Hemodynamic Correlates of Echocardiographic Aortic Root Motion*

Observations on Normal Subjects and Patients with Idiopathic Hypertrophic Subaortic Stenosis

Premindra A. N. Chandraratna, M.D.; Weikom Chu, M.D.; Eliot Schechter, M.D.; and Eugene Langevin, D.O.

In ten normal subjects, we observed an initial hump in the aortic root echocardiogram after the onset of the QRS complex, following which a sharp anterior motion was noted. The onset of the anterior motion of the aortic root coincided with the onset of the upstroke of the aortic root pressure pulse and the onset of the velocity signal in five of seven patients with coronary arterial disease; in the other two, the anterior aortic motion followed the onset of the pressure and velocity signal by 10 msec. The aortic root echocardiogram was abnormal in patients with idiopathic hypertrophic subaortic stenosis; the slope (normalized for the scales of time and depth) in early systole was steeper and in the latter part of systole was flatter than normal in these patients. The slope in early diastole was flatter and the slope due to atrial contraction was steeper in the patients with idiopathic hypertrophic subaortic stenosis than in the normal subjects. These features were consistent with rapid ejection in early systole and slow filling in the early phase of ventricular diastole in idiopathic hypertrophic subaortic stenosis. Fourier analysis of the wave form of the aortic root allowed separation between patients with idiopathic hypertrophic subaortic stenosis and normal subjects.

Gramiak and Shah1 described the echocardiographic features of the normal and diseased aortic valve. Subsequent investigators have outlined the ultrasonic characteristics of various forms of aortic valvular disease.2-5 Strunk and associates4 described the pattern of motion of the posterior wall of the aortic root and found a good correlation between posterior aortic root motion and the left atrial angiographic area.

Our report describes the morphologic features of normal motion of the aortic root, with special emphasis on the hemodynamic correlates in systole. The motion of the aortic root in normal subjects was strikingly different from that seen in patients with idiopathic hypertrophic subaortic stenosis.

Materials and Methods

Normal Subjects

Echocardiograms of the aortic root, electrocardiograms, and phonocardiograms were simultaneously obtained in ten normal subjects (range of ages, 27 to 47 years). An ultrasonoscope (Ekoline 20 Ultrasonoscope), a 2.25-MHz 0.5-inch transducer with a 10-cm focus, and a strip-chart recorder (Honeywell 1856) were used. The examination was performed from the interspace from which the mitral valve could be visualized by perpendicular or nearly perpendicular placement of the transducer. The aortic root echocardiogram was obtained by superior and medial angulation of the transducer. In order to standardize the echocardiographic examination, two cusps of the aortic valve were recorded when obtaining the aortic root echocardiogram. A blowup of the aortic root and aortic valve was then recorded at a paper speed of 50 mm/sec.

Coronary Arterial Disease

To help clarify the timing of events in the aortic root, seven patients with coronary arterial disease had studies performed at the time of cardiac catheterization. Aortic root echocardiograms, ECGs, and tracings of ascending aortic pressures were simultaneously obtained by a catheter-tip micromanometer (Millar) and were recorded at paper speeds of 50 and 100 mm/sec. Tracings of the velocity of the ascending aortic flow (obtained by a catheter-tip electromagnetic probe measuring flow), aortic root echocardiograms, and ECGs were also simultaneously recorded at paper speeds of 50 and 100 mm/sec.

Idiopathic Hypertrophic Subaortic Stenosis

Ten consecutive patients (range of ages, 30 to 52 years) who had asymmetric septal hypertrophy (ratio of septal thickness to thickness of posterior wall greater than 1.5) and marked systolic anterior motion of the mitral valve with mitral septal apposition during systole had echocardiograms.
of the aortic root, ECGs, and phonocardiograms (eight patients) simultaneously recorded at a paper speed of 50 mm/sec. No patient was receiving cardiac medications at the time of the study.

Methods

Several cycles of echocardiograms of the posterior wall of the aortic root were traced by hand from the strip chart. These tracings were then enlarged onto graph paper. Coordinates of these wave forms were read off at 61 equally spaced locations and were analyzed on a computer (IBM 370/158). During the read-off process, the wave forms were normalized both in the scale of time and the scale of depth. This procedure of normalization was performed during the computerized analysis and consisted of adjusting both the scale of time and the scale of depth so that all wave forms had numerically the same maximum depth and duration. The

amplitude of each aortic root wave form was divided into 100 divisions, with the lowest point being zero and the highest point being 100. The duration of each wave form was divided into 61 divisions, with the beginning of the wave form being time zero and the end of the wave form being time 61. This reduces the variation within the set (caused by different heart rates and different amplitudes), while still preserving the essential configuration of the wave forms.

