An Angiocardiographic Analysis of the Thickness of the Left Ventricular Wall and Cavity in Aortic Stenosis and Other Valvular Lesions

Hemodynamic-Angiographic Correlations in Patients with Obstruction to Left Ventricular Outflow

By Norman D. Levine, M.D., S. David Rockoff, M.D., and Eugene Braunwald, M.D.

A n understanding of the alterations in the gross structure of the heart that occur in various forms of heart disease has, in the past, been dependent primarily on examinations of postmortem specimens. Although this approach has yielded considerable information, there are a number of disadvantages to relying entirely on autopsy material. Postmortem changes distort the details of ventricular configuration significantly and to varying degrees and, as a consequence, the relationships between the dimensions of the ventricular cavity and wall that existed during life can only be surmised. Since postmortem specimens are usually obtained from patients with the end stages of heart disease, the data obtained from such material are not necessarily relevant to patients with less severe forms of heart disease. Finally, the use of postmortem specimens does not usually permit physiologic-anatomic correlations, since relatively few hearts become available for study shortly after physiologic investigation.

In order to obtain information concerning some of the alterations that occur in the left ventricle in various disease states during life, the thickness of the left ventricular wall and the width of the left ventricular cavity were measured on angiocardiograms. The objectives of this report are to present the results of such measurements in 57 patients and to show the correlations between physiologic changes, determined by left heart catheterization, and of anatomic alterations, determined by angiocardiography, in a group of 15 patients with valvular aortic stenosis and in seven patients with discrete subvalvular aortic stenosis.

Patient Material and Methods

The angiocardiograms selected for study were obtained from patients in whom the diagnosis had been established by detailed catheterization studies and, in many instances, confirmed subsequently at operation. The angiocardiograms obtained from patients in whom more than a single hemodynamic abnormality was present, and those in which good definition of the opacified left ventricle during diastole in the frontal plane was not available, were eliminated from consideration. The 57 patients studied ranged in age from 4 to 52 years; 35 were 12 years of age or younger, and subsequently will be referred to as children, while 22 were older than 12 years and subsequently will be referred to as adults. Their diagnoses are presented in table 1.

The group of 10 patients considered to have no abnormalities involving the left ventricle, consisted of four who had uncomplicated atrial septal defects, three patients with valvular pulmonic stenosis, and three with pure mitral stenosis. The diagnosis was confirmed at operation in nine of these patients. In all six patients with aortic regurgitation this diagnosis was confirmed by retrograde thoracic aortography. The diastolic brachial arterial pressures were under 55 mm. Hg while the pulse pressures exceeded 60 mm. Hg in all six of these patients. In the four patients with mitral regurgitation, the diagnoses were substantiated by selective left ventricular angiocardiography. One of these patients proved to have an ostium primum atrial septal defect with mitral regurgitation at operation, while the other three patients had rheumatic mitral regurgitation. Left heart catheterization showed that all of four patients had elevations of the mean left atrial pressure with prominence of the "v" waves.
A selective left ventricular angiocardiogram showing the manner in which wall thickness (W) and cavity diameter (C) were determined.

The angiocardiograms were obtained with a biplane Schonander apparatus, at a rate of four or six exposures per second. The contrast material was injected directly into the left ventricle in 47 patients, during transseptal left heart catheterization (26 patients), retrograde arterial catheterization (20 patients), and percutaneous left ventricular puncture (1 patient). The injection was made into the left atrium in two patients and into the right ventricle in two others. In the six patients with aortic regurgitation the left ventricle was opacified by contrast material that had refluxed from the aorta.

Measurements of the diameter of the left ventricular cavity and of the thickness of the left ventricular wall were made on films exposed at the end of diastole in the frontal projection (fig. 1). Line A-B was drawn between the center of the aortic orifice (A) and the most distal point of the left ventricular cavity, at the apex (B). Line X-Y was drawn perpendicular to A-B at its midpoint, and the length of X-Y was taken as the diameter of the left ventricular cavity (C). Line Y-Z, obtained by extending line X-Y through the free wall of the left ventricle, was used to measure the thickness of the free wall of the left ventricle (W). No corrections were made for x-ray distortion. In previous studies, with the same radiographic techniques and equipment, the maximum variations in the degree of distortion among different patients, calculated by the method of Dodge et al., was found to be less than 10 per cent.

Results

In the 10 patients without left ventricular disease, W, the thickness of the free wall of the left ventricle ranged between 5.0 and 9.5 mm./M.² body surface area (B.S.A.) (fig. 2). W exceeded the highest value observed in the normal group in 11 of the 15 patients with valvular aortic stenosis, in six of the seven patients with discrete subaortic stenosis, in 11 of the 15 patients with idiopathic hypertrophic subaortic stenosis, and in three of the six patients with aortic regurgitation. The thickest ventricular walls were noted in the patients with hypertrophic subaortic stenosis. In contrast, in all four patients with pure mitral regurgitation, W was within the range observed in the patients without left ventricular abnormalities.

