Echocardiographic spectrum of hypertrophic cardiomyopathy¹

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Echocardiographic patterns in 15 patients with hypertrophic cardiomyopathy were compared with those in 30 healthy persons. Correlations with angiocardiographic data indicated that most of the anatomical abnormalities in hypertrophic cardiomyopathy can be assessed reliably by echocardiography. These include abnormal mitral valve motion, a reduction of the anteroposterior dimension of the left ventricular outflow tract and of the left and right ventricular cavities, increased thickness of the interventricular septum and the posterior left ventricular wall. Comparison of the haemodynamic and echocardiographic data showed that some degree of abnormal mitral valve motion during systole may occur in the absence of left ventricular outflow tract obstruction. On the other hand, it need not always be present with left ventricular outflow tract obstruction.

Other, hitherto unrecognized, abnormalities in hypertrophic cardiomyopathy detected by this technique were: (1) Aortic valve regurgitation in three out of nine patients with evidence of left ventricular outflow tract obstruction at cardiac catheterization. (2) Left ventricular inflow tract obstruction at the mitral valve level associated with gross septal hypertrophy (five cases). (3) Abnormal forward displacement of the posterior mitral valve leaflet and of the chordae tendineae during systole in 10 patients, in seven of whom there was confirmatory angiocardiographic evidence.

Seven patients with miscellaneous cardiac disorders are described in whom asymmetric septal hypertrophy was revealed by echocardiography. In one of these patients coexisting hypertrophic cardiomyopathy was excluded histologically; thus asymmetrical septal hypertrophy is not confined to patients with hypertrophic cardiomyopathy.

During the past four years echocardiography has proved of diagnostic value in hypertrophic cardiomyopathy with or without obstruction. Moreyra *et al.* (1969) were the first to study patients with hypertrophic cardiomyopathy and described a cluster of echoes of varying thickness impinging on the anterior mitral leaflet echoes during diastole. They suggested that the thickened interventricular septum was responsible for this appearance. Sometimes they observed a reduction of the slope of the anterior mitral leaflet echoes, and they attributed this to decreased left ventricular filling as a result of reduced left ventricular compliance. However, these early recordings were lacking in definition and did

not permit accurate evaluation of all the features described.

The occurrence of an abnormal forward movement of the anterior mitral leaflet during systole in hypertrophic obstructive cardiomyopathy was first suspected by Bjork (1964) and was angiographically documented by Dinsmore, Sanders, and Harthorne (1966). This abnormality was confirmed by Simon, Ross, and Gault (1967), who also observed a similar abnormality involving the posterior mitral valve leaflet. They postulated that the abnormal systolic motion of the mitral valve leaflets resulted from abnormal traction on the chordae tendineae, secondary to maldirection of the hypertrophied papillary muscles. They also suggested that the abnormal systolic position of the mitral valve leaflets together with asymmetrical septal hypertrophy played an important part in the production of intraventricular pressure gradients.

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Soon afterwards Shah, Gramiak, and Kramer (1969) reported that the abnormal forward displacement of the anterior mitral leaflet in hypertrophic obstructive cardiomyopathy could be visualized echocardiographically. Furthermore, they suggested that the forward displacement of this leaflet towards the interventricular septum during systole was responsible for the left ventricular outflow tract obstruction and for the mitral valve regurgitation, which are commonly seen in this disease. These observations and interpretations have been supported by Popp and Harrison (1969) and Pridie and Oakley (1970).

Echocardiographic evidence of extreme narrowing of the left ventricular outflow tract in hypertrophic cardiomyopathy was presented by Gramiak, Shah, and Kramer (1969). This was in contrast to the wide left ventricular outflow tract observed in patients with aortic valve disease. However, no details of their measurements were given. Gramiak *et al.* (1969) also noted an abnormal aortic valve echo pattern in this disease. The aortic cusp echoes were seen to move centrally towards a position of closure during mid-systole and then back towards the original systolic position. They suggested that this pattern was secondary to obstruction in the left ventricular outflow tract produced by the abnormal movement of the anterior mitral leaflet during systole.

More recently Abbasi *et al.* (1972) and Henry, Clark, and Epstein (1973) have measured the thickness of the interventricular septum and of the posterior left ventricular wall by echocardiography. They have suggested that a significant increase in the ratio of septal to posterior free wall thickness is a specific finding in hypertrophic cardiomyopathy and is useful in detecting the non-obstructive cases in whom the abnormal anterior displacement of the anterior mitral echoes does not occur.

In the present report the echocardiographic patterns in documented cases of hypertrophic cardiomyopathy are described in detail and compared with the patterns found in patients with asymmetrical septal hypertrophy from other causes. A spectrum of abnormalities of the aortic valve echoes and some new observations on the anterior and the posterior mitral valve leaflet echoes in association with hypertrophic cardiomyopathy are described.

Subjects and methods

Echocardiographic studies of the mitral and aortic valves, the left and right ventricular cavities, the interventricular septum, and the posterior left ventricular wall were performed in 30 healthy persons (aged 15 to

55 years) with no symptoms or signs referable to the cardiovascular system, in 15 patients with hypertrophic cardiomyopathy, and in seven patients with asymmetrical ventricular septal hypertrophy from miscellaneous causes.

The echocardiograms were recorded with an Ekoline 20 ultrasonoscope and a focused 0.75-in (19.1 mm) diameter 2.25 MHz transducer with a repetition rate of 1000 impulses/s. The patients were examined in the left lateral position with the transducer applied over the left third or fourth intercostal space near the left sternal edge. As an initial point of reference the echoes from both mitral leaflets were identified together with those from the ventricular septum and posterior free wall of the left ventricle. Tilting the transducer slightly inferiorly until the mitral echoes were just lost permitted examination of the left ventricular cavity in the submitral valve region. From this position the transducer was gradually directed superiorly so that the ultrasound was beamed in an arc towards the aortic root, according to the method of Feigenbaum (1972). The ultrasound patterns were viewed on an oscilloscope using M mode of display. Permanent recordings were made with a polaroid camera in 16 of the 52 cases studied, and in the remaining 36 the information from the Ekoline was displayed on a Cambridge recorder oscilloscope, and strip chart recordings were made together with simultaneous electrocardiogram and phonocardiogram. The recordings in these instances were made on photographic paper.

