A Noninvasive Technique for the Determination of Velocity of Circumferential Fiber Shortening in Man


ABSTRACT

Velocity of circumferential fiber shortening \((V_{CF})\) as determined by analysis of left ventricular cineangiocardiograms has been proposed as a measure of left ventricular myocardial contractility. In this study, a noninvasive ultrasonic technique was used to measure the rate of shortening of the left ventricular internal minor axis throughout ejection in 61 patients. These measurements permitted calculation of mean \(V_{CF}\). In 23 patients with normal left ventricular function, mean \(V_{CF}\) averaged \(1.45 \pm 0.08\) circumferences/sec (mean \(\pm SE\)). In contrast, mean \(V_{CF}\) in 38 patients with impaired left ventricular function was significantly depressed \(0.91 \pm 0.09\) circumferences/sec, \(P < 0.001\). In 17 patients, adequate resolution of septal and posterior wall thicknesses permitted measurement of midwall radius at 50-msec intervals throughout the cardiac cycle. These measurements permitted computation of instantaneous and peak \(V_{CF}\). Values for peak \(V_{CF}\) at the midwall were generally similar to those observed for mean \(V_{CF}\) at the internal axis. In patients with normal left ventricular function, peak \(V_{CF}\) averaged \(1.58 \pm 0.23\) circumferences/sec. This study has demonstrated the feasibility of measuring the velocity of left ventricular circumferential fiber shortening in man by a noninvasive method. Initial studies indicate that this approach may prove useful in the detection and serial evaluation of left ventricular performance in patients with heart disease.

KEY WORDS

- echocardiography
- left ventricular function
- ultrasound
- myocardial mechanics
- myocardial contractility
- left ventricular performance
- cardiac muscle function

In man, analysis of left ventricular performance in terms of the framework provided by myocardial mechanics (1-3) generally involves studies of left ventricular pressure-time relationships during isovolumetric systole, utilizing \((\frac{dP}{dt})/P\) as an approximation of the contractile element's shortening velocity (1, 4, 5), or studies of the rates of change in measures of left ventricular geometry by frame-by-frame analysis of left ventricular cineangiocardiograms (6, 7). Both approaches have theoretical limitations, but the major obstacle to their widespread clinical application in the study of patients with heart disease is a practical drawback: both require cardiac catheterization.

Recently, several investigators have used pulsed ultrahigh-frequency sound waves to study the dynamic geometry of the mitral valve (8, 9), the interventricular septum, and the posterior wall of the left ventricle (10-12). Moreover, at least four different groups (13-16) have shown that this noninvasive technique can be employed to accurately measure the left ventricular internal minor axis throughout systole and diastole. Such measurements may be used to calculate left ventricular end-systolic and end-diastolic volumes, stroke volume, and ejection fraction.
It seemed appropriate, therefore, to determine if this technique could be applied to the study of left ventricular myocardial mechanics. Accordingly, this study was undertaken to determine whether the rate of shortening of the internal minor axis of the left ventricle throughout ejection could be measured by the ultrasonic technique and whether the mean and the instantaneous velocities of circumferential fiber shortening calculated from the measurements could be applied to the analysis of left ventricular performance in man.

Methods and Materials

Studies were performed on 61 patients undergoing diagnostic evaluation for heart disease. A history was taken and a physical examination, an electrocardiogram, and a cardiac fluoroscopy were done on all patients; 25 patients had cardiac catheterizations. Left ventricular cineangiocardiograms were obtained for patients who underwent cardiac catheterization. These studies were performed in only one plane to assess mitral competency. Unfortunately, the absence of an adequate timing device or reference grid and the use of only one plane precluded accurate angiocardiographic measurement of the velocity of circumferential fiber shortening in these patients.

On the basis of this evaluation, the patients were divided into two groups. One group consisted of 23 patients (10 men and 13 women) who had no evidence of impaired left ventricular performance. This group included 15 patients with no evidence of organic heart disease, 4 with minimal valvular heart disease, 2 with "lone" atrial fibrillation, 1 with an atrial septal defect, and 1 with mild pulmonic stenosis. The second group comprised 38 patients (27 men and 11 women) who had definite evidence of impaired left ventricular function. This group included 20 patients with valvular heart disease, 12 with coronary artery disease, 4 with cardiomyopathy, 1 with a ventricular septal defect, and 1 with subaortic stenosis.

Ultrasonic echocardiographic studies were performed using a commercially available ultrasonoscope (Hewlett Packard 7214A) with a 2.5-MHz transducer and a pulse repetition rate of 500 impulses/sec. Patients were examined in the recumbent position. An air-free contact between the patient's skin and the transducer was ensured by using a water-soluble gel. The transducer was positioned in the fourth or fifth intercostal space at the left sternal border and was directed posteriorly and slightly inferolaterally. The sensitivity control for far-field echoes ("compensation") was adjusted until a band of synchronously moving posterior echoes was recorded on the time-motion scan. The sensitivity control for near-field echoes ("sensitivity") was adjusted until a broad echo approximately 1 cm thick (septum, Fig. 1) was recorded. Transducer position, sensitivity controls, and compensation controls were adjusted to obtain a simultaneous recording of the interventricular septum and the epicardium and endocardium of the posterior wall of the left ventricle just below the plane of the mitral valve. Echoes were identified by their characteristic motion and distance from the transducer (10, 14).

