Ultrasound in the Diagnosis and Evaluation of Therapy of Idiopathic Hypertrophic Subaortic Stenosis

By Richard L. Popp, M.D., and Donald C. Harrison, M.D.

SUMMARY

Twenty patients with idiopathic hypertrophic subaortic stenosis (IHSS) were studied with cardiac echography. Eight of these patients were studied during left heart catheterization. The echographic pattern of mitral valve motion during systole was altered in a characteristic manner when hemodynamically significant left ventricular outflow obstruction was present in the eight patients studied at catheterization. The abnormal systolic pattern was abolished by spontaneous loss of outflow obstruction or loss of obstruction induced by beta-adrenergic blockade. An abnormal systolic mitral valve pattern was seen on the echogram in 17 of the 20 patients with proven IHSS. The abnormal pattern was lost after the institution of chronic propranolol therapy in one patient. The three patients not showing an abnormal systolic pattern were also taking propranolol. The pattern of mitral valve motion during diastole indicated an impaired rate of left ventricular filling. The basic abnormalities and variability in the degree of abnormality seen with echography of the left ventricular outflow tract are consistent with the proposed anatomy and pathophysiology of IHSS.

Additional Indexing Words:
Echogram Propranolol Mitral valve Left ventricular outflow tract
Isoproterenol Amyl nitrite

THE RECOGNITION of idiopathic hypertrophic subaortic stenosis (IHSS) as an entity separate from the other forms of congenital and acquired aortic stenosis occurred only within the past decade. Although many studies have been carried out and much data accumulated about this condition in such a short time, the basic etiology, pathophysiology, and anatomic site of obstruction are still debated. In its milder forms, the obstruction may be evanescent, making the diagnosis difficult unless elaborate provocative maneuvers to enhance the outflow tract obstruction are used during cardiac catheterization. Several forms of medical and surgical therapy have been attempted once the diagnosis has been established, but there are few methods to evaluate responses to therapy except by repeated hemodynamic measurements. Recently, two studies have suggested abnormal patterns in the pulsed reflected ultrasound tracings of mitral valve motion in patients with IHSS. The present study was designed to explore the uses of cardiac echography in IHSS, both as a diagnostic tool and as a technic, through which the mechanism of left ventricular outflow obstruction could be further elucidated. Taking cardiac echograms during cardiac catheterization in several patients allowed meaningful correlation of the data obtained by both procedures.
Table 1

Echographic Findings on 20 Patients with Idiopathic Hypertrophic Subaortic Stenosis

<table>
<thead>
<tr>
<th>IHSS</th>
<th>Known prior to study</th>
<th>Type</th>
<th>CEG during cath</th>
<th>SAM</th>
<th>Septum contact</th>
<th>Propranolol therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
<td></td>
<td></td>
<td></td>
<td>Slope (mm/sec)</td>
<td>Amplitude (mm)</td>
<td></td>
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<tr>
<td>P.H.</td>
<td>0</td>
<td>Labile</td>
<td>+</td>
<td>V</td>
<td>(250)</td>
<td>(15)</td>
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<tr>
<td>R.G.</td>
<td>0</td>
<td>Labile</td>
<td>+</td>
<td>V</td>
<td>(50)</td>
<td>(12)</td>
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<td>F.G.</td>
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<td>Stable</td>
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<td>+</td>
<td>150</td>
<td>12</td>
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<td>+</td>
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<td>15</td>
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<td>+</td>
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<td>15</td>
</tr>
<tr>
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<td>+</td>
<td>65</td>
<td>14</td>
</tr>
<tr>
<td>S.R.</td>
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<td>V</td>
<td>(230)</td>
<td>(15)</td>
</tr>
<tr>
<td>J.B.</td>
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<td>+</td>
<td>V</td>
<td>(50)</td>
<td>(12)</td>
</tr>
<tr>
<td>G.R.</td>
<td>+</td>
<td>Latent</td>
<td>+</td>
<td>0</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>J.P.</td>
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<td>Stable</td>
<td>0</td>
<td>+</td>
<td>65</td>
<td>12</td>
</tr>
<tr>
<td>H.S.</td>
<td>+</td>
<td>Stable</td>
<td>0</td>
<td>+</td>
<td>50</td>
<td>11</td>
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<tr>
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<td>0</td>
<td>85</td>
<td>20</td>
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<tr>
<td>K.W.</td>
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<td>10</td>
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<td>R.W.</td>
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<td>+</td>
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<td>12</td>
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<tr>
<td>M.P.</td>
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<td>11</td>
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<td>V</td>
<td>(95)</td>
<td>(14)</td>
</tr>
<tr>
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<td>+</td>
<td>Latent</td>
<td>0</td>
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<td>N.A.</td>
<td>N.A.</td>
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<tr>
<td>W.A.</td>
<td>+</td>
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<tr>
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<td>Labile</td>
<td>0</td>
<td>V</td>
<td>(80)</td>
<td>(11)</td>
</tr>
</tbody>
</table>

Abbreviations: IHSS = idiopathic hypertrophic subaortic stenosis; CEG = cardiac echogram; SAM = systolic anterior movement; MV = mitral valve; 0 = no; + = yes; V = variable; ( ) = measurement when present; N.A. = not applicable.