Fig. 1 illustrates the levels at which the various echocardiographic measurements were made. The tube-like left ventricular outflow tract is bounded anteriorly by the interventricular septum and posteriorly by the anterior mitral leaflet. The echocardiographic assessment of the high and the low anteroposterior dimensions of the left ventricular outflow tract were made by measuring the distances between the endocardial echoes from the interventricular septum (on the left side) and the nearest anterior mitral leaflet echoes during mid-systole in positions 3 and 2, respectively (as defined in Fig. 1). With the mitral valve leaflets open during diastole the anteroposterior dimension of the left ventricular inflow tract extends from the interventricular septum to the posterior left ventricular wall and corresponds again to position 2. The submitral valve region corresponds to the left ventricular cavity at the level between the tips of the mitral valve leaflets and the posterior papillary muscle and corresponds to position 1. The left ventricular inflow tract and the left ventricular submitral valve dimensions were measured as the distance between the echoes of the endocardial surfaces of the interventricular septum and posterior left ventricular wall at positions 2 and 1 respectively. The right ventricular dimensions were measured by the distance between the echoes from the anterior right ventricular wall endocardial surface and the endocardial surface of the right side of the interventricular wall at position 2. All the end-diastolic dimensions were measured at the time of the R wave of the simultaneously recorded electrocardiogram. The end-systolic dimensions of the ventricular cavities were taken at the point when the endocardial echoes of the posterior left ventricular wall and anterior right ventri-

FIG. 1 Diagrammatic cross-section of the heart. Arrows indicate presumed path taken by the ultrasonic beam in the M-mode scan positions 1 to 4. Position 1 = Submitral valve level. Position 2 = Left ventricular inflow tract (LVIT) and lower left ventricular outflow tract (LVOT) level. Position 3 = Upper LVOT level (position at which the PM echoes are just lost). Position 4 = Aortic root (AO) level. T = transducer; CW = chest wall; ARV = anterior right ventricular wall; RV = right ventricular cavity; IVS = interventricular septum; Aa and Ap = anterior and posterior aortic root walls; LV = left ventricular cavity; LA = left atrium; AM and PM = anterior and posterior mitral valve leaflets; PLV = posterior left ventricular wall; PPM = posterior papillary muscle; PLA = posterior left atrial wall.

cular wall were nearest the ventricular septal echoes. The aortic valve was assessed as described by Feizi, Symons, and Yacoub (1974). The left atrial dimension was measured at end-systole by the distance between the echoes from the posterior aortic root wall and the posterior left atrial wall. The amplitude of the excursion of the anterior mitral leaflet echoes was measured as the vertical distance between point C and E of the mitral valve echogram (Fig. 2A). The E-F slope of the mitral valve was estimated as described by Edler (1966).

Results

Echocardiographic studies of 30 healthy persons

The echocardiographic patterns of the mitral and the aortic valves of one of the healthy controls are shown

in Fig. 2A and 2B for comparison with patterns seen in patients with hypertrophic cardiomyopathy. Fig. 2A shows the mitral valve echocardiogram; both the anterior and posterior leaflet echoes are demonstrated. These echoes come together at the onset of ventricular systole (C) and stay together until the onset of ventricular diastole (D). Fig. 2B shows the aortic valve echocardiogram. The anteriorly and posteriorly visualized slender cusp echoes (Ca and Cp respectively) are seen within the aortic root area (Aa and Ap). At the onset of ventricular systole echoes (C), which represent cusp echoes in the closed position, are rapidly replaced by two parallel lines Ca and Cp which represent the valve cusps in the fully open position. Ca and Cp lie in close proximity to the Aa and Ap echoes. Fig. 3 shows the M-mode scan of the left ventricular cavity.

The measurements of the various echocardiographic parameters in the 30 healthy controls are shown in Table 3.

Studies on 15 patients with hypertrophic cardiomyopathy

The clinical, catheter-angiographic, and some of the echocardiographic data are shown in Tables 1, 2, and 3.

Additional echocardiographic data on individual patients. Case 1. The mitral valve echogram (Fig. 4A) showed pronounced forward displacement of the anterior leaflet echoes during systole, with apparent complete obliteration of the lower left ventricular outflow tract during mid-systole. The posterior leaflet and the posterior chordal echoes also showed forward displacement. In diastole the anterior leaflet echoes were again in contact with the wide interventricular septal echoes. The excursion of the anterior leaflet echoes was reduced. These suggested that there was incomplete opening of the anterior leaflet resulting in left ventricular inflow obstruction. Fig. 4B is a diagram of the cross-section of a heart with septal hypertrophy to illustrate how gross interventricular septal hypertrophy may mechanically interfere with full opening of the anterior leaflet and result in left ventricular inflow obstruction. The interventricular septal echoes showed reduced amplitude of motion, suggesting impaired contractility. The posterior left ventricular wall echoes were slightly widened and the amplitude of motion suggested good contractility. The aortic valve echogram (Fig. 4C) was abnormal. The Ca echoes showed a succession of chaotic posterior and anterior movements throughout systole. The posterior motion invariably coincided with increased intensity of the murmur recorded by phonocardiogram. The Cp echoes, though visualized, were not clearly defined.

