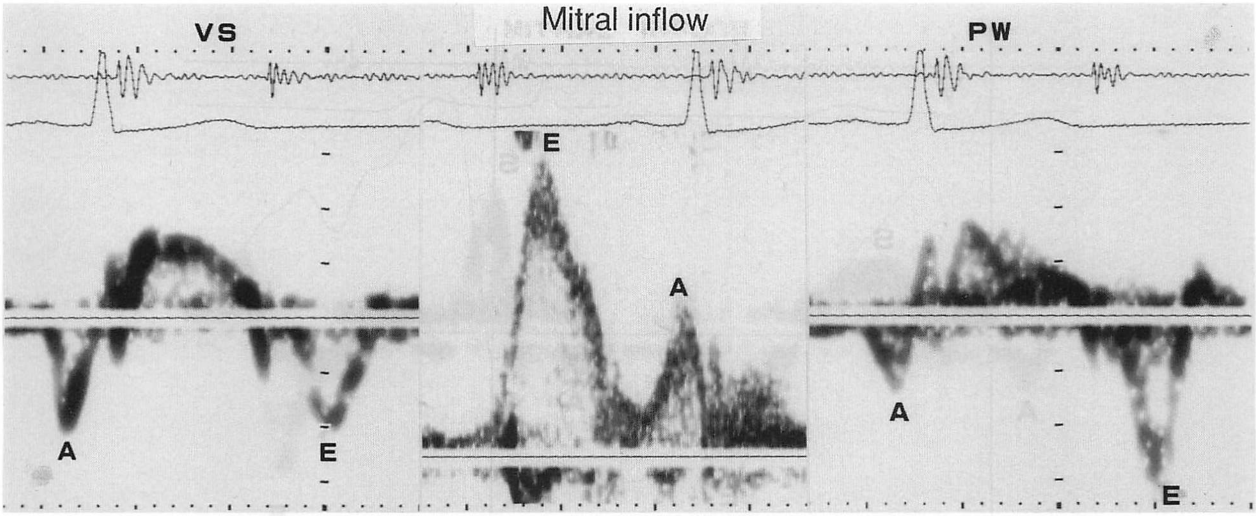

Fig. 4 Representative Doppler tracings showing relationships of the A/E ratio between wall motion velocities and mitral inflow (30-year-old normal subject)

The A/E ratio (0.51) of mitral inflow was between those of the septal (1.09) and posterior walls (0.44).

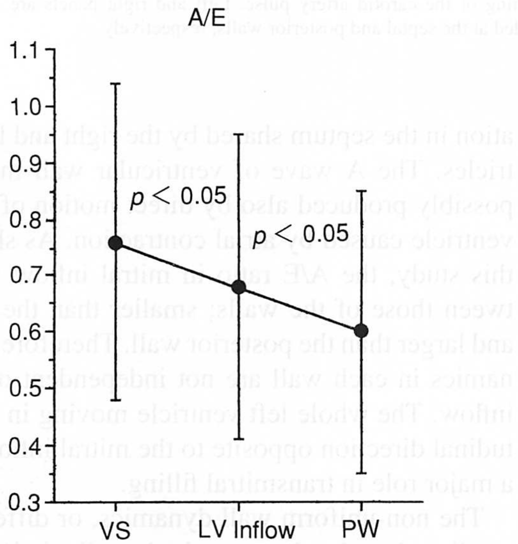

Fig. 5 Relationships of the A/E ratio with wall motion velocities and left ventricular inflow

There were significant differences (paired *t*-test).

cardiograms of the left ventricle, we propose the scheme of systolic and diastolic motion of the left ventricle shown in **Fig. 7**.

Early diastolic and presystolic motion of the left ventricle toward the mitral annulus is not a striking feature, which is consistent with the findings of annular motion previously evaluated with other techniques[7,8].

Diastolic function of the left ventricle

Normally, transmitral velocity consists of an early diastolic E wave and a presystolic A wave, and this biphasic pattern has been found to be useful in the evaluation of diastolic function. The most outstanding finding of this study was the same biphasic pattern of the diastolic left venticular wall motion. Normal velocity patterns of the septal and posterior walls recorded in the present study are basically similar to those of the left ventricular posterior wall or the cardiac base in previous studies using conventional pulsed method[5,6], although the septal motion has not been described before.

Recording of higher S and E wave velocities in the posterior wall also clarified that the posterior wall contracted and expanded more rapidly than the septum. This finding may be because the posterior myocardium is free wall while the septum is also a part of the left ventricle and right ventricle. The non-homogeneity between the walls has also been studied by M-mode echocardiography[9], in which the septum thickened and thinned more slowly than did the posterior wall.