Results

After an initial hump following the QRS complex, the aortic root moved anteriorly (Fig 1). The anterior motion of the aortic root consisted of an initial rapid slope (slope 1, which was the slope of the first quarter of the systolic segment), followed by a less steep slope (slope 2, which was the slope of the

Figure 1. Simultaneous recordings of phonocardiogram, ECG, carotid pulse tracing (CA), and aortic root echocardiogram. Following P wave of ECG, there is posterior motion of aortic root (beginning at point A and ending at V) (nomenclature of Strunk et al). This is followed by hump, after which sharp anterior motion (beginning at B) is seen. Dip in aortic root (point C) corresponds to anterior component of second heart sound (S2). Point O represents peak of anterior motion, following which sharp posterior motion (ending in R) is noted. After point R, flat segment (ending in A) is evident. S2. Second heart sound; AwAo, anterior wall of aortic root; PwAo, posterior wall of aortic root; and AV = aortic valve.

Figure 2. A (left), Schematic diagram of normal posterior wall of aortic root, illustrating slopes that were measured. Slope 1 (SL1) and slope 2 (SL2) are in systole, whereas slope 3 (SL3) is in early diastole, and slope 4 (SL4) is result of atrial contraction. Vertical height of OR segment (see Fig 1) is X, and that of AV segment is Y. B (right), Schematic diagram of posterior aortic wall in idiopathic hypertrophic subaortic stenosis.
pulse by 10 msec (Fig 3). The dicrotic notch of the pressure pulse coincided with the dip on the aortic root echocardiogram in each instance.

The onset of the velocity signal in the aortic root (measured by a catheter-tip electromagnetic probe measuring velocity) occurred at the same time as the start of the anterior motion of the aortic root echo (Fig 4) in five patients with coronary arterial disease. In two others, the anterior aortic motion followed onset of the velocity signal by 10 msec.

**Idiopathic Hypertrophic Subaortic Stenosis**

The pattern of motion of the aortic root in patients with idiopathic hypertrophic subaortic stenosis was clearly different from that seen in normal subjects. To quantitatively describe these morphologic differences, several slopes (shown in Fig 2) were calculated by fitting (via method of least squares) a line to each section of interest. The results are shown in Table 1. The initial systolic slope of the aortic root (Fig 2 and slope 1) was steeper than normal in patients with idiopathic hypertrophic subaortic stenosis. In contrast, slope 2 was considerably flatter.

**Coronary Arterial Disease**

The onset of anterior motion of the aortic root in systole coincided with the onset of the rise of the pressure in the ascending aorta (measured by a catheter-tip micromanometer) in five patients with coronary disease; and in two others, the anterior aortic motion followed the onset of the pressure.
in idiopathic hypertrophic subaortic stenosis (Fig 2). The initial diastolic slope of the aortic root (slope 3) was flatter than normal, and a clear-cut flat or slightly anteriorly moving segment (RA segment) was not present in most patients with idiopathic hypertrophic subaortic stenosis. A prominent “a” wave (slope 4), which was steeper than in the normal subjects, was noted in those who had idiopathic hypertrophic subaortic stenosis. The vertical height of the sharp posterior motion (OR segment; X in Fig 2) was significantly smaller, the height of the “a” wave (Y in Fig 2) was greater, and the ratio of X/Y was smaller in the group with idiopathic hypertrophic subaortic stenosis. Two representative examples are shown in Figure 5.

To further establish the differences between the aortic root wave forms observed in normal subjects and in patients with idiopathic hypertrophic subaortic stenosis, a well-established method of analysis of wave forms, Fourier analysis, was applied. This technique has been applied to the analysis of mitral valvular wave forms. The results are shown in Figure 6. The average amplitudes (normalized for scales of time and depth) of the aortic root were higher for patients with idiopathic hypertrophic subaortic stenosis. Normal subjects tended to have higher amplitudes for their first cosine component but lower amplitudes for their sine component than patients with idiopathic hypertrophic subaortic stenosis. All of these differences are statistically significant (P < 0.005).

**DISCUSSION**

Following an initial hump after the onset of the QRS complex, a sharp anterior motion of the aortic root was seen, the onset of which coincided with the initial rise of pressure in the aorta and with the upstroke of the tracing of aortic flow in five patients; and in two others, a 10-msec lag was noted. The anterior motion had two components, an initial rapid motion followed by a less steep movement. A dip on the aortic root echocardiogram coincided with the onset of the aortic component of the second heart sound and the diastolic notch of the aortic root pressure pulse, and therefore the dip represented the end of systole. Thus, the onset and end of left ventricular ejection were definable on the aortic root echocardiogram.