Case 2. The mitral valve echogram showed variable forward displacement of the anterior leaflet. The posterior leaflet echoes, on the other hand, showed regular, pronounced forward displacement during

FIG. 2 Normal echocardiogram. A) Mitral valve area corresponding to position 2 in Fig. 1. AM=anterior mitral valve leaflet echoes, of which C denotes leaflet echoes at onset of ventricular systole. D=leaflet echoes at onset of ventricular diastole. E=most anterior point of the anterior leaflet (AM) echoes during diastole. F=echoes representing partial closure of the mitral valve during diastole. PHONO=phonocardiogram. ECG=electrocardiogram. B) Aortic valve area. Ca and Cp=echoes from the anteriorly and posteriorly positioned aortic valve cusps. C'=cusp echoes during diastole. Other abbreviations as in Fig. 1.

systole. During diastole the anterior leaflet echoes were in contact with the interventricular septal echoes. The septal echoes suggested gross hypertrophy and reduced contractility while the posterior left ventricular wall echoes suggested mild hypertrophy and good contractility. The aortic valve echogram was compatible with incomplete closure during mid-systole and then reopening of the valve. Both Ca and Cp echoes were recorded.

Case 3. The mitral valve echogram did not show abnormal forward displacement of the anterior or posterior leaflet echoes during systole (Fig. 5) even after amyl nitrite inhalation. The interventricular septal echoes suggested gross hypertrophy and reduced contractility, while the posterior ventricular wall echoes suggested normal thickness and contractility. The aortic valve echogram was compatible with incomplete closure of the valve during mid-systole. Both Ca and Cp echoes were recorded.

Case 4. The mitral valve echogram (Fig. 6A) showed pronounced forward displacement of the anterior leaflet echoes similar to that seen in Case 1. However, the posterior leaflet echoes showed a minor degree of displacement during systole. The septal

echoes and the posterior wall echoes suggested poor contractility. The aortic valve echogram was recorded with difficulty (Fig. 6B), presumably because of a bulging septum. Only the Ca echoes were clearly recorded and these moved normally anteriorly to the fully open position at the onset of ventricular systole; they then immediately moved posteriorly towards a position of almost complete closure instead of remaining in the open position until the onset of ventricular diastole.

Case 5. The mitral valve echogram (Fig. 7A) showed pronounced forward displacement of the anterior leaflet echoes during systole. The posterior leaflet echoes also showed forward displacement. The appearance of the anterior and posterior leaflet echoes suggested thickening of these leaflets. The septal echoes were wide and showed reduced amplitude of motion, the posterior wall echoes were slightly widened and showed normal amplitude of motion. The aortic valve echogram was abnormal (Fig. 7B). The Ca echoes showed a succession of chaotic posterior and anterior movements throughout systole. The Cp echoes also showed chaotic motion during systole. In addition the Ca and the Cp echoes showed increased intensity and abnormal separation during diastole, suggesting thickened cusps and aortic regurgitation. The M-mode scan (Fig. 8) showed

FIG. 3 *M-mode scan of normal left ventricle. Echocardiographic patterns corresponding to positions 1 to 4 are shown. Abbreviations as in Fig. 1 and 2.*

TABLE 1 *Clinical data on 15 patients with hypertrophic cardiomyopathy*

Case No.	Age and sex	Presenting features	Rhythm	Murmurs			
				Grade	Systolic timing	Location	Grade
1	25 M	Dyspnoea and palpitation	Junctional	3/4	Late	LSE and apex	
2	50 F	Dyspnoea (previous hemiparesis)	AF	2/4	Late	LSE	1/4
3	72 F	Dyspnoea	AF*	1/4	Late	LSE	
4	47 M	Hemiparesis, palpitation, and dyspnoea	AF	4/4	Pan	Generalized	1/4
5	58 M	Angina pectoris and palpitation	AF	3/4	Late	LSE	2/4
6	65 M	Syncope and palpitation	AF*	3/4	Late	LSE	1/4
7	25 M	Murmur	SR	3/4	Late	LSE	1/4
8	10 M	Murmur and chest pain	SR	3/4	Late	LSE	
9	38 F	Murmur and dyspnoea	SR	2/4	Mid	LSE	1/4
10	27 M	Abnormal electrocardiograph and atypical chest pain	SR	1/4	Mid	Apex	
11	41 M	Murmur and abnormal electrocardiograph	SR	2/4	Mid	LSE	
12	51 M	Epigastric pain	SR	2/4	Late	LSE	
13	17 M	Dyspnoea and angina pectoris	SR	3/4	Mid	LSE	
14	43 M	Palpitation	SR	2/4	Mid	LSE	
15	39 M	Dyspnoea and syncope	AF*	1/4	Mid	LSE	

*Recent onset.

†Clinical diagnosis before echocardiography and cardiac catheterization.

LSE=Left sternal edge. AF=Atrial fibrillation. SR=Sinus rhythm. AR=Aortic regurgitation.

complete obliteration of the left ventricular cavity area at the submitral valve level.

Case 6. The mitral valve echogram resembled that of Case 1. However, the forward displacement of the anterior leaflet echoes was less pronounced for they fell just short of those from the ventricular septum. In diastole the anterior leaflet made variable contact with the septal echoes. The septal echoes were compatible with septal hypertrophy and impaired contractility. The posterior wall echoes were slightly widened and the amplitude of motion suggested good contractility. The aortic valve echogram was abnormal (Fig. 9). It showed a pattern compatible with normal opening at the onset of ventricular systole. This was followed by partial closure during mid-systole. The abnormality was more pronounced after extrasystolic beats, when a pattern was recorded compatible with normal opening of the valve followed by closure and then reopening. As in Case 5, the Ca and Cp echoes showed increased intensity and abnormal separation during diastole.

