Idiopathic Ventricular Septal Hypertrophy Causing Muscular Subaortic Stenosis

By E. Douglas Wigle, M.D., Raymond O. Heimbecker, M.D., and Ramsay W. Gunton, M.D.

Discrete, fixed supravalvular, valvular, and subvalvular forms of aortic stenosis are well recognized clinical entities. In 1957, Brock\(^1\) first drew attention to the fact that hypertrophied left ventricular musculature could also lead to obstruction of the left ventricular outflow tract. He termed this “functional obstruction of the left ventricle” or “acquired aortic subvalvar stenosis.”\(^1\) One of three cases reported at that time was believed to have developed the outflow tract obstruction as the result of left ventricular hypertrophy secondary to severe systemic hypertension. Two years later Brock reported an additional three cases of muscular obstruction of the left ventricular outflow tract,\(^2\) none of which had previous hypertension. In five of his six reported cases, there was no obvious cause for the left ventricular hypertrophy, and it was evident that previous hypertension was not the principal cause of this new syndrome.

Since Brock’s original observations a number of reports have appeared,\(^3\)-\(^11\) describing cases of obstruction of the left ventricular outflow tract by hypertrophied musculature, there being no obvious cause for the hypertrophy. Ten different terms have been used to describe this condition.\(^1\)-\(^11\)

Of particular interest and importance in considering the cause of this muscular subaortic stenosis is the necropsy study by Teare in 1958,\(^3\) entitled “asymmetrical hypertrophy of the heart in young adults.” This report described a series of eight cases in which the common feature was massive hypertrophy of the interventricular septum of unknown cause. One of these cases was studied clinically during life and presented signs of inflow obstruction to the right ventricle.\(^12\) Goodwin et al.\(^7\) reported eight cases of “obstructive cardiomyopathy simulating aortic stenosis,” and they believed the underlying cause for this syndrome was “asymmetrical hypertrophy of the heart.” In addition to dominant features of aortic stenosis, their cases also had obstruction of right and left ventricular inflow, which they believed was due to encroachment of the septal muscle mass on the tricuspid and mitral orifices. Two of their cases also had systolic pressure gradients in the mid right ventricle. The over-all picture they described was that of bilateral obstruction of the ventricular inflow and outflow tracts. It seemed reasonable that massive enlargement of the interventricular septum could cause this. Brent et al.,\(^6\) using the term “familial muscular subaortic stenosis,” had earlier described the familial incidence in this condition, and the postmortem findings in two of their cases showed marked hypertrophy of the interventricular septum. Neufeld et al.\(^8\) described the pathologic findings in a stillborn infant and in a 1-month-old child with “combined congenital subaortic and infundibular pulmonary stenosis.” The striking feature in both these cases was the massive size of the interventricular septum compared with the size of the rest of the heart. They thought that in life this septal muscle would encroach on both ventricular cavities and lead to bilateral obstruction of the ventricular outflow tracts.

Braunwald et al.\(^9\) reported 14 cases of “idiopathic hypertrophic subaortic stenosis,” and they also believed that the condition Teare described was probably responsible for the
muscular obstruction of the left ventricular outflow tract. One of their cases had a systolic pressure gradient in the mid right ventricle and another a mitral diastolic gradient. Most of their cases also had mitral insufficiency. They believed that both the mitral diastolic gradient and the mitral regurgitation could be due to distortion of the mitral leaflets by the septal muscle mass as suggested by Teare.³

Pare et al.¹¹ described a family with a high incidence of clinical findings of muscular subaortic stenosis. Postmortem examination of two hearts from this family showed marked hypertrophy of the interventricular septum.