The pattern of aortic root motion was strikingly abnormal in patients with idiopathic hypertrophic subaortic stenosis. These patients had an initial anterior motion of the aorta that was steeper than normal, followed by a flat segment which demonstrated little or no anterior motion. This pattern of motion is consistent with the characteristic abnormality of left ventricular ejection that has been de-
scribed in idiopathic hypertrophic subaortic stenosis. Normal subjects eject about 50 to 55 percent of the stroke volume during the first half of systole. In contrast, in patients with idiopathic hy-
pertrophic subaortic stenosis, flow in the latter half of systole is markedly attenuated, so that 80 to 85 percent of the stroke volume is ejected during the first half of systole. It is likely that the steep initial anterior motion of the aortic root echo corresponds to rapid ventricular ejection, and the relatively flat segment that follows is due to a decrease in aortic flow caused by obstruction of the left ventricular outflow tract. The observation that the systolic notch on the aortic valve corresponded to the end of the steep initial anterior motion of the aortic root (Fig 5) further supports our contention.

A striking abnormality in the pattern of diastolic motion of the aortic root was also noted in patients with idiopathic hypertrophic subaortic stenosis. Strunk and his associates described the motion of the posterior aortic wall echocardiogram. After opening of the mitral valve, the posterior aortic wall exhibited rapid posterior motion (OR segment). This was followed by a flat or slightly anterior movement (RA segment); and following the P wave of the ECG, an abrupt posterior motion of the aortic wall (AV segment) was observed. Strunk et al correlated these changes with alterations in the left atrial area. In idiopathic hypertrophic subaortic stenosis, the early diastolic slope was reduced. This is consistent with a reduced rate of ventricular filling because of decreased left ventricular compliance. A clear-cut flat or slightly anteriorly moving segment (RA segment) was not present in most patients with idiopathic hypertrophic subaortic stenosis. It should be noted that tachycardia also eliminates this flat or slightly anteriorly moving segment. None of our patients had tachycardia (heart rate greater than 100 beats per minute) during the study. A prominent "a" wave was noted on the aortic root echocardiogram in all of our patients. In the majority of normal subjects, the height of the sharp posterior motion (OR segment) was greater than that of the further sharp posterior motion (AV segment), whereas in patients with idiopathic hypertrophic subaortic stenosis, the latter segment exceeded the former (with the exception of one).

Since Strunk et al observed a good correlation between posterior aortic wall movement and change in the left atrial angiographic area (hence, probably change in left atrial volume), our findings suggest that a greater amount of left ventricular filling occurred in the group with idiopathic hypertrophic subaortic stenosis during the "a" wave than during the early phase of diastole, whereas in the normal subjects, early diastolic filling was greater than that during atrial contraction. This underscores the importance of atrial contraction to ventricular filling in patients with idiopathic hypertrophic subaortic stenosis. Our observations suggest that the motion of the aortic root in idiopathic hypertrophic subaortic stenosis is consistent with rapid ejection during early systole and slow ventricular filling in the initial phase of diastole. The sensitivity and specificity of these echocardiographic abnormalities remain to be established.

We wish to emphasize the importance of proper angulation of the transducer in obtaining an adequate study for proper analysis. Both walls of the aortic root and portions of two aortic valvular cusps should be clearly recorded. Improper angulation may distort the tracing and lead to errors in interpretation.

Any well-behaved wave form can be easily transformed into its appropriate representation of Fourier series, which is a superimposition of a set of sinusoidal components having different amplitudes and different frequencies. The morphologic differences of the original wave forms are then reflected upon the different parameters of their Fourier series. The differences between aortic root wave forms of normal subjects and those of patients with idiopathic hypertrophic subaortic stenosis were reflected in the average amplitude of the wave forms and the amplitudes of the first cosine and sine components. The increase in average amplitude in this group with idiopathic hypertrophic subaortic stenosis could have been due in part to mitral regurgitation causing greater anterior motion of the aortic root. These data show how a nonquantitative clinical description of an echocardiographic wave form can be quantitatively evaluated with the help of a technique developed in applied mathematics.

A study of the motion of the aortic root may yield useful information regarding the ejection and diastolic filling of the left ventricle in other forms of heart disease. We are presently exploring the possibility of using this information as an aid in the evaluation of other cardiac conditions.

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REFERENCES