Case 7. The mitral valve echogram showed a moderate degree of forward displacement of the anterior and posterior leaflet echoes during systole. The septal echoes were compatible with gross thickening and poor contractility while those from the posterior wall suggested normal thickness and good contractility. The aortic valve echogram was compatible with partial closure of the valve during mid-systole, as in Cases 2 and 3.

Case 8. The mitral valve echogram showed pronounced forward displacement of the anterior and posterior leaflet echoes during systole. The septal echoes suggested septal hypertrophy with good contractility. The posterior wall echoes were slightly widened and the amplitude of motion suggested good contractility. The aortic valve echogram was similar to that in Cases 2, 3, and 7.

Case 9. The mitral valve echogram showed no forward displacement of either anterior or posterior leaflet echoes during systole. The anterior leaflet echoes showed fine fluttering during diastole suggestive of aortic regurgitation. The septal echoes suggested hypertrophy and poor contractility while the posterior wall echoes were compatible with normal thickness and reduced contractility. The aortic valve echogram could not be recorded, presumably because of a bulging septum.

Case 10. The mitral valve echogram showed pronounced forward displacement of the anterior leaflet echoes during systole (Fig. 10). The posterior leaflet echoes showed mild displacement. The septal echoes were compatible with hypertrophy and poor contractility. The posterior wall echoes were unremarkable.

Case 11. The mitral valve echogram showed forward displacement of the anterior and posterior leaflet echoes during systole. Furthermore, the anterior chordae tendineae (AC) echoes were prominent and also showed forward displacement. The septal echoes suggested hypertrophy and very good contractility. The posterior wall echo pattern also suggested good contractility (Fig. 11A).

Case 12. The mitral valve echogram was similar in most respects to that of Case 11, but the forward displacement of the anterior and posterior leaflet echoes during systole was less pronounced. The septal echoes were wide and suggested good contractility. The posterior wall echoes were unremarkable.

Case 13. The mitral valve echogram was normal (Fig. 11B) even after amyl nitrite inhalation. The septal and posterior wall echoes suggested hypertrophy and good contractility.

Case 14. The mitral and aortic valve echograms were normal, as in Case 13. The septal pattern suggested hypertrophy and good contractility.

Case 15. The mitral and aortic valve echograms were normal, as in Cases 13 and 14. The septal echoes suggested hypertrophy and poor contractility while the posterior wall echoes were unremarkable.

Diastolic systolic	Initial clinical diagnosis†	
	Location	
not heard		Hypertrophic cardiomyopathy
id	Apex	Mitral stenosis and regurgitation
not heard		Aortic stenosis
id	Apex	Hypertrophic cardiomyopathy
immediate	LSE	Hypertrophic cardiomyopathy
id	Apex	Hypertrophic cardiomyopathy
id	Apex	Mitral stenosis
not heard		Noonan's syndrome and pulmonary stenosis
immediate	LSE	Aortic stenosis + AR
not heard		Coronary artery disease
not heard		Coronary artery disease
not heard		Peptic ulcer or coronary artery disease
not heard		No diagnosis
not heard		No diagnosis
not heard		Hypertrophic cardiomyopathy

Echocardiographic studies of seven patients with asymmetrical septal hypertrophy due to miscellaneous causes

A 15-year-old boy with aortic stenosis caused by a congenital bicuspid aortic valve was studied by echocardiography four weeks after valvotomy. Exploration at operation had shown an abnormal anterolateral papillary muscle and a muscular band extending from its apex to the anterior leaflet of the mitral valve. At the end of the operation a withdrawal pressure trace from the left ventricle to the aorta showed the following peak systolic pressures: at mid-left ventricular cavity 230 mm Hg (30.6 kPa); outflow tract 120 mm Hg (16.0 kPa); aorta 80 mm Hg (10.6 kPa). The echocardiogram (Fig. 12A) showed wide interventricular septal echoes (2.0 cm), slightly widened posterior left ventricular wall echoes (1.2 cm), and the ratio of septal to posterior

TABLE 2 Catheter-angiographic data on 15 patients with hypertrophic cardiomyopathy

Case No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Peak systolic LVOT pressure gradient (mmHg)	{ Resting	40	20-75	20	192	60	10	30	40	40	0	0	0	0	0	0
	{ Postectopic	60	75	NE	200	NE	85	60	80	NE	0	0	0	0	0	0
Indirect MV diastolic gradient (mmHg)		7	0	0	7	0	6	NT	0	0	0	NT	NT	NT	NT	0
Grade of mitral regurgitation		2/4	0	0	2/4	NC	0	0	1/4	0	0	0	0	0	0	0
Grade of aortic regurgitation		NC	NC	NC	NC	NC	1/4	NC	NC	1/4	NC	NC	NC	NC	NC	NC
Abnormal V-shaped MV configuration by angiography		+	+	0	+	NC	+	+	NV	0	+	+	NV	0	0	0
Coronary arteriography		NC	NC	NC	NC	NC	NC	NC	NC	NC	N	N	N	NC	N	NC

LVOT=Left ventricular outflow tract. MV=Mitral valve. NT=Simultaneous left ventricular and pulmonary wedge pressure not taken. NE=Not examined. +=Present. NC=Investigation not carried out. NV=Mitral valve not visualized. N=Normal.

Conversion factors from Traditional units to SI units: 1 mmHg $\approx$ 0.133 kPa.