Compared with A wave velocities, E wave velocities were different in the septal and posterior walls in our study. The reason for the different behavior between E and A waves is unknown. During relaxation, left ventricular pressure descends rapidly below left atrial pressure and the mitral valve opens resulting in accelerated filling and rapid expansion of the left ventricle, or the E wave velocity of wall motion. The lower E wave velocity of the septum is probably due to decreased diastolic relax-

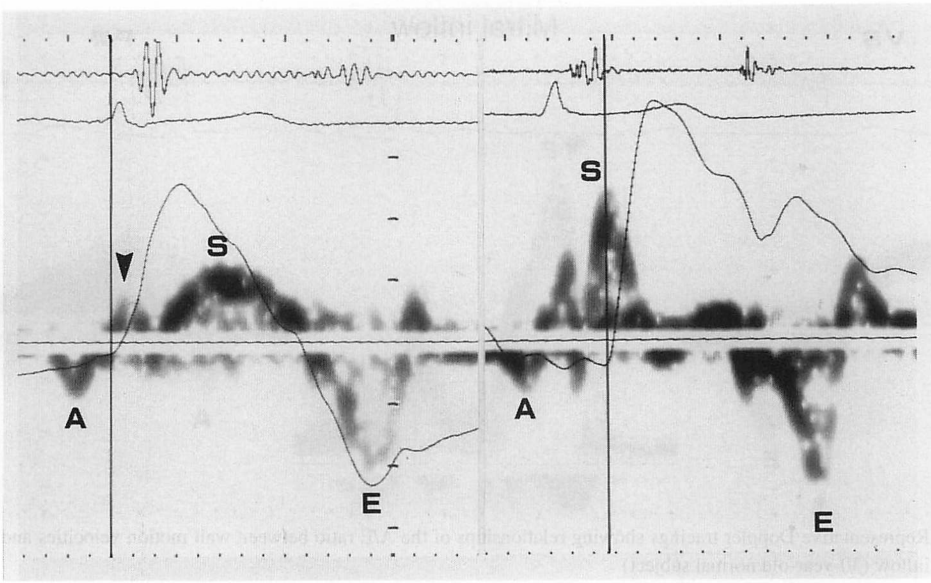

Fig. 6 Correlation of sharp velocity components and apexcardiogram (*left*) or carotid artery pulse tracing (*right*)

An abrupt brief component (*arrowhead*) just before the first heart sound starts at the upstroke of the apexcardiogram, and the peak of the S wave coincides with the beginning of the carotid artery pulse. Left and right panels are intramyocardial pulsed Doppler echocardiograms recorded at the septal and posterior walls, respectively.

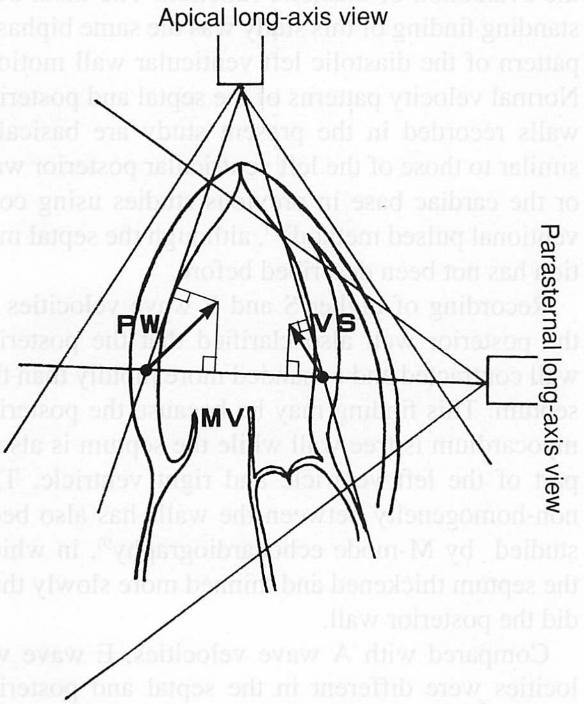

Fig. 7 Schematic drawing showing normal left ventricular wall motion

Left ventricular walls move more rapidly longitudinally than latitudinally and, at the same time, move inward and outward throughout the cardiac cycle.

ation in the septum shared by the right and left ventricles. The A wave of ventricular wall motion is possibly produced also by direct motion of the left ventricle caused by atrial contraction. As shown in this study, the A/E ratio in mitral inflow was between those of the walls; smaller than the septum and larger than the posterior wall. Therefore, the dynamics in each wall are not independent of mitral inflow. The whole left ventricle moving in a longitudinal direction opposite to the mitral inflow plays a major role in transmitral filling.

The non-uniform wall dynamics, or different diastolic relaxation between both walls, is important and must be taken into consideration for future assessment of the function of the diseased left ventricle. The A/Es of the septal and posterior wall velocities will be helpful and important indicators for diastolic function.