The observation of Neufeld et al.⁹ that massive hypertrophy of the interventricular septum was present before, and just after birth, is important. It suggests that this localized hypertrophy is the primary fault and that any generalized ventricular hypertrophy could be secondary to this. Whether the mechanism of the ventricular septal hypertrophy is similar in all cases is not known. A review of reported cases suggests three modes of presentation: congenital nonfamilial, familial noncongenital, and a nonfamilial type occurring in adults.⁹

All cases of muscular subaortic stenosis, however, are not due to ventricular septal hypertrophy. In Brock’s case,¹ it was due to concentric hypertrophy secondary to severe hypertension, in the cases of Bereu et al.,⁴ to concentric hypertrophy of unknown cause, and in the cases of Björk et al.,¹³ the subaortic stenosis appeared to the authors to be due to a combination of an abnormally placed anterior mitral leaflet, plus ventricular septal hypertrophy.

It is the purpose of this report to describe 10 cases of muscular subaortic stenosis and to show that there is clinical, hemodynamic, and angiographic, as well as surgical and postmortem evidence that this condition is caused by idiopathic ventricular septal hypertrophy (asymmetrical hypertrophy of the heart).³ This septal muscle mass leads to obstruction of the right as well as the left ventricular outflow tract and to impaired ventricular filling in diastole, not because of obstruction of the mitral or tricuspid valves or cardiac failure, but rather from low ventricular distensibility or compliance.

Materials and Methods

Seventeen cases of the condition under consideration have been seen in the Cardiovascular Unit of the Toronto General Hospital since 1958. Of these, 10 cases have had left heart catheterization to prove the diagnosis and this report is confined to the findings in these 10 cases. In the remaining seven cases not catheterized, it was believed that the clinical picture was distinctive enough to justify the diagnosis. Left heart catheterization was carried out by the transthoracic method of Björk¹⁴ or by retrograde catheterization of the left ventricle percutaneously via the femoral artery and aorta. Right heart catheterization was carried out in nine of the 10 cases in the usual manner. All pressures recorded had as their zero reference a point 10 cm. above the catheterization table. Left ventricular angiograms were carried out in five cases; in two, cineangiograms were obtained; in the other three, serial exposures on roll film were taken at the rate of 12 frames per second. Left atrial angiography with subsequent left ventricular opacification was carried out in one case. Right ventricular angiograms were performed in five of the 10 cases. Surgical observations were available in three cases, and postmortem observations in three, two of which had undergone previous surgery. One surgical case has had a brachial arterial pressure tracing and clinical studies postoperatively.

Results

Clinical and Routine Investigation

Table 1 details the significant clinical, electrocardiographic, and roentgenologic findings in the 10 cases. There were eight men and two women, a ratio of 4:1. All cases were in their third, fourth, or fifth decade, reflecting the patient population of this hospital, rather than the age incidence of the disease. The occurrence of the condition in a sibling of case 3, has been proved post mortem and in a sibling of case 4, hemodynamically. Cases 8 and 10 had family histories suggestive of involvement of one parent and at least one sibling. Symptoms attributable to the cardiac lesion had been present from 1 to 18 years, and the murmur had been known to be present from 1 to 21 years. Dyspnea, angina pectoris, and lightheadness or syncope on
IDIOPATHIC VENTRICULAR SEPTAL HYPERTROPHY

Table 1

Clinical Findings in Ten Cases

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Symptoms
- Family history + + + ? ?
- Duration of symptoms (yr.) 1 4 4 3 9 3 3 18 5 6
- No. years of symptoms + + + + + + + + +
- Murmur present + + + + + + + + +
- Dyspnea + + + + + + + + +
- Angina + + + + + + + + +
- Syncope + + + + + + + + +
- Light headedness + + + + + + + + +
- Fatigue + + + + + + + + +
- Palpitations + + + + + + + + +

Signs
- Blood pressure 110 110 115 130 130 110 110 110 125 115
- Dominant "a" wave in J.V.P. + + + + + + + + +
- LV heave + + + + + + + + +
- RV heave + + + + + + + + +
- Left atrial gallop A - - - P P P P P
- Third sound - - - - + + + + +
- Right atrial gallop - - - - + + + + +
- Systolic thrill - - - - + + + + +
- Systolic murmur + + + + + + + + +
- Diastolic murmur + + + + + + + + +
- Second heart sound S N N N R R S R R R