TABLE 3 Echocardiographic data on 30 healthy controls and 15 patients with hypertrophic cardiomyopathy

Echocardiographic data	Healthy range	controls mean	1	2	3*	4	5	6*	7	8
Upper LVOT dimension (cm)	1.8-3.0	2.0	2.0	1.8	1.5	1.0	1.1	1.6	1.8	2.0
Lower LVOT dimension (cm)	2.2-3.0	2.4	0.0	0-0.6	1.0	0.0	0.0	0.7	0.9	0.0
End-diastolic LV dimension (cm)										
LVIT level	{ 4.0-5.0	4.5	5.0	3.8	3.2	4.5	4.3	5.0	3.4	2.4
Sub-MV level	{ 4.0-5.2	4.6	5.5	3.2	3.0	NE	1.7	4.0	3.5	2.4
End-systolic LV dimension (cm)										
LVIT level	{ 3.0-3.8	3.1	2.6	2.8	3.3	4.0	2.3	3.8	2.5	1.3
Sub-MV level	{ 2.9-3.6	3.3	4.0	1.8	1.5	NE	0.0	2.5	3.0	0.0
RV dimension (cm)										
diastolic	{ 1.5-3.0	1.8	2.0	2.6	2.3	NE	2.0	3.0	1.3	1.3 (approx)
systolic	{ 1.3-3.0	1.4	1.8	1.7	1.3	NE	1.5	2.0	1.3	1.3 (approx)
LA dimension (cm)										
systolic	2.0-4.0	3.2	3.8	6.5	5.6	6.0	4.0	4.4	3.0	3.2
IVS thickness (cm)										
upper LVOT level	{ 0.8-1.1	0.9	2.0	2.0	2.0	1.7	1.6	2.0	1.5	1.8
lower LVOT level	{ 0.7-1.2	1.0	2.1	2.7	2.5	2.0	2.0	2.2	2.6	2.3
sub-MV level	{ 0.8-1.3	1.1	2.3	3.0	3.0	NM	2.5	2.6	2.6	2.3
PLV thickness (cm)										
lower LVOT level	{ 0.7-1.1	1.0	1.2	1.2	1.1	NM	1.1	1.1	1.1	0.8
sub-MV level	{ 0.7-1.1	1.0	1.2	1.4	1.1	NM	1.4	1.3	1.2	1.2 (approx)
IVS to PLV thickness ratio (diastolic)										
lower LVOT level	{ 0.8	1.0	1.7	2.2	2.5	NM	1.8	2.0	2.3	2.8
sub-MV level	{ 1.1	1.0	1.9	2.1	3.0	NM	1.8	2.0	2.2	1.9
Amplitude of AM echoes at diastole (cm)	1.8-3.0	2.0	1.5	1.6	1.8	1.4	1.9	1.7	1.5	1.5
E-F slope mm/sec (mean of 6 beats)	60-170	130	NM	NM	60	NM	110	NM	NM	45
Duration of AM to IVS apposition (% of diastolic period)	0-5	3	45	35	<5	60	<5	5-10	45	<5
Duration of AM to IVS apposition (% of systolic period)	0	0	40	0-50	0	80	65	0	0	30
Aortic valve echocardiogram			Abn	Abn	Abn	Abn	Abn	Abn	Abn	Abn

*Echocardiography carried out simultaneously with cardiac pressure traces.

**Aortic valve examined after amyl nitrite inhalation.

LV=Left ventricular. RV=Right ventricular. LVOT=Left ventricular outflow tract. MV=Mitral valve.

LVIT=Left ventricular inflow tract. LA=Left atrial. IVS=Interventricular septum. PLV=Posterior left ventricular wall.

AM=Anterior mitral valve leaflet. E-F slope=Slope of mitral valve echoes during diastole (see text). NM=Not measurable.

Abn=Abnormal. NR=Not recorded. Other abbreviations as in Table 2.

wall thickness was increased (1.7). The anterior mitral leaflet echoes recorded showed forward displacement during systole which became more prominent after amyl nitrite inhalation (Fig. 12B). The posterior leaflet echoes also showed forward displacement during systole.

Four other patients (aged 14, 16, 18, and 23) with aortic stenosis due to bicuspid valve have been studied by echocardiography. In three the study was carried out after valvotomy and in one pre-operatively. All four showed echocardiographic features compatible with severe asymmetric septal hypertrophy and two showed abnormal forward displacement of the anterior mitral leaflet echoes during systole. One of the patients who did not show the abnormal mitral valve pattern at rest or after amyl nitrite inhalation had a myotomy. All four patients, like the patient described above, had valvar and subvalvar gradients. These cases will be described in detail elsewhere.

A 28-year-old man with pulmonary valve atresia and a small ventricular septal defect, and who had Blalock's operation at the age of 23 years, was also studied (Fig. 13A). The echocardiogram showed wide interventricular septal echoes (1.7 cm) and a normal posterior left ventricular wall pattern (1.0 cm), thus the ratio of the septal to posterior wall thickness was increased (1.7). This patient subsequently died. At necropsy the measurement of the septal and posterior wall thickness correlated well with those measured by echocardiography. The histological appearance of both the septum and of the posterior wall was that of secondary hypertrophy.

A 16-year-old girl with Eisenmenger's syndrome associated with a persistent ductus arteriosus was studied by echocardiography (Fig. 13B). This showed wide interventricular septal echoes (1.8 cm) and normal posterior wall echoes which measured 1.0 cm. Thus the ratio of the septal to posterior wall thickness was increased (1.8).

Discussion

The abnormal forward displacement of the anterior mitral valve leaflet echoes during systole is generally accepted to be pathognomonic of hypertrophic obstructive cardiomyopathy. Our experience thus far has shown this abnormal mitral valve pattern to be specific for hypertrophic cardiomyopathy but not necessarily with obstruction, since three patients (Cases 10, 11, and 12) showed some degree of abnormal systolic displacement of the anterior mitral valve leaflet echoes and yet no pressure gradients were recorded at cardiac catheterization, even after provocation with isoprenaline. This suggests that echocardiography can detect abnormal mitral valve leaflet motion when there is no detectable haemodynamic effect.