Methods

Twenty patients with IHSS, documented by cardiac catheterization and angiography, were studied. Of these, four were new patients studied with ultrasound prior to definitive diagnosis. In addition, two of these four new patients were studied again during cardiac catheterization. Of the remaining 16 patients with previously documented IHSS, six were studied at the time of follow-up catheterization while receiving chronic propranolol therapy (table 1). Nine additional patients were studied with cardiac echography for clinically suspected IHSS but subsequently were proven not to meet the diagnostic criteria for this condition by cardiac catheterization. The criteria for diagnosis of IHSS are those reported in the American Heart Association monograph on IHSS.9 The cardiac echograms obtained in 10 patients with pure mitral regurgitation and 10 patients with pure valvular aortic stenosis were also analyzed.

All cardiac echograms were recorded by means of a Smith Kline, Ekoline 20 instrument which produces 1,000 pulses/sec and utilizes a 2.25 megahertz transducer of 0.75-inch diameter. The transducer acts as a sound transmitter for 1 microsecond and as a sound receiver for the remaining 999 microseconds until the subsequent pulse. The echo received from each interface between tissues of differing acoustical impedance is displayed on a cathode-ray tube. The elapsed time between transmission and reception of the signal allows measurement of the distance between the transducer and each interface since ultrasound waves have a relatively constant velocity through most soft tissue. Thus, 1,000 measurements are obtained per second and yield a virtually constant signal. The echoes may be displayed on the face of the cathode-ray tube with distance from the transducer on one axis and time on the other axis. In this time-motion presentation the intensity of the echo is represented by the brightness of the signal, and any structure moving with respect to the transducer traces a pattern of motion as the echogram is recorded over a 4-sec period. To facilitate measurements, calibration marks representing each centimeter of tissue depth are displayed on the face of the tube at 0.5 sec intervals, and a single lead electrocardiogram is usually incorporated in the record. The face of the cathode-ray tube with its time-motion display is photographed using Polaroid film. In addition to the standard photographic record, the mitral valve signal may...
be placed on a separate strip chart recorder using the electrical output from the echograph instrument. A gating device included within the instrument may be brought into the area of the mitral valve signal. As the mitral valve signal moves along the "gate," the voltage output from the echograph varies and may be fed to any suitable external recorder. This allows more direct comparison of cardiac events recorded by several methods.

All patients were studied in the supine position with the transducer placed in the third or fourth intercostal space, 1 to 4 cm from the left sternal border. The transducer was directed slightly superomedially until the characteristic rapid motion of the mitral valve was seen. This signal has been described by many investigators.20-22 After control records were obtained at rest, further records were made during the Valsalva maneuver, amyl nitrite inhalation, or after exercise. Cardiac echograms were obtained during isoproterenol infusion in those patients studied during left heart catheterization as previously described from this laboratory.23

Results

In figure 1A the classic pattern of normal mitral valve motion (anterior leaflet only) is illustrated. In early diastole the anterior leaflet moves toward the transducer on the anterior chest wall as the valve opens rapidly. During rapid ventricular filling, the whole valve structure moves away from the anterior chest wall as the ventricular volume increases. At the end of the rapid filling phase, the leaflet shows rapid motion toward the closed position, where it remains until atrial systole again widens the valve. After atrial systole, and before ventricular systole, the leaflet again shows a rapid posterior motion to the closed position. During ventricular systole, the anterior leaflet inscribes a gradual movement toward the anterior chest wall as the total volume of the heart increases.20-24 The area of the left ventricular outflow tract between the interventricular septum and the anterior leaflet of the mitral valve decreases only slightly during systole in the normal heart.25 The anterior mitral valve leaflet moves toward the interventricular septum when opening in diastole, but the mitral valve echogram only occasionally makes contact with the interventricular septum signal. The normal slope of initial mitral valve motion after opening in diastole ranges between 80 and 150 mm/sec.