Electrocardiogram
- LAH + + + + + + + + +
- LVH + + + + + + + + +
- RAH ±
- RVH + + + + + + + + +
- Mean QRS axis 0° +45 0 -45 +60 +90 -40 +60 +45 +10
- Abnormal Q waves + + + + + + + + +

X-ray
- Aorta SM N N N SM SM SM SM N N
- Left atrium + + + + + + + + +
- Left ventricle + + + + + + + + +
- Right atrium + + + + + + + + +
- Right ventricle + + + + + + + + +
- CTR % 52 62 59 58 53 45 58 57 48 49

Valve calcium
- FR, fast rising; A, audible; P, palpable; N, normal; S, single; R, reversed splitting; — indicates no observations recorded; SM, small.

Exertion were the common symptoms as in other types of aortic stenosis. Four cases complained of "pounding" of their hearts, frequently on assuming the recumbent posture. In no case was there a history of congestive heart failure. A number of patients volunteered the information that there was a variability in the severity of their symptoms, as might be expected with a muscular obstructive lesion.
Both systolic and diastolic blood pressures were in the low normal range. The arterial
pulse (Fig. 1) was fast rising in all 10 cases, its upstroke being similar to the waterhammer pulse of aortic insufficiency. The percussion wave was of short duration and in several cases a delayed late tidal wave was also palpable. In all cases there was clinical evidence of left ventricular hypertrophy, and a loud systolic ejection murmur was heard maximal at the cardiac apex and left sternal border (Fig. 2). This murmur was faint or absent in the aortic area or neck vessels. A distinct systolic ejection click was not noted in any case; the presence of a faint click was queried in two cases. A basal diastolic murmur was not noted in any case but two cases did have short mid-diastolic murmurs at the cardiac apex. The second heart sound split normally on inspiration in three cases, was single in both phases of respiration in two cases, and split on expiration (reversed splitting) (Fig. 3) in five cases. Of interest was the fact that day-to-day observations on the behavior of the second heart sound in any one case revealed that it could change from being normally split, to being single, to demonstrating a reversed split. Since these changes are the result of variable prolongation of left ventricular systole, it is not surprising that they should occur in a varying or muscular stenosis, the severity of which depends on the strength of left ventricular contraction. Special attention to two clinical features was paid in cases 5 to 10 by one of us (E.D.W.). Five of these six cases had both a dominant "a" wave in the jugular venous pulse (at least 2 cm. greater than the "v" wave at 30°), which increased in height during inspiration, and a palpable left atrial gallop sound (Fig. 4). This gallop sound was more easily appreciated on palpation than on auscultation and was a notable feature in these cases. The combination of this palpable gallop sound plus the left ventricular heave gave rise to a double apical impulse on palpation.11 A third heart

Figure 1
Brachial arterial pressure tracing. Case 8. P, percussion wave; T, tidal wave; D, dicrotic wave. There is a rapid rise of pressure to the percussion wave (peak systolic pressure). On palpation of the peripheral pulse, the rapid rise of pressure and occasionally the late tidal wave could be recognized.

Figure 2
Phonocardiogram, case 9. There is an ejection systolic murmur (E.S.M.) maximal at the cardiac apex and left sternal border (L.S.B.) being very faint in the aortic area. A prominent fourth heart sound (S4) is also evident. S1, first heart sound; S2, second heart sound; expir., expiration; inspir., inspiration.
sound was heard in four cases; in three (cases 6, 8, and 10) it was an inconstant finding on repeated examinations.

Electrocardiograms in the 10 cases showed evidence of left ventricular hypertrophy in nine, left atrial hypertrophy in seven, and abnormal Q waves suggestive of myocardial infarction in five cases (fig. 5).

