Impaired Rate of Left Ventricular Filling in Idiopathic Hypertrophic Subaortic Stenosis and Valvular Aortic Stenosis

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SUMMARY

In order to determine whether there is any interference with left atrial emptying or left ventricular filling in idiopathic hypertrophic subaortic stenosis (IHSS) and aortic stenosis, the fall in pressure (y descent) of the left atrial v wave following the opening of the mitral valve was analyzed in 27 patients with IHSS and in 22 patients with valvular aortic stenosis, and the results were compared to those for 13 normal subjects and 24 patients with mitral stenosis. The y descent in 0.1 sec and the mean rate of the y descent, as well as the maximum rate of decline, were reduced in all three groups of patients, as compared to those of the normal group. The changes in IHSS were more marked than those occurring in patients with aortic stenosis or mitral stenosis. These findings in patients with IHSS and valvular aortic stenosis appear to result from reduced left ventricular compliance. It is concluded that there is an impairment of left ventricular filling in IHSS and that obstruction to ventricular inflow, as well as to outflow, contributes to the hemodynamic changes in this condition.

Additional Indexing Words: Compliance Obstruction Mitral stenosis

Although extensive investigations have been carried out in order to elucidate the precise nature of the obstruction to ventricular outflow in idiopathic hypertrophic subaortic stenosis (IHSS), relatively little attention has been directed toward an analysis of ventricular inflow in this condition. It has been appreciated for some time that the circulatory changes and intensity of symptoms in IHSS are not necessarily related to the severity or even the presence of obstruction to left ventricular ejection. In attempts to explain the hemodynamic picture in this condition, it has been suggested that the distensibility of the hypertrophied left ventricle is diminished. This suggestion has been based on the finding of an elevated left ventricular end-diastolic pressure in the presence of a normal or even reduced left ventricular end-diastolic volume.1-8 Since the compliance of the left ventricle is diminished and ventricular volume tends to be reduced, the possibility was considered that this reduction of compliance might impair left ventricular filling and thus alter the hemodynamic and clinical state in patients with IHSS. Accordingly, in order to determine whether there is any interference with left atrial emptying and left ventricular filling, the fall in pressure of the left atrial v wave following opening of the mitral valve (y descent) was examined in patients with IHSS, and the results compared with those in normal subjects, in patients with valvular aortic stenosis, and finally in patients with mitral stenosis, in whom the major hemodynamic abnormality is an impairment of left ventricular filling.

Methods

A total of 86 patients was studied. Thirteen had normal cardiovascular systems and ranged in

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The pathic patients and two proved obstruction of continuously age from 5 to 54 years (average, 19). Twenty-two patients had valvular aortic stenosis; the site of obstruction was visualized at open operation in 14 of them, and the presence of valvular stenosis was proved by left ventricular angiography or continuously recorded pressure tracings during catheter withdrawal across the valve in the other eight. The peak systolic left ventricular-arterial pressure gradient in these patients ranged between 35 and 145 mm Hg (average, 75). Twenty-four patients had mitral stenosis with mean left atroventricular pressure gradients ranging between 5 and 24 mm Hg (average, 13); in 17 of these 24 patients the diagnosis was confirmed at operation. In 27 patients with IHSS the diagnosis was established by a combination of hemodynamic and angiographic means, as described previously. Intraventricular pressure gradients ranging from 15 to 130 mm Hg (average, 50) were recorded in the basal state in 26 of these patients. In the one patient with IHSS without a gradient in the basal state, there was angiographic evidence of left ventricular hypertrophy and significant obstruction developed during the Valsalva maneuver and during the infusion of isoproterenol.

Left atrial pressure was measured by transseptal left heart catheterization through a large-bore catheter after the transseptal needle had been removed. At least six complexes, covering a complete respiratory cycle, were analyzed in each tracing and averaged.