The diameter of the left ventricular cavity (C) averaged 41 mm./M.² B.S.A. in the four adult patients, and averaged 72 mm./M.² B.S.A. in the six children without left ventricular disease. It was observed that C, when corrected for body surface area, tended to be larger in children than in adults. Figure 3 shows that C was not distinctly different in most of the patients with obstruction to left ventricular outflow than in patients without

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number of patients</th>
</tr>
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<tbody>
<tr>
<td>No left ventricular disease</td>
<td>10</td>
</tr>
<tr>
<td>Valvular aortic stenosis</td>
<td>15</td>
</tr>
<tr>
<td>Discrete subvalvular aortic stenosis</td>
<td>7</td>
</tr>
<tr>
<td>Idiopathic hypertrophic subaortic stenosis</td>
<td>15</td>
</tr>
<tr>
<td>Aortic regurgitation</td>
<td>6</td>
</tr>
<tr>
<td>Mitral regurgitation</td>
<td>4</td>
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<tr>
<td></td>
<td>57</td>
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</tbody>
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left ventricular disease, when the ages of the patients were taken into consideration. There was a tendency, however, for C to be smaller than normal in several patients with hypertrophic subaortic stenosis. The values for C in the adults with aortic regurgitation exceeded the values observed in the adults without left ventricular disease. Likewise, in the child with aortic regurgitation, C greatly exceeded the “normal” values in children. C was always greater in patients with valvular regurgitation than in patients with valvular or discrete subvalvular obstruction to left ventricular outflow; the values for C in all nine adults with valvular regurgitation exceeded 42 mm. /M² B.S.A., but were less than this value in all 11 adults who had valvular or discrete subvalvular obstruction to left ventricular outflow.

The ratios of the diameter of the left ventricular cavity to the thickness of the free wall of the left ventricle (C/W) are shown in figure 4. In the patients with obstruction to left ventricular outflow, C/W tended to be distinctly lower than in the patients without ventricular disease; the lowest ratios were noted in the patients with hypertrophic subaortic stenosis, in two of whom the ratios were approximately equal to 1. In the adults with valvular regurgitation the values for C/W did not differ in any consistent fashion from those observed in the patients without left ventricular disease.
Relationship between the peak systolic left ventricular-brachial artery pressure gradient (L.V. - B.A.) and the thickness of the left ventricular wall in patients without left ventricular disease, valvular aortic stenosis and discrete subaortic stenosis. The broken lines indicate that there was no overlap in the values of wall thickness in patients with gradients under 50 mm. Hg and those in patients whose gradients exceeded 50 mm. Hg.

Hemodynamic-Angiocardiographic Correlations. There was a positive correlation between W and the peak systolic pressure gradient between the left ventricle and brachial artery in patients with valvular or discrete subvalvular aortic stenosis (fig. 5). W was less than 9.6 mm./M.² B.S.A. in all patients whose gradients were less than 50 mm. Hg, and exceeded 9.6 mm./M.² B.S.A. in all patients with higher gradients. W correlated well with the peak systolic left ventricular pressure in adults (fig. 6), although such a correlation was not so striking in the children. An inverse relationship existed between W and the effective aortic orifice size, calculated by Gorlin’s formula, and in the adults. C did not correlate with the peak systolic ventricular pressure, the pressure gradient or the orifice size.

The C/W ratio varied inversely with the peak systolic pressure gradient (fig. 7). In the children with gradients under 50 mm. Hg, C/W exceeded 6.3, while the ratios were lower in all of those with gradients exceeding 50 mm. Hg. In the adults with gradients under 50 mm. Hg, C/W exceeded 5.0, while the ratios were lower in the patients whose gradients exceeded 50 mm. Hg. In adults, C/W varied inversely with the peak left ventricular systolic pressure (fig. 8).

Discussion

Angiocardiography has been employed primarily to provide information regarding the presence or absence of specific cardiac defects or valvular lesions. In addition, in the interpretation of angiocardiograms, some qualitative estimate of the size of the individual cardiac chambers, and of the thickness of the ventricular walls is often made. Although methods for measuring the volume of various cardiac chambers are now available, they are far too complex and tedious to be suitable for routine use. In the present study, the measurements of the diameter of the left ventricular cavity and of the thickness of the free wall of the left ventricle were made in an attempt to determine whether these simple measurements would add any significant information to that usually derived from inspection of the angiocardiogram. It is appreciated that the results can be influenced by

Figure 5

Relationship between left ventricular systolic pressure and left ventricular wall thickness in patients above the age of 12 years.

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rotation of the heart and that the x-ray distortion varies among different patients, depending on the precise position of the heart. However, the variations in distortion among different patients is relatively small (less than 10 per cent) and, since they affect the measurements of C to the same extent as W, they do not affect the ratio C/W. Although corrections for x-ray distortion can be made, elaborate calculations are necessary, and it was thought that if the method for analyzing the angiocardiograms is to be clinically useful, it must be relatively simple. Thus, while the measurements described in this report are admittedly gross, they can be made rapidly enough to be incorporated into the routine interpretation of all angiocardiograms in which the left ventricle is opacified in the frontal projection during diastole. Analysis of the results obtained from these simple measurements suggests that they may provide meaningful information concerning the gross structure of the left ventricle in patients with various forms of heart disease.