Absolute versus averaged velocities of the wall motion

Regional wall motion velocities can also be obtained by on-line positioning of the sample volume within the region of interest during display of myocardial imaging[10–12]. In this method, absolute and transmyocardial velocities or myocardial velocity gradient can be determined at any stage within the cardiac cycle, but cannot be obtained continuously.

In contrast, the velocities recorded in the present study are averaged wall motion velocities moving in the direction of the ultrasonic beam, and are dependent on the incident angle. However, the myocardial imaging-guided pulsed Doppler echocardiography used in this study has better temporal resolution, and is the most accurate and simplest method for regional wall motion analysis. It is also possible to repeat the measurements at any time.

Genesis of sharp and brief velocity components

The genesis of sharp deflections observed just before the first heart sound and at the timing of the second heart sound remains unclear. These high velocity motions could be identified at both walls although not in all subjects. The clinical significance of these high velocity motions is unknown. From consideration of the timing, the initial high frequency velocity component is likely to be related to left ventricular myocardial contraction occurring during isovolumetric contraction time, because this period starts at the upstroke of the apexcardiogram which reportedly coincides with the initial rise of left ventricular pressure[13]. This component corresponds to the B wave motion of the cardiac base of Isaaz *et al.*[6] which occurred after mitral valve closure and before aortic ejection. The second high frequency velocity may be attributable to left ventricle twitch caused by aortic valve closure. Further studies including recording of simultaneous intracardiac pressures are necessary for accurate timing and more complete understanding.

Clinical implications

Transmitral inflow velocity is an indicator of global diastolic function of the left ventricle, whereas the present method can independently evaluate myocardial systolic and diastolic function of the septal or posterior walls. As reported in our previous study[3], in which wall motion velocities were recorded at lower, middle and upper ventricular walls, intramyocardial velocities become lower toward the apex and higher toward the annulus. Left ventricular wall motion velocities are not identical to the annular velocities. Thus, using Doppler tissue imaging, we can accurately determine the region of interest. Assessment of regional wall motion velocities will greatly contribute to understanding of the pathogenesis and physiology of left ventricular myocardial disease or ischemic heart disease in the near future.

Two approaches, apical and parasternal, are available for recording wall motion velocities. The approaches are equivalent, but not competitive, and not substitutable for each other. For routine Doppler echocardiographic examinations, the apical approach will be superior to the parasternal approach because of the higher velocities recorded by the former. However, either approach may be utilized in some cardiac conditions.

Study limitations

The limitations of this study were that we cannot separate true wall motion from the motion of the annulus or the whole cardiac translation, and that the velocities recorded here are not transmyocardial, but averaged velocities within the sampling volumes moving throughout the cardiac cycle. Wall motion velocities are dependent on the sampling position. Thus, sampling positions should be carefully determined for measuring regional wall motion velocities in various cardiac disorders.

CONCLUSIONS

The analysis of wall motion velocities with apical intramyocardial pulsed Doppler method will be a valuable new modality, and the present data can provide the basis for assessment of left ventricular myocardial function.

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要　約

新しい壁運動評価法としての心筋内パルス・ドップラー法：健常者での検討

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ドップラー組織イメージング法は心筋壁の速度分布をリアルタイムで表示する新しい検査法である．本法ガイド下のパルス・ドップラー法によれば局所心筋の壁運動速度が測定されるが，その臨床応用については十分な検討がなされていない．本研究では正常な左室壁動態を明らかにし，記録方法の標準化決定のために，健常者31例(平均年齢38±18歳)を対象として本法を施行した．

心筋イメージング像を描出後，胸骨左縁と心尖部アプローチで僧帽弁先端–腱索レベルの中隔と後壁で運動速度波形を記録し，比較検討した．両アプローチにより，中隔と後壁で収縮期S波，拡張早期E波，心房収縮期A波が記録された．S波は左室内側に向かいつつ心尖部に近付き，E波とA波は左室外方に向かいながら心尖部より遠ざかる速度成分であった．全成分は心尖部から記録可能で，より速く，S波とE波は中隔より後壁側でより大となった．したがって中隔のA/E比は後壁よりも大きく(それぞれ0.77±0.3，0.63±0.3; $p<0.01$)，僧帽弁流入血A/Eの値は両者の間にあった．これは中隔と後壁の拡張期動態の差異に由来するものであり，壁運動は僧帽弁流入血と密接な関係を有するものと思われた．

心尖部アプローチは胸骨左縁アプローチより優れ，本法による心筋内パルス・ドップラー法は新しい壁運動評価法になることが示唆された．本研究はその時の基礎データになるものである．

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