Three characteristics of the left atrial pressure pulse were evaluated: (1) the absolute decline in pressure that occurred during the initial 0.1 sec of the y descent; (2) the mean rate of pressure fall of the y descent, calculated as the ratio of the v wave pulse pressure (pressure difference between the highest and lowest points of the v wave) to the duration of the y descent (Ry index); and (3) the most rapid rate of pressure decline (maximum dp/dt) of the y descent.

**Results**

In the normal subjects, the 0.1-sec y descent averaged 7.5 ± 0.8 (SEM) mm Hg (fig. 1). This value was significantly lower (P < 0.01) both in the patients with aortic stenosis, in whom it averaged 4.8 ± 0.6 mm Hg, and in the patients with IHSS in whom it averaged

**Table 1**

<table>
<thead>
<tr>
<th><strong>y Descent indices</strong></th>
<th>N-IHSS</th>
<th>N-AS</th>
<th>N-MS</th>
<th>AS-IHSS</th>
<th>IHSS-MS</th>
<th>AS-MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1-sec y descent</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>NS</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>NS</td>
</tr>
<tr>
<td>Ry index</td>
<td>&lt; 0.01</td>
<td>NS</td>
<td>&lt; 0.01</td>
<td>&lt; 0.05</td>
<td>NS</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>−dp/dt</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.05</td>
<td>NS</td>
<td>&lt; 0.01</td>
<td>NS</td>
</tr>
</tbody>
</table>

Abbreviations: N = normal; AS = valvular aortic stenosis; IHSS = idiopathic hypertrophic subaortica stenosis; MS = mitral stenosis; −dp/dt = maximum rate of fall of left atrial pressure; NS = not significant.
3.4 ± 0.2 mm Hg (table 1). In patients with mitral stenosis the y descent in 0.1 sec averaged 6.3 ± 0.5 mm Hg, a value which was significantly greater (P < 0.01) than in the patients with IHSS, but not significantly different (P > 0.05) from that observed in patients with aortic stenosis and in normal subjects.

Figure 2 illustrates the Ry index in the patients studied. In the normal subjects this variable averaged 63.6 ± 6.1 mm Hg/sec, a value significantly greater (P < 0.01) than in patients with IHSS, in whom it averaged 34.4 ± 2.6 mm Hg/sec, and in patients with mitral stenosis in whom it averaged 35.7 ± 3.4 mm Hg/sec (table 1). The difference between Ry indices in normal subjects and in patients with aortic stenosis, in whom this value averaged 49.0 ± 5.8 mm Hg/sec, was not significant.

The most rapid rate of pressure decline (maximum negative dp/dt) averaged 128 ± 20 mm Hg/sec in the normal subjects, a value that was significantly greater (P < 0.01) than that observed in patients with aortic stenosis, in whom it averaged 77.0 ± 8.4 mm Hg/sec, and in patients with IHSS, in whom it averaged 66.6 ± 5.1 mm Hg/sec, as well as in those with mitral stenosis, in whom it averaged 91.0 ± 7.6 mm Hg/sec (P < 0.05) (fig. 3, table 1).

Discussion

Immediately following the opening of the mitral valve, left atrial pressure ordinarily falls rapidly, as blood flows from the left atrium into the left ventricle. However, when there is interference with left atrial emptying, as occurs in patients with mitral stenosis, the left atrium cannot empty rapidly in early diastole and the y descent of the left atrial pressure pulse is slow and prolonged. In addition, when there is restriction to diastolic filling of the left
ventricle as a result of reduced compliance of this chamber, the rate of decline of the y descent is also diminished. It has recently been proposed that the compliance of the hypertrophied left ventricle is reduced in patients with IHSS, since in these patients the left ventricular end-diastolic volume is reduced or normal, while the left ventricular end-diastolic pressure is elevated.1-6