Radiologic examination (chest roentgenograms and fluoroscopy) revealed left ventricular enlargement in all 10 cases, left atrial enlargement in nine, right atrial enlargement in six, and right ventricular enlargement in one (fig. 6). The aorta was small in half the cases, normal in size in the other half, and was noted to be excessively pulsatile in half the cases. No valve calcification was noted.

**Figure 3**

Phonocardiogram, case 8. There is an ejection systolic murmur (E.S.M.) maximal at the cardiac apex, faint in the aortic area, and well seen also in the pulmonary area. The latter may represent a separate right-sided ejection murmur due to the right ventricular obstruction by the hypertyrophied ventricular septum, since it remained (fig. 14) after the left-sided murmur vanished after surgical relief of the left ventricular outflow obstruction. Reversed splitting shown in the pulmonary area where aortic valve closure (A2) occurs after pulmonary valve closure (P2) on expiration and the two closure sounds superimpose on inspiration. A prominent fourth sound (S4) is also seen at the cardiac apex. Time lines 0.2 second.

**Figure 4**

Low-frequency phonocardiogram, case 6. There is a very marked fourth heart sound or left atrial gallop sound (S4), at the cardiac apex. In these cases this sound was usually more easily felt than heard. S1, first heart sound; S2, second heart sound; E.S.M., ejection systolic murmur. Time lines 0.2 second.

Hemodynamic Investigation

Special attention has been directed to the contour of the arterial pressure tracing in this condition (fig. 1), since its characteristics were described by Brachfield and Gorlin.15 There is a rapid rise of pressure to the peak systolic pressure (percussion wave), which is greater than the delayed tidal wave.15 These characteristics in the arterial pulse tracing in muscular subaortic stenosis contrast with the findings in valvular15 and discrete, fixed subvalvular aortic stenosis,16 where the rate of rise of pressure is slow and the tidal wave greater than the percussion or anacrotic wave. This fast-rising type of peripheral arterial pressure pulse in the presence of a demonstrated left ventricular-arterial pressure gradient has been, in our experience, diagnostic of muscular outflow tract obstruction.

The results of left heart catheterization are shown in table 2. The pressure gradients
across the left ventricular outflow tract varied from 20 to 113 mm. Hg in these 10 cases and averaged 56 mm. Hg. These gradients are measured as the pressure difference between the systolic pressure in the body of the left ventricle and the percussion wave in the arterial or aortic pulse (fig. 7). Since the stenosis is muscular in type, and greater in late systole, there is perhaps reason to measure the pressure gradient between the systolic pressure in the body of the left ventricle and the tidal wave in the arterial pulse tracing as...
Table 2

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*300 Kgm./min.

BA, brachial artery; LV, left ventricle; LA left atrium; PA, pulmonary artery; RV, right ventricle; RA, right atrium.

a better indication of the severity of the stenosis. This latter gradient averaged 22 mm. Hg (range 9 to 35 mm. Hg) more than the low ventricle-percussion wave gradient.

Withdrawal pressure traces across the left ventricular outflow tract were obtained in five cases and the gradient occurred 2 to 3 cm. below the aortic valve in every case (fig. 8).

The mean left atrial pressure was elevated in eight of the 10 cases and the end-diastolic left ventricular pressure was elevated in nine of the 10 cases (figs. 8 and 9). These pressure elevations were present in four cases (cases 6, 8, 9, and 10), which were shown at the time of right heart catheterization to have normal cardiac indices. It is therefore difficult to attribute these elevations to left ventricular failure. It is believed they are due to decreased left ventricular distensibility or compliance as suggested by Braunwald et al. In eight of the 10 cases the "a" wave exceeded the "v" wave in the direct left atrial or...
Figure 6
Chest roentgenograms in cases 4 (left) and 8 (right). Considerable enlargement of the right atrium as well as of the left ventricle is evident in each case.

Figure 7
Simultaneous low left ventricular and brachial arterial pressure tracings in cases 7, 4, 8, and 2 (left to right). In each case the percussion wave is greater in height than the tidal wave. (See fig. 1 and text.)