Contrary to previous reports (Shah *et al.*, 1969) we have not found it possible to predict the severity of the left ventricular outflow tract obstruction by assessing echocardiographically the degree of the abnormal systolic displacement of the anterior mitral valve leaflet echoes. For example, in Cases 6 and 10 pronounced systolic forward displacement of the anterior leaflet echoes was observed with apparent narrowing of the left ventricular outflow tract yet the resting outflow tract gradient was zero in Case 10 and only 10 mm Hg (1.3 kPa) in Case 6. In Case 3 there was no abnormal forward displacement of the mitral valve leaflets, yet an outflow tract gradient of 20 mm Hg (2.6 kPa) was present. (The echocardiograms were carried out simultaneously with the cardiac catheterization studies.) It is of interest that the angiocardiograms also suggested a narrowed outflow

10*	11*	12*	13	14*	15
1.0	2.1	2.0	2.8	2.0	1.6
1.0	1.0	1.5	3.0	1.8	1.7
5.0	4.0	4.8	4.8	4.8	4.0
3.8	4.0 (approx)	NE	4.9	NE	4.0
2.8	2.0	3.3	3.5	3.5	3.0
1.3	1.7 (approx)	NE	3.0	NE	3.0
1.5	NE	1.9	1.3 (approx)	2.0	2.0
1.5	NE	1.2	1.3 (approx)	1.5	1.5
4.0	3.8	3.5	3.3	3.0	4.3
2.0	1.3	1.5	1.3	1.3	2.8
2.3	1.6	2.5	1.6	1.8	2.0
2.3	1.6	NE	1.6	NE	2.0
0.8	1.1	1.1	1.0	0.8	1.0
1.5	1.1	NE	1.0	NE	1.0
2.8	1.5	2.3	1.6	2.3	2.0
1.5	1.5	NE	1.6	NE	2.0
2.4	1.5	2.0	2.4	2.4	1.3
120	50	106	130	120	110
<5	0	0	0	0	0
0	0	0	0	0	0
N**	N**	N**	N**	N**	N**

FIG. 4 Echocardiogram of Case 1 with hypertrophic cardiomyopathy. *A*) Mitral valve area. Arrows indicate pronounced abnormal forward displacement of the anterior mitral leaflet (AM), posterior mitral leaflet (PM), and posterior chordal (PC) echoes during systole. Excursion of AM echoes in diastole is reduced; these echoes make contact with the interventricular septum (IVS) during 40% of systole and 45% of diastole. IVS echoes are wide and show reduced amplitude of motion while those from the posterior left ventricular wall (PLV) are slightly widened and show good amplitude of motion. *B*) Diagram of cross-section of a heart showing gross septal hypertrophy to illustrate how IVS hypertrophy may interfere with full AM leaflet opening and cause left ventricular inflow tract obstruction. Abbreviations as in Fig. 1. *C*) Aortic root area. Arrows indicate pronounced posterior displacement of anteriorly visualized cusp echoes (Ca) during systole, coinciding to peaks (P) in accompanying phonocardiogram. *D*) Left ventriculogram in right anterior oblique position during systole. Arrow indicates V-shaped configuration produced during systole by the anterior and posterior mitral leaflets. Left atrial (LA) opacification is also demonstrated. Abbreviations as in Fig. 1.

tract. This is presumably because of the limitation of one-dimensional visualization of the outflow tract by these techniques. Furthermore, Cases 1, 4, 5, and 8 showed apparent complete obliteration of the lower outflow tract during mid-systole, yet

there was a wide range of gradients (40 to 192 mm Hg (5.3 to 25.5 kPa).

We have confirmed that distinct narrowing of the anteroposterior dimensions of the outflow tract may occur in hypertrophic cardiomyopathy. However,

FIG. 5 Echocardiogram of Case 3 with hypertrophic cardiomyopathy showing mitral valve area. No abnormal forward displacement of the AM or the PM echoes. IVS echoes are very wide and show reduced amplitude of motion; those from the PLV show normal motion. Other abbreviations as in Fig. 2A.

recent studies (Ö. Feizi, unpublished observations) have shown similar degrees of narrowing in several patients with fixed outflow tract obstruction. In hypertrophic cardiomyopathy the narrowed outflow tract appears to be the result of hypertrophy of the interventricular septum with or without the abnormal forward displacement of the anterior mitral valve leaflet towards the interventricular septum during systole.

This study has shown that in hypertrophic cardiomyopathy forward displacement of the echoes from the posterior mitral valve leaflet and from the chordae tendineae often occurs in addition to the forward displacement of the anterior leaflet echoes during systole. In seven of the 10 patients who showed abnormal displacement of the mitral valve leaflet echoes there was confirmatory angiographic evidence. Our experience has also shown that the presence of the abnormal systolic forward displacement of the mitral valve leaflet echoes is not invariably associated with mitral regurgitation. The presence of haemodynamically significant mitral regurgitation was usually reflected on the echocardiogram by an increase in size of the left atrium and a relatively large left ventricular dimension. The aneurysmal left atrium in the patient

(Case 2) who did not have mitral regurgitation was presumably secondary to the left ventricular inflow-tract obstruction at the mitral valve level.

Table 3 shows that the finding of a reduced upper left ventricular outflow tract dimension and a prolonged period of apposition of the anterior mitral leaflet to the septum during systole is helpful in detecting the patients with moderate to severe outflow tract gradient, presumably because it reflects the extent of the outflow tract narrowing. However, a better prediction of the presence of outflow tract obstruction and its haemodynamic significance can be made by inspecting the aortic valve echogram. Case 4, in which there was severe left ventricular outflow obstruction, showed a pattern compatible with almost complete closure of the aortic cusp during systole, while patients with relatively smaller gradients showed patterns suggesting variable degree of incomplete closure of the cusp during systole. Patients with no detectable outflow tract gradient showed a normal pattern of aortic cusp movement.