The major finding in this investigation is that slowing of the y descent also occurs in patients with IHSS. Thus, it was observed that three indices of the y descent, that is, the absolute decline in pressure during the initial 0.1-sec interval, the mean rate of pressure decline, and the maximum rate of fall of left atrial pressure decline were decreased in patients with IHSS when they were compared to normal subjects (figs. 1 to 4, table 1). These findings suggested that the ventricular inflow is impeded as a result of reduced ventricular compliance in IHSS, and it appears likely that limitation of left ventricular inflow contributes importantly to many of the hemodynamic changes in IHSS. It is appreciated that the left atrial pressure pulse is influenced by the pattern of blood flow entering the atrium throughout the cardiac cycle, as well as by

Figure 4

Representative left atrial (LA) pressure pulses in the four groups of persons studied. The values of the y descent that were calculated are shown at the bottom of each tracing.
flow from the chamber during ventricular diastole. However, the characteristics of the fall of the y descent are related principally to the manner in which blood exits from the atrium. Further, the reduced compliance of the ventricle may result in elevations of left atrial pressure and often in reduced stroke volume and cardiac output. In attempting to produce more complete filling of the hypertrophied ventricle, a powerful atrial contraction occurs, reflected in prominent atrial contraction waves (a waves) in the left atrial pressure pulse (fig. 4). Despite a powerful atrial contraction, mean left atrial pressure remains elevated and leads to pulmonary venous and occasionally even to pulmonary arterial hypertension. Thus, the hemodynamic picture of left ventricular failure can be mimicked in the absence of true myocardial insufficiency.

It is important to note that the extent of elevation of the left ventricular end-diastolic pressure observed in patients with IHSS does not necessarily correlate with the severity of systolic obstruction nor with the presence of congestive heart failure. Since the major fraction of the stroke volume is expelled during the first half of systole in these patients and the ratio of the forward stroke volume to the end-diastolic volume (systolic ejection fraction) is normal, it appears that the reduction in ventricular end-diastolic volume may play a significant role in the small stroke volume which is noted in some patients with IHSS. In addition, diminished left ventricular compliance appears to play a significant role in the mechanism of one of the characteristic features of this condition, that is, the failure of the arterial pulse pressure to rise following a premature ventricular contraction. Thus, despite the prolonged diastolic pause following the premature contraction, the stiff, thickened left ventricle prevents the left ventricular end-diastolic pressure and volume from increasing normally. This factor combined with the post-extrasystolic potentiation of myocardial contractility prevents the stroke volume and therefore the arterial pulse pressure from increasing after the premature contraction.

It was observed in this study that the y descent is also slowed in valvular aortic stenosis; the decline during the initial 0.1-sec interval and the maximum negative dp/dt of the y descent were reduced, suggesting that the compliance of the left ventricle is also diminished in this condition. It appears, however, that the massively hypertrophied ventricle in patients with IHSS is even less compliant than that of patients with valvular aortic stenosis. Thus, both the left atrial pressure decline during the 0.1 sec following the opening of the mitral valve and the mean rate of y descent were significantly lower in patients with IHSS than in those with valvular stenosis (figs. 1 and 2, table 1). Further, in patients with IHSS the pressure decline during the initial 0.1 sec and the maximum negative dp/dt of the y descent were significantly lower than in patients with mitral stenosis (figs. 1 and 3, table 1).

The finding that ventricular compliance in IHSS appears to be more abnormal than in valvular aortic stenosis is consonant with other observations. Thus, left ventricular end-diastolic volumes in patients with valvular aortic stenosis tend to be larger than in patients with IHSS and, indeed, may be greater than in normal subjects. Further, mean left atrial and ventricular end-diastolic pressures tend to reach higher levels in IHSS than in patients with valvular aortic stenosis with a comparable severity of obstruction. These findings, taken together with the reduced systolic ejection fraction in patients with valvular aortic stenosis, suggest that the reduction of stroke volume which occurs in some patients with valvular stenosis results largely from inadequate ventricular emptying, while in patients with IHSS it is primarily consequent to inadequate filling of the left ventricle.