The distances between the endocardial surfaces of the left ventricular posterior wall and the interventricular septum were measured at end-diastole (DED) and end-systole (DES) in each of 61 patients (Fig. 1). End-diastole and end-systole (actually end-ejection) were defined as the points of maximum...
Values for midwall velocity of circumferential fiber shortening ($V_{CF}$) plotted at 50-msec intervals throughout systole for two representative patients. Note the higher peak $V_{CF}$, shorter time to peak $V_{CF}$, and longer left ventricular ejection period in the patient with normal left ventricular function.

**FIGURE 2**

and minimum distance between the endocardial surfaces. These definitions are supported by the findings of Popp and Harrison (14), and of Pombo et al. (15). In 17 patients, distances between the endocardial surfaces were measured at 50-msec intervals throughout left ventricular systole, and a midwall diameter was calculated by adding the distance between endocardial surfaces ($D$) to one-half the septal thickness ($h_s/2$) and one-half the posterior wall thickness ($h_p/2$).

Calibration was provided by a grid, the distance between each pair of horizontal lines representing 2 cm of tissue. Time calibration was provided by vertical time lines 0.5 seconds apart on the oscillographic sweep.

**CALCULATIONS OF THE VELOCITY OF CIRCUMFERENTIAL FIBER SHORTENING**

Velocity of circumferential fiber shortening ($V_{CF}$) at the left ventricular midwall was computed as: $V_{CF} = 2\pi r/\Delta t$ where $r = D/2 + (h_s + h_p)/4$ with midwall radius, $r$, measured at 50-msec intervals ($\Delta t = 50$ msec). Thus, the sampling frequency was 20 cps. Velocity of circumferential fiber shortening was normalized for the corresponding average midwall left ventricular circumference (circumference = $2\pi r$) during the 50-msec interval and expressed as circumferences/sec. The normalized velocity of circumferential fiber shortening so obtained was plotted against time to give a characteristic curve (Fig. 2).

The mean velocity of shortening of the internal circumference was calculated by dividing the extent of circumference shortening by the systolic ejection time, which was measured directly from the echocardiogram. This mean velocity of circumferential fiber shortening was also normalized for the average internal circumference during ejection and expressed as circumferences/sec: $V_{CF} = \frac{[\pi(D_{ED} - D_{ES})/\Delta t]}{[\pi(D_{ED} + D_{ES})/2]} = \frac{[2(D_{ED} - D_{ES})]}{[D_{ED} + D_{ES}]\Delta t}$. Data was analyzed by standard statistical methods using the t-test for independent samples.

**Results**

Average values for mean velocity of circumferential fiber shortening at the internal circumference in patients with and without impairment of left ventricular performance are summarized in Figure 3. The average value for mean $V_{CF}$ was significantly higher in patients with normal left ventricular function (mean $V_{CF} = 1.45 \pm 0.08$ circumferences/sec, mean ± se) than in all patients with impaired left ventricular function (mean $V_{CF} = 0.91 \pm 0.09$ circumferences/sec, $P < 0.001$). Despite the statistically significant ($P < 0.001$) difference between these two groups, considerable overlap in the values for mean $V_{CF}$ was noted. More detailed analysis indicated that patients with severe mitral regurgitation (15 patients) and ventricular aneurysm or dyskinesis (4 patients, including 1 patient with subaortic stenosis) had values for mean $V_{CF}$ (1.24 ± 0.14 circumferences/sec) close to the normal range despite gross impairment of left ventricular performance as judged by elevated left ventricular filling pressures and decreased forward stroke output. When these two
Values for mean velocity of circumferential fiber shortening ($V_{CF}$) are plotted for three groups of patients: those without left ventricular (LV) impairment, those with LV impairment but without severe mitral regurgitation (M.R.), aneurysm or dyskinesis, and those with LV impairment with evidence of severe mitral regurgitation, aneurysm, or dyskinesis. The average values for the groups are represented by horizontal bars. The difference between the average values of the first two columns was statistically significant ($P < 0.001$). The difference between the average values of the first and third columns was not statistically significant.

Groups are removed from the group of all patients with impairment of left ventricular performance, the difference between mean $V_{CF}$ in those with normal left ventricular function as compared to those with impaired left ventricular function (mean $V_{CF} = 0.58 \pm 0.08$ circumferences/sec) becomes dramatic (Figs. 3 and 4).