Left ventricular outflow-tract obstruction in hypertrophic cardiomyopathy has received much attention but less mention has been made of left ventricular inflow-tract obstruction. The latter has been attributed to impaired left ventricular filling secondary to reduced cavity size and to loss of ventricular wall compliance associated with extreme hypertrophy (Hansen, Davidsen, and Fabricius, 1962; Goodwin, 1964; Wigle, 1964). In this study, in order to evaluate further the cause of the left ventricular inflow-tract obstruction, the E-F slope of the mitral valve leaflet was examined, since this is known to be affected by the rate of blood flow across the mitral valve (Shah *et al.*, 1968; Moreyra *et al.*, 1969). A reduced E-F slope (in the absence of mitral valve stenosis (Duchak, Chang, and Feigenbaum, 1972) would be expected when there is decreased compliance. We found that prolonged contact of the anterior leaflet with the septal echoes precluded the measurement of the E-F slope in five patients with hypertrophic cardiomyopathy (Cases 1, 2, 4, 6, and 7) (Figs. 4A and 6A). In addition, these patients had a reduced amplitude of anterior leaflet echo excursion during diastole. Cardiac catheterization in three of these five patients showed a mitral diastolic gradient (Tables 2 and 3).

These observations suggest that in hypertrophic cardiomyopathy there can be mechanical left ventricular inflow-tract obstruction at the mitral valve level, due presumably to incomplete valve opening, secondary to gross septal hypertrophy of the type described in a single case by Teare (1958). It is of interest that two or the five patients who had left ventricular inflow-tract obstruction suffered acute

FIG. 6 Echocardiogram of Case 4 with hypertrophic cardiomyopathy. A) Mitral valve area. Arrow indicates pronounced forward displacement of AM echoes during systole. Excursion of AM echoes in diastole is reduced. These echoes made contact with IVS echoes during 80% of systole and 60% of diastole. IVS pattern is compatible with gross hypertrophy and poor contractility (c.f. Fig. 2A). B) Aortic root area. Anteriorly visualized echoes (Ca) show pattern compatible with premature closure (arrowed) during systole. LA dimension is compatible with aneurysmal dilatation (c.f. Fig. 2B). Other abbreviations as in Fig. 2.

hemiparesis thought to have been embolic in origin. By demonstrating inflow tract obstruction, echocardiography may thus predict the risk of embolism in hypertrophic cardiomyopathy and also assist the selection of patients suitable for septal myotomy and myectomy. It may be this category of patients in whom mitral valve replacement has been found effective (Cooley *et al.*, 1971). However, septal myectomy (Bentall *et al.*, 1965) may be more logical, since septal hypertrophy appears to be the main contributing factor to the development of both inflow and outflow tract obstruction to the left ventricle. The majority of the patients with hypertrophic cardiomyopathy were found to have a normal mitral valve mechanism (Wigle *et al.*, 1969). Shabetal and Davidson (1972) reported three cases of asymmetrical hypertrophic cardiomyopathy in whom left ventricular inflow-tract obstruction at the mitral valve level was suspected clinically. Only one of their patients was shown to have a mitral diastolic gradient. Though echocardiography was carried out to exclude mitral stenosis this might have been overlooked, since the posterior mitral valve leaflet

echoes were not recorded (Duchak *et al.*, 1972). Furthermore, they did not observe any echocardiographic pattern diagnostic of left ventricular inflow-tract obstruction. In the remaining 10 patients in the present series with hypertrophic cardiomyopathy two had a reduced E-F slope, suggesting underlying non-compliant left ventricle, and eight had values within the normal range, thus showing that a normal E-F slope does not exclude the diagnosis of hypertrophic cardiomyopathy.

Though there are a few reports of the occurrence of both early and mid-diastolic murmurs in hypertrophic cardiomyopathy (Brachfeld and Gorlin, 1961; Hansen *et al.*, 1962; Braunwald *et al.*, 1964) there has been no satisfactory explanation of their mechanism. Some authors, however, do not regard early diastolic murmurs to be an integral feature of this disease and would consider that its presence makes the diagnosis of hypertrophic cardiomyopathy unlikely (Menges, Brandenburg, and Brown, 1961; Wigle, 1964). We propose that an early diastolic murmur present in hypertrophic cardiomyopathy is likely to be secondary to aortic valve

FIG. 7 Echocardiogram of Case 5 with hypertrophic cardiomyopathy. A) Mitral valve area showing pronounced forward displacement of AM (white arrow) and PM (black arrow) leaflets during systole. Echoes from leaflets are dense. LSE=left sternal edge. B) Aortic root area. Arrows indicate pronounced posterior displacement of Ca echoes during systole coinciding with peaks (P) in accompanying phonocardiogram. Cp echoes also showing abnormal motion. Ca and Cp echoes are dense and abnormal diastolic separation is demonstrated (c.f. Fig. 2B). Other abbreviations as in Fig. 2.

FIG. 8 M-mode scan of left ventricle of Case 5. Arrows show fusion of IVS and PPM echoes compatible with complete left ventricular cavity obliteration at submitral valve level, position 1 (c.f. Fig. 3). Other abbreviations as in Fig. 2.

FIG. 9 Echocardiogram of Case 6 with hypertrophic cardiomyopathy showing aortic valve area. Aortic valve echogram shows posterior displacement of the Ca echoes during systole coinciding with peaks in the murmur on accompanying phonocardiogram. The arrow shows failure of valve opening after ventricular ectopic beat. Increased intensity of murmur and pronounced abnormality of aortic valve pattern are shown after ventricular ectopic beat. As in Fig. 7B, the Ca and Cp echoes are dense and abnormal separation is demonstrated during diastole. Other abbreviations as in Fig. 2.