The typically abnormal findings in mitral valve motion found in patients with IHSS are illustrated in figure 1B. These are as follows:

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**Figure 1**

*The echographic pattern. (A) Normal motion of anterior mitral valve leaflet. (B) Motion of anterior mitral valve leaflet of a patient with IHSS. The systolic phase of valve motion is indicated by brackets (see text). In this and all subsequent figures, anterior motion is toward the top of the records. EKG = electrocardiogram; IVS = interventricular septum; MV = mitral valve.*
The mitral valve shows a sharp anterior (upward) movement beginning with ventricular ejection and reaching its peak coincident with the peak of the systolic murmur (SM) recorded at the cardiac apex. CEG = cardiac echogram. (Arrow marks the systolic bulge.)

1. The normal slow systolic motion was replaced by an abrupt motion toward the interventricular septum, beginning with the onset of ejection and reaching its peak or contacting the interventricular septum at the end of the first third of systole. The mitral valve tracing then reached a plateau through the second third of systole and receded from the interventricular septum in the last third of systole. The mitral valve thus narrows the left ventricular outflow tract, with the peak of this motion corresponding in time with both the peak of the murmur (fig. 2) and the dip in the arterial pulse contour (fig. 3). The movement away from the septum corresponds with the appearance of the tidal wave in the arterial pulse. This abnormal pattern was present in 17 of the 20 patients with IHSS studied (table 1).

2. The anterior mitral valve tracing made contact with the interventricular septum in 11 of 20 patients during systole.

3. In 10 of 20 patients the mitral valve tracing made contact with the interventricular septum in diastole.

4. The slope of the initial mitral valve motion after opening in diastole ranged from 35 to 78 mm/sec (mean, 51 mm/sec) which is much slower than normal.

In addition to these objective changes from the normal pattern, the patients with the more severe hemodynamic obstruction tended to have the highest amplitude of mitral valve motion in the systolic phase, and thus the smallest left ventricular outflow tract. The reverse was also true of those patients with a stable degree of obstruction at rest. The most

The brachial artery pulse (BA) shows the typical percussion and tidal waves seen in IHSS. The simultaneously recorded mitral valve motion shows a sharp systolic anterior movement beginning coincident with ventricular ejection. The mid-systolic dip and tidal wave in the arterial pulse correspond with the peak anterior motion and reversal of this motion in the mitral valve record, respectively. The arterial pulse is delayed temporally 0.05 sec because of the peripheral recording point. LV = left ventricular pressure. (Arrow marks the systolic bulge.)
fascinating findings were those seen in the four patients with labile left ventricular outflow tract obstruction at rest who were studied during catheterization. In these patients a normal echographic pattern was present when no pressure gradient was recorded across the left ventricular outflow tract. However, the appearance of a spontaneous or induced gradient of as little as 5 to 10 mm Hg was accompanied by a minor but definite change in the systolic pattern of mitral valve motion in that the echogram showed a

Figure 4

Echograms of mitral valve motion during cardiac catheterization. Arrows indicate systole. (A) Resting control with normal systolic valve motion; no left ventricular outflow gradient. (B) During amyl nitrite inhalation a systolic anterior movement is seen in the valve; outflow gradient of 62 mm Hg. (C) Control after amyl nitrite inhalation with reversion to a normal systolic pattern; no outflow gradient. (D) During isoproterenol infusion the systolic anterior movement again appears; outflow gradient of 10 mm Hg.

(A and C) These echograms are records similar to those seen in patients with mitral stenosis.
hump in mid-systole (fig. 4). This change in pattern was most striking when seen only in a post-extrasystolic beat, accompanied by a pressure gradient in this beat only (figs. 5 and 6). Continuous observation of the echogram during catheterization repeatedly and consistently allowed prediction of the presence or absence of a pressure gradient in all patients.

The following diagnoses resulted from catheterization and angiographic study of the
nine patients suspected clinically of having IHSS but who were without an abnormal echogram: pure mitral regurgitation in six, nonobstructive cardiomyopathy in one, valvular aortic stenosis and regurgitation with mitral regurgitation in one, and mitral stenosis with tachycardia in one. A single false-positive test was obtained on the patient just mentioned with mitral stenosis and tachycardia. While the heart rate was approximately 130 to 140/min, a suggestion of a "systolic hump" was present and accompanied by a mid-systolic dip in the arterial pulse contour, but without a pressure gradient across the left ventricular outflow tract. Repeat study with the patient in sinus rhythm at a rate of 92/min showed a normal pattern.

False negative tests were obtained at least once during repeated studies of eight patients with proven IHSS (table 1). These patients will be discussed subsequently.

The abnormal systolic pattern was not observed in any of the 10 patients with pure mitral regurgitation or the 10 patients with pure valvular aortic stenosis.