“wedge” pressure curve. In one case “a” exceeded “v” by 11 mm. Hg. This may also be an expression of decreased left ventricular distensibility.9 None of the eight cases in which simultaneous left ventricular and left atrial pressure curves were recorded showed a diastolic pressure gradient across the mitral valve. In five cases that had left ventricular angiograms there was evidence of left atrial opacification, indicating mitral insufficiency. The two cases that had double-dye studies17 also showed evidence of mitral insufficiency of mild degree.

The results of right heart catheterization in nine of the 10 cases are shown in table 2. The mean pulmonary artery “wedge” pressure was elevated in five of eight cases. The pulmonary artery pressure was normal in seven of the nine cases in spite of the fact that in cases 6, 8, and 9 there was considerable elevation of the “wedge” pressure. In six of the nine cases there was a pressure gradient...
in the mid right ventricle varying from 7 to 24 mm. Hg (fig. 10). This gradient occurred lower in the body of the right ventricle than that seen in the more usual forms of subvalvular pulmonary stenosis. In seven of nine cases the end-diastolic right ventricular pressure and the "a" wave in the right atrial tracing were 8 mm. Hg or more (fig. 11). There was no end-diastolic pressure gradient across the tricuspid valve. In four cases (cases 6, 8, 9, and 10) a cardiac output was determined by the Fick method and in each case the cardiac index was normal. In case 10, the cardiac index was 3.7 L./min./M.² at rest and rose to 6.7 L./min./M.² during leg exercise on a bicycle ergometer at a work load of 300 Kgm./min.

It is of interest that in the cases where the cardiac index was shown to be normal the mean pulmonary artery "wedge" pressure was elevated and at left heart catheterization all four of these cases had elevated end-diastolic left ventricular pressures. Cases 9 and 10 also had elevated end-diastolic right ventricular pressures. As pointed out previously, these elevated pressures in these four cases are difficult to explain on the basis of cardiac failure and are probably related to low ventricular compliance in this condition.⁹

Six of the 10 cases had left ventricular angiograms and in all of them there was evidence of a contractile narrowing in the left ventricular outflow tract from 2 to 4 cm. below the aortic valve, as described by Morrow and Braunwald.⁸ In the straight lateral views there appeared to be indentation of the left ventricular cavity anteriorly, as would occur

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if the constricting muscle causing the narrowing were situated in the interventricular septum, since the septum is almost parallel with the frontal plane of the body. Hence, if the septum were enlarged, it would protrude posteriorly into the cavity of the left ventricle and anteriorly into the cavity of the right ventricle in lateral angiocardiograms (fig. 12).

In addition to this indentation into the anterior aspect of the left ventricular cavity, in some cases there was also evidence of a filling defect in the posterior aspect of this cavity. This is believed to be due to the septal hypertrophy extending into the posterior wall of the left ventricle. At postmortem examination the hypertrophy extends into the anterior and posterior wall of the left ventricle to a variable degree and, when it does so, it gives rise to a muscular bar that can be seen in the posteroanterior projection of the left ventricular angiogram, as well as at autopsy (fig. 16, lower left). However, even when this is so, the ventricular septum is the site of the most marked degree of hypertrophy (fig. 16).

Right ventricular angiograms were done in cases 5, 6, 8, and 10. In addition to a filling defect in the posterior aspect of the right ventricular cavity in the lateral view, there was gross encroachment of the left aspect of the right ventricular cavity in the posteroanterior view. This is believed to be due to the bulging ventricular septum (figs. 13 and 16, lower right). A right ventricular cineangiogram in the left anterior oblique position was obtained in case 9 and although there was no mid right ventricular pressure gradient, there was evidence of a mild filling defect in the posterior aspect of the right ventricular cavity.