FIG. 10 Case 10 with hypertrophic cardiomyopathy. A) Echocardiogram showing mitral valve area. Arrow shows pronounced forward displacement of AM echoes during systole. PA=pulmonary area. APEX=apical area. B) Left ventricular angiogram in right oblique position during systole. Arrow indicates V-shaped configuration produced during systole by the AM and PM leaflets. No LA opacification demonstrated (c.f. Fig. 4). Other abbreviations as in Fig. 4.

FIG. 11 Mitral valve echograms of Cases 11 and 12 with hypertrophic cardiomyopathy. A) Echogram of Case 11 showing wide IVS echoes with good amplitude of motion. AM, PM, and anterior chordae (AC) echoes show forward displacement (arrowed) during systole. B) Echogram of Case 13 showing patterns of IVS and PLV echoes compatible with muscle hypertrophy and good contractility. E-F slope is fast. No abnormal systolic forward displacement of the AM echoes.

FIG. 12 Mitral valve echogram of patient with bicuspid aortic valve. A) Wide IVS echoes with good amplitude of motion. Slight forward displacement of AM echoes during systole. B) Increased forward displacement of AM echoes after amyl nitrite inhalation. PM echoes show forward displacement (arrowed) during systole.

regurgitation, since there was evidence of this in three patients in this small series of haemodynamically documented hypertrophic cardiomyopathy. The regurgitation in one patient was clinically silent but was confirmed by angiography. The regurgitation could conceivably be caused by distortion of the aortic valve ring by the grossly hypertrophied septum, resulting in impaired aortic valve approxi-

mation during diastole. On the other hand, it could have been secondary to valve damage associated with infective endocarditis of the type described by Boiteau and Allenstein (1961), Nagle (1967), Frank and Braunwald (1968), and Cardelia *et al.* (1971). In our cases subclinical infective endocarditis could have caused the aortic dysfunction. The incidence of aortic regurgitation in hypertrophic cardiomyo-

pathy is unknown, as routine aortography is rarely undertaken in this condition. In some patients this lesion can be detected by echocardiography (Feizi *et al.*, 1974), as was shown in three cases reported here. In only two of these was the reflux shown angiographically. In the third case aortography had to be abandoned because of technical problems. However, this patient had the classic

pathy was clinically excluded in all and at necropsy in one case. In the latter case cardiac muscle histology was compatible with secondary hypertrophy. The four patients with bicuspid aortic valve and asymmetrical septal hypertrophy are an interesting group, since in three there was also echocardiographic evidence of abnormal forward displacement of the anterior mitral valve leaflet echoes during

FIG. 13 Mitral valve echocardiogram of cases with pulmonary atresia and Eisenmenger's syndrome. Both show patterns compatible with asymmetric septal hypertrophy. B) Echoes from anterior right ventricular wall (ARV) thickened and suggest hypertrophy of this structure also.

early diastolic murmur of aortic regurgitation. The mid-diastolic murmur, on the other hand, may be secondary to mechanical left ventricular inflow-tract obstruction associated with incomplete mitral valve opening secondary to gross septal hypertrophy, and this could simulate mitral stenosis. The mid-diastolic murmur could also be caused by underlying regurgitation when this is severe.

It has been suggested that an interventricular septal to posterior left ventricular wall thickness ratio greater than 1.3 is a specific finding in hypertrophic cardiomyopathy. Our findings confirm that a distinct increase of this ratio occurs in this disease, since all the patients in our series had values ranging from 1.5 to 3.0 (normal 0.8 to 1.1). However, this does not appear to be specific for hypertrophic cardiomyopathy, since in the miscellaneous group of patients in whom asymmetrical septal hypertrophy was shown the diagnosis of hypertrophic cardiomyo-

systole indistinguishable from the pattern of hypertrophic cardiomyopathy. Thus the possibility was raised of coexisting cardiomyopathy. During the preparation of this paper the possibility of hypertrophic cardiomyopathy coexisting with fixed left ventricular outflow obstruction has been reported in four children (Chung, Manning, and Gramiak, 1974). One had valvar aortic stenosis, two had discrete subaortic stenosis, and one had coarctation of the aorta. However, myocardial histological confirmation is lacking in their study and also in our own. Since reports from many centres have shown the abnormal displacement of the mitral valve during systole to be specific for hypertrophic cardiomyopathy, probably these patients do indeed have this condition, or that they develop secondary myocardial changes which can produce echocardiographic pattern and haemodynamic abnormalities of the types seen in hypertrophic cardiomyopathy.

In conclusion, the diagnosis of hypertrophic cardiomyopathy can be made by echocardiography alone. It is possible to assess the extent of the anatomical abnormalities by this technique without resort to angiocardiography. Aortic valve echocardiography has proved to be of undoubted value not only in detecting some cases of aortic regurgitation but also in assessing and quantifying left ventricular outflow-tract obstruction. Mitral valve echocardiography has been shown to be of value in establishing the diagnosis of hypertrophic cardiomyopathy and in detecting mechanical left ventricular inflow-tract obstruction.

This study casts doubt on the need for routine cardiac catheterization and angiography in investigating suspected hypertrophic cardiomyopathy. When these results have been confirmed in a larger number of patients we believe that cardiac catheterization should be reserved for the following situations: (1) when surgery is indicated because of persistent symptoms despite medical treatment or in situations when the drugs are not tolerated in symptomatic patients; (2) to confirm or to exclude aortic valve disease; (3) when it is necessary to confirm the presence of mitral regurgitation and to assess its severity; and (4) when the echocardiographic findings are technically unsuitable to make a definitive diagnosis.

It is true that echocardiography in hypertrophic cardiomyopathy does not give precise pressure gradients, but this is of doubtful importance in a disease that is known to have a labile left ventricular tract obstruction which can alter from beat to beat.

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