Since the patients varied markedly in size, it was thought that absolute measurements would not be helpful in comparing the data obtained from different patients, and all measurements were therefore corrected for body surface area. Although the group of patients without left ventricular disease is small, the cavity diameters appeared to be consistently greater in children than in adults (fig. 3). Accordingly, the age groups of the patients were also considered when the angiocardiograms of patients with heart disease were analyzed.

Attention has recently been directed to the elevation of ventricular end-diastolic pressure which occurs in many patients with obstruction to ventricular outflow without other evidence of congestive heart failure. The possibility has been considered that this finding may reflect diminished ventricular compliance due to ventricular hypertrophy, and not necessarily be indicative of any elevation of the ventricular end-diastolic volume. The observation, in this study, that in patients with obstruction to left ventricular outflow, C does not increase along with W (figs. 3 and 4) offers additional support for this concept, since it suggests that in these patients there is marked thickening of the left ventricular wall without an increase in the volume of the left ventricular cavity. There has been considerable speculation concerning the etiology of
Relationship between left ventricular systolic pressure and the ratio of the width of the left ventricular cavity to the thickness of the wall.

The extent of thickening of the left ventricular wall in patients with valvular and discrete subvalvular stenosis appeared to be related to the degree of obstruction, as reflected in the left ventricular systolic pressure (fig. 6), the peak systolic gradient (fig. 5), and the calculated effective orifice size. These results are consonant with the view that the ventricular hypertrophy which develops in such patients is secondary to the hemodynamic burden placed on the left ventricle, and that the magnitude of the hypertrophy is dependent upon the severity of obstruction. The correlations between the hemodynamic abnormalities and the angiographic measurements that are presented may make it possible, in the future, to identify those patients with aortic stenosis in whom the degree of hypertrophy or dilatation is inappropriate to the hemodynamic stimulus. No correlation between W and the degree of obstruction was observed in the patients with hypertrophic subaortic stenosis, a finding compatible with the concept that this is a diffuse myocardial disease in which the myocardial hypertrophy is not secondary to the hemodynamic burden placed on the left ventricle.

As anticipated, the response of the left ventricle to an increased volume load produced by aortic or mitral valve regurgitation differed from the response to obstruction to left ventricular outflow. Thus, the diameter of the left ventricular cavity tended to be increased in the presence of valvular regurgitation, while ventricular hypertrophy, as reflected in the thickness of the free wall was not prominent.

Summary

In order to provide information concerning changes in the width of the left ventricular cavity and the thickness of the left ventricular wall in patients with various forms of heart disease, relatively simple measurements were carried out on angiograms exposed during diastole in the frontal projection. The diameter of the left ventricular cavity and the thickness of the free wall of the left ventricle were measured in a standardized manner in 57 patients, in all of whom the diagnosis had been established. In patients with valvular or discrete subvalvular aortic stenosis, the thickness of the free wall of the left ventricle was usually greater than in patients without abnormalities of the left ventricle, and the degree of thickening correlated closely with the degree of obstruction. This type of correlation was not present in patients with hypertrophic subaortic stenosis. No increase in the width of the left ventricular cavity was noted in patients with obstruction to left ventricular outflow. In patients with aortic or mitral regurgitation, the width of the left ventricular cavity tended to be increased without any consistent increase in the thickness of the left ventricular wall. The measurements described are simple enough to be applied routinely in order to provide information concerning the
effects of various forms of heart disease on the gross structure of the left ventricle during life.

References

William Withering

In 1778 there was a very severe epidemic of scarlet fever in Birmingham and indeed in the whole of England and Wales. In the following year Withering published the results of his experiences in this epidemic in book form, under the title, "An Account of the Scarlet Fever and Sore Throat or Searlatina Anginosa, particularly as it appeared in Birmingham in 1778." A second edition of this book appeared in 1793. Withering's description of scarlet fever and of the dropsy that so frequently followed it is excellent. In reference to the contagiousness, he says:

"Whether this disease be caused by animalcules capable of generating their kind, or by certain miasmata, which have the property of assimilating other particles of matter to their own nature by some mode of fermentation hitherto but little understood, there can be no doubt but it is contagious, and perhaps so in a degree nearly equal to the smallpox and the measles."

It is evident from this that medical thought at that time was not unfamiliar with what amounted to a germ theory of disease, the "animalcules capable of generating their kind" being a fair substitute for bacteria. He showed great common sense in dealing with the question of isolation and quarantine:

"For several years I have never thought it necessary either to break up a school or to disperse a private family. Allotting apartments on separate floors to the sick and to the healthy; choosing for nurses the older parts of the family or such as had had the disease heretofore, and prohibiting any near communication between the sick or their attendants and the healthy...has very universally been found sufficient to check the further progress of the infection."—Louis H. Roddis, M.D. William Withering: The Introduction of Digitalis into Medical Practice. New York, Paul B. Hoeber, Inc., 1936, p. 