Cardiac surgery with bypass was attempted in cases 1 and 2, four and three years ago respectively. In both cases, pieces of muscle from the left side of the ventricular septum were removed at operation. Both survived surgery but died 2 weeks postoperatively, case 1 from recurrent pulmonary emboli, case 2 from rupture of the aortotomy incision secondary to sepsis. Goodwin et al.7 have reported a successful result by a similar technique. A third case, case 9, has recently been operated upon by Dr. W. G. Bigelow, using the technique originally suggested by Cleland8 and utilized successfully by Morrow and Brockenbrough.18 Considerable improvement has been brought about by the incision made on the left side of the ventricular septum from the apex to the base of the heart and deepened manually to a depth of 2 cm. Preoperatively he was shown to have both left and right ventricular pressure gradients (fig. 8, top, and fig. 10) and filling defects in both right (fig. 13) and

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left ventricular cavities in the angiocardiograms suggestive of massive enlargement of the ventricular septum. At operation a mass of muscle the size of a small orange was found in the interventricular septum and it could be felt and seen to be bulging the free wall.
of the right ventricle anteriorly. At the time of surgery the left ventricular systolic pressure gradient was reduced from 75 mm. Hg to zero. Postoperatively two interesting findings have been noted: the left atrial gallop sound vanished and the apical systolic murmur became very faint, whereas a pulmonary systolic ejection murmur presumably due to this narrowing of the right ventricular outflow tract (fig. 14).

In addition to the two postoperative deaths, one patient, case 3, died suddenly. Postmortem examination was done in all three. Photographs of the heart of case 3 (fig. 16) showed massive enlargement of the ventricular septum and septal hypertrophy extending into the adjacent anterior and posterior walls of the left ventricle. This extension into the anterior and posterior wall produced a muscular bar evident both in the specimen of the heart (fig. 16, lower left) and in the left ventricular angiogram. There was localized enlargement of the interventricular septum in the two postoperative deaths also. Microscopic exam-
ination of the ventricular septum in these three cases revealed marked hypertrophy of the individual muscle fibers. Neither endothelial-lined vascular channels nor particularly bizarre muscle fibers were noted.

Discussion

From clinical, hemodynamic, angiographic, surgical, and postmortem evidence it appears that the basic abnormality in these cases of muscular subaortic stenosis was massive hypertrophy of the interventricular septum. This septal muscle mass, in addition to causing obstruction of the left ventricular outflow tract in all cases, caused obstruction of the right ventricular outflow tract in six of nine cases. Nine of 10 cases had elevated end-diastolic left ventricular pressures and seven of nine had right ventricular end-diastolic pressures of 8 mm Hg or more. These elevated end-diastolic ventricular pressures were shown to exist in some patients with normal cardiac indices and the presumed absence of cardiac failure. The total hemodynamic abnormality could be explained by the septal muscle mass during systole obstructing the outflow of blood from both ventricles. During diastole, ventricular filling is impeded by the relatively non-yielding or non-compliant ventricles, which are rendered rigid and whose cavities are encroached upon by this mass of muscle in the ventricular septum. In addition, the mild mitral insufficiency that is almost invariably present could be explained on the basis of distortion of the mitral leaflets by the septal muscle mass.

Low right ventricular compliance due to the septal muscle mass can account for the elevated end-diastolic pressure in the right ventricle as well as for the prominent "a" wave in the right atrial pressure tracing and in the jugular veins on clinical examination. It would also account for the increase in the height of the "a" wave in the jugular venous pulse on inspiration and for the roentgenologic evidence of right atrial enlargement. Contraction of the muscle mass in systole causes the right ventricular filling defect and pressure gradient.

Similarly, on the left side of the heart decreased left ventricular compliance can lead to elevated left atrial pressures, especially the "a" wave, and elevated end-diastolic left ventricular pressures. The very forceful left atrial gallop sound could also be accounted for on this basis, since it is produced by increased resistance to ventricular filling. The fact that this sound is so much more forceful in this condition than in severe systemic hypertension or in severe valvular aortic stenosis.