Values for peak $V_{CF}$ at the midwall, although determined in a smaller number of patients, were generally similar to those observed for mean $V_{CF}$ at the internal circumference. For the group with normal left ventricular function, peak $V_{CF}$ was $1.58 \pm 0.23$ circumferences/sec (6 patients), while mean $V_{CF}$ for this group was $1.45 \pm 0.08$ circumferences/sec (23 patients). In contrast, for the group with definite impairment of left ventricular function but without ventricular aneurysm or dyskinesis, subaortic stenosis, or severe mitral regurgitation, peak $V_{CF}$ averaged $0.92 \pm 0.09$ circumferences/sec (5 patients) while mean $V_{CF}$ was $0.58 \pm 0.08$ circumferences/sec (19 patients). The difference in peak $V_{CF}$ between these two groups was statistically significant ($P < 0.05$).

**Discussion**

Gault et al. (6) have proposed that $V_{CF}$ is a measure of left ventricular myocardial performance, and its usefulness in the evaluation of patients with impaired cardiac muscle function has been well documented (6, 7, 17-20).

This study has shown that $V_{CF}$ can be determined by noninvasive methods and that measurements so obtained appear to differentiate between patients with and without...
impaired left ventricular performance. The ranges and average values for mean $V_{CF}$ measured at the internal circumference (0.96 to 2.50 circumferences/sec, average 1.45 ± 0.08 circumferences/sec) and peak $V_{CF}$ measured at the midwall (0.87 to 2.15 circumferences/sec, average 1.58 ± 0.23 circumferences/sec) in patients with normal left ventricular function were quite similar to those reported for normal patients in studies employing the usual left ventricular cineangiographic techniques (6, 7, 17, 18). Patients with severe mitral regurgitation or ventricular aneurysm or dyskinesis seemed to represent an exception to the rule, frequently showing values of $V_{CF}$ in the normal range despite clinical and hemodynamic evidence of left ventricular failure. This finding was not unexpected in view of the unique hemodynamic situations presented by these two conditions.

In severe mitral regurgitation, an increase in the total extent of left ventricular circumferential fiber shortening combined with the relatively low impedance offered by the left atrium may account for the disproportionately high shortening velocities that we observed. With regard to patients with ventricular aneurysms or dyskinesis, it should be pointed out that the velocity of circumferential fiber shortening in the plane of the internal minor axis cannot be expected to represent the functional state of the left ventricle as a whole, owing to the inhomogeneity of the contracting ventricular wall. This observation also pertains to the single patient with subaortic stenosis; his left ventricle, as observed angiographically, clearly contracted in a dyskinetic fashion. In spite of hemodynamic evidence of left ventricular failure (left ventricular end diastolic pressure was 22 mm Hg, cardiac index was 1.9 liters/min m$^{-2}$), this patient's observed peak midwall $V_{CF}$ was 1.11 circumferences/sec and mean $V_{CF}$ was 1.25 circumferences/sec. In patients with atrial septal defect, the movement of the interventricular septum is usually in the opposite direction from normal (21). In our patient with an atrial septal defect, peak midwall $V_{CF}$ was 0.87 circumferences/sec and mean $V_{CF}$ 1.16 circumferences/sec in the absence of left ventricular failure. These special circumstances are under further study.

A major limitation of the present method is its inability to offer simultaneous intraventricular pressure measurements; it therefore cannot be used alone to study the tension-velocity relations of the left ventricle. For such a study, simultaneous cardiac catheterization is required. It is interesting, however, that values of peak and mean $V_{CF}$ as measured in this study, although unrelated to instantaneous myocardial tension measurements, nevertheless appear to distinguish patients with and without impaired left ventricular function.

It should be emphasized that it is not always possible to obtain adequate resolution of the ultrasonic echoes from the septum and posterior wall to measure peak midwall $V_{CF}$, whereas, in our experience, adequate studies to determine mean $V_{CF}$ can be obtained in roughly 90% of patients. Resolution adequate to determine peak midwall $V_{CF}$ was obtained in only 25% of patients in this study. Technical advances in ultrasonic equipment promise to increase the power of resolution. Making use of these improvements, peak midwall $V_{CF}$ should be obtainable in most patients. It is appreciated that a sampling frequency greater than 20 cps would be desirable for a more accurate estimation of peak midwall $V_{CF}$. Further improvements in equipment which have recently become available facilitate recording at more rapid time sweeps. With such equipment, a sampling frequency of 40 cps or greater will be possible.

The major usefulness of this technique will reside in the serial study of left ventricular performance in a given patient. The ability to detect early deterioration of myocardial function in patients with myocardial infarction, chronic valvular disease, etc., without the need for repeated cardiac catheterization, may prove to be of value in guiding therapy for these patients.

In conclusion, this study has demonstrated the feasibility of measuring the velocity of...
shortening of the left ventricular circumferential fibers in man by a noninvasive ultrasonic technique. Initial studies indicate that this approach may prove useful in the detection and serial evaluation of left ventricular performance in patients with heart disease.

References


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