Discussion

The anatomic site of obstruction in IHSS has been inferred from the location of the pressure gradient recorded at cardiac catheterization, and angiographic studies have demonstrated narrowing of the left ventricular outflow tract in the area just below the aortic valve. Several investigators have suggested that the anterior leaflet of the mitral valve has an abnormal position during systole, due to reorientation of the axes of the papillary muscles and that it is an important part of the outflow tract obstruction. The mitral valve position in systole then is a reflection of a hypertrophic contraction band near the base of the ventricle, which distorts the valve apparatus. In our studies an abnormal motion of the mitral valve toward the interventricular septum was seen during systole. The degree of obstruction was reflected in the severity of compromise of the left ventricular outflow tract seen between the interventricular septum and mitral valve by cardiac echography (fig. 7). When no pressure gradient was present during catheterization studies, narrowing of the left ventricular outflow tract was not seen on the echogram of the five patients with latent or labile disease. In three other patients an abnormal and stable echographic pattern was observed at a time when left ventricular outflow gradients were recorded. In patients without resting gradients (who had normal echograms), gradients were induced by either isoproterenol or amyl nitrite, and abnormal echograms were then recorded (figs. 4 and 6).
In our studies the most reliable sign of the abnormal systolic pattern in the echogram was the reversal of the mitral valve motion in late systole (fig. 3). This phenomenon seems to correlate with the tidal wave seen in the arterial pulse. This anterior motion of the mitral valve during systole and its reversal was first observed by Shah and associates\textsuperscript{18} on echograms from patients with IHSS. Angiographic studies and previous echographic observations have not provided an explanation for this reversal\textsuperscript{28, 29} since no relaxation of the posterior wall of the left ventricle in late systole has been noted. Clearly this reversal occurs when a gradient across the outflow tract is still recorded, and no adequate explanation for its occurrence is presently available. Shah and associates\textsuperscript{18} have suggested this late reversal may be due to mitral regurgitation which frequently occurs in patients with IHSS.

Despite the use of provocative procedures in eight of the nine control patients suspected of having IHSS but without abnormal echograms, no pattern similar to that seen in patients with IHSS could be created. Furthermore the abnormal pattern described in this report could not be induced by using the Valsalva maneuver, amyl nitrite, or exercise in the 10 patients with valvular aortic stenosis or the 10 patients with mitral regurgitation. It appears important, however, to employ provocative techniques while screening for IHSS with the cardiac echograph just as it is during cardiac catheterization.

An abnormal systolic pattern was recorded in a patient with severe mitral stenosis, in whom a rapid heart rate was presumed to produce the pattern, since a normal pattern occurred with the reversion to a slow heart rate. Of note was another adult patient with documented atrial septal defect showing a systolic hump in the mitral valve echogram. While this might be a false positive IHSS pattern, the left ventricular outflow tract was not narrowed owing to an altered septal motion observed with cardiac echographic studies in many patients with atrial septal defect.\textsuperscript{29} The explanation for the systolic hump in patients with atrial septal defects is the large volume change in the right heart during ejection. As the right ventricle empties, the whole mitral valve structure has an exaggerated anterior motion as compared with the normal, and this is reflected in the cardiac echogram.

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A decreased initial slope of mitral valve motion in diastole was noted which supports the studies of Stewart and Moreyra and their associates. The mitral valve pattern in diastole could be mistaken for true mitral stenosis unless test procedures were done to bring out the abnormal systolic motion (figs. 4 to 6).

Only one half of our patients showed diastolic contact of the mitral valve with the interventricular septum. Therefore, we do not think diastolic contact is a good echographic sign of IHSS as has been reported by others.

In two recently diagnosed cases of IHSS studied during left heart catheterization, abolition of both the left ventricular outflow obstruction and the abnormal mitral valve pattern was observed after acute beta-adrenergic blockade by propranolol (150 mg/kg). One patient (S.R.) of the previously diagnosed group with IHSS has converted from an abnormal resting echogram pattern prior to the institution of chronic propranolol therapy (160 mg/day) to a normal pattern in the resting state while receiving the drug. Follow-up catheterization in this patient confirmed the absence of a resting pressure gradient across the left ventricular outflow tract.

Several preliminary conclusions seem warranted from the observations presented in this study: First, an abnormal and highly unusual pattern of mitral valve motion is seen in the cardiac echogram of patients with IHSS. Secondly, the basic abnormalities and variability in the degree of abnormality seen on the echogram are consistent with the proposed anatomy and pathophysiology of IHSS. Thirdly, the conversion from an abnormal to a normal systolic pattern on echogram indicates the disappearance of a hemodynamically significant left ventricular outflow obstruction. Fourthly, cardiac echography seems to be a simple, safe, convenient, and atraumatic technic by which to diagnose and evaluate therapeutic responses in patients with IHSS.

References


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