Figure 15
Top. Postoperative brachial arterial pressure tracing in case 8 showing that the arterial pulse pressure in the beat following the long diastolic pause after a premature beat is greater than the normal pulse pressure. Bottom. Preoperative simultaneous left ventricular and brachial arterial pressure tracings in case 2 demonstrating that the arterial pulse pressure in the beat following the long diastolic pause after a premature beat is smaller than normal, presumably due to the increased force of left ventricular contraction in the post-extrasystolic beat which would increase the muscular subaortic stenosis.
suggests that the left ventricular compliance in ventricular septal hypertrophy is reduced much more than in either of the two conditions noted above, in either of which left ventricular hypertrophy can be extreme. Systolic contraction of the septal muscle mass causes the left ventricular filling defect and the systolic pressure gradient. It would appear from the pulmonary arterial, aortic, and peripheral arterial pressure tracings that in spite of the large size of the ventricular septum there is no obstruction to the outflow of blood from either ventricle in the early phases of systolic ejection, in that the rates of rise of pressure in the arteries and in the ventricle are virtually identical. It is only later in systole, with significant contraction of the septal musculature, that obstruction to the ejection of blood occurs.

The findings in case 6 of a small left ventricular pressure gradient, a normal cardiac output and index, and marked elevation of the end-diastolic left ventricular pressure (fig. 9) bring up the possibility that in some cases the septal muscle mass may disable a patient more from poor ventricular filling in diastole than from the obstruction of the outflow of blood in systole. In this respect the ventricles in some cases may be thought of as being "muscle bound." In other cases the muscular subaortic stenosis is evidently the dominant abnormality, judging from the size of the left ventricular-arterial pressure gradient (cases 8, 9, and 10).

In the cases reported here, the ventricular septal hypertrophy has led to obstruction of left and right ventricular inflow and outflow, the dominant feature being obstruction to left-sided outflow. Goodwin et al. have reported isolated obstruction of right ventricular outflow and Hollman et al. have reported clinically isolated obstruction of right ventricular inflow due to this septal muscle mass. Thus ventricular septal hypertrophy may manifest itself in a number of ways, by far the commonest being muscular subaortic stenosis. As noted previously, muscular subaortic stenosis may also be caused by concentric hypertrophy of the left ventricle.

The differentiation of muscular subaortic stenosis from the conditions with which it could be confused, such as mitral insufficiency, ventricular septal defect, and the discrete varieties of aortic stenosis, was possible on clinical examination. In muscular subaortic stenosis the combination of a prominent "a" wave in the jugular venous pulse, a fast-rising upstroke to the arterial pulse, a double apical impulse on palpation (palpable left atrial gallop sound plus the left ventricular heave) and a systolic ejection murmur maximal at the cardiac apex and lower left sternal border (faintly heard or absent in the aortic area and neck vessels) permitted this differentiation.

Summary

The clinical, hemodynamic, angiographic and, where available, surgical and postmortem findings of 10 cases of muscular subaortic stenosis have been reviewed and, from the evidence at hand, it would appear that the majority of these cases had as the basis for the stenosis, idiopathic ventricular septal hypertrophy (asymmetrical hypertrophy of the heart). This septal muscle mass leads to obstruction of the right as well as the left ventricular outflow tract, in addition to impeding diastolic ventricular filling as a result of low ventricular compliance. These features give rise to a unique clinical, hemodynamic, and angiographic picture.

Figure 16

Postmortem heart specimen, case 3. Upper left shows the thickness of the interventricular septum between the arrows. Upper right shows the marked thickening of the anterior left ventricular wall as it comes off the septum, compared with the lateral wall of the left ventricle. Lower left, viewed from above, shows how the hypertrophied septal musculature bulges into the left ventricular outflow tract below the aortic valve (arrow). Lower right shows how the septum also bulges into the cavity of the right ventricle.
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References
Idiopathic Ventricular Septal Hypertrophy Causing Muscular Subaortic Stenosis
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