Although the mean left atrial pressure is elevated, the a wave dominant, and the y descent prolonged in each of the three conditions examined herein, only in mitral stenosis is there an absence of diastasis in the left

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atrial pressure pulse during mid and late dias-
tole (fig. 4). In IHSS and valvular aortic ste-
nosis, ventricular filling, while slower than
normal, does occur to an extent sufficient to
fill the poorly distensible left ventricle and
hence ventricular and atrial pressures usually
rise during the latter half of diastole. The
absence of diastasis with long diastolic inter-
vals in the left atrial pressure pulse occurs
characteristically in patients with mitral ste-
nosis, as a consequence of the impaired fill-
ing of the normally compliant left ventricle.

It is appreciated that in patients with mitral
stenosis, and perhaps in other conditions as
well, the mitral valve may not open for a
short interval after the peak of the \( v \) wave,
that is, after the onset of the \( y \) descent.\(^\text{17}\) Thus,
under these circumstances, the first portion of
the \( y \) descent may be slightly less rapid than
that which occurs after the valve opens, and
the first portion might not be influenced by the
size of the mitral orifice or the compliance of
the left ventricle. However, this factor, which
might result in a slight reduction of the pres-
sure decline during the initial 0.1 sec and of
the mean rate of the \( y \) descent, is generally of
minor significance since this delay is generally
of the order of only a few hundredths of a
second. In addition, the maximum rate of pres-
sure decline of the \( y \) descent, which occurred
in the midportion of the \( y \) descent, well after
the mitral valve had opened, was also exam-
ined in this study and the differences between
the groups were similar in direction and de-
gree to those obtained from the other charac-
teristics of the \( y \) descent. The characteristics
of the left atrial pressure pulse analyzed here-
in were not related to the mean left atrial
pressure as is sometimes done,\(^\text{8}\) although such
a relation would have resulted in an even
greater separation of the measurements be-
tween the patients and normal subjects, since
mean left atrial pressures were elevated in all
three groups of patients.

Two possible mechanisms might be invoked
to explain the reduced left ventricular com-
pliance in patients with IHSS. It may reflect
merely an increase in the total mass of the left
ventricular myocardium, that is, an augmen-
tation of the thickness of the left ventricular
wall, without a change in the compliance of
each individual myocardial fiber. Compliance
may also be reduced by an increased stiffness
of the myocardial fibers themselves. While no
definite choice between these two mechanisms
can be made, it is relevant that in studies of
isolated myocardium obtained from rats\(^\text{18}\) and
cats\(^\text{19}\) with experimentally induced ventricular
hypertrophy, no abnormalities of resting
length-tension relations were observed, when
appropriate corrections were made for the
thickness of the muscle. Since the left ven-
tricular wall tends to be thicker in patients
with IHSS than with other conditions,\(^\text{2,20}\) per-
haps the reduced compliance can be best ex-
plained by a simple increase in thickness of
the left ventricular wall. Finally, it is possible
that there might be interference with complete
opening of the mitral valve by massive ven-
tricular hypertrophy in patients with IHSS.
This postulation that there may actually be
obstruction to left ventricular inflow in IHSS
is consonant with the view of Goodwin and
his collaborators\(^\text{21,22}\) that the enlarged se-
ptum may interfere with blood flow across the
tricuspid and mitral valves.

In conclusion, the present investigation
showed that the rate of left atrial pressure fall
after the opening of the mitral valve and,
presumably therefore, the rate of left ventricu-
lar filling are reduced in IHSS and valvular
aortic stenosis in a manner similar to that ob-
served in mitral stenosis. In contrast to mitral
stenosis, inflow in the conditions associated
with ventricular hypertrophy is attenuated
by the decreased compliance of the thickened
ventricular wall. Based on examination of the
\( y \) descent, this diminution is most severe in
IHSS and appears to contribute to certain
hemodynamic abnormalities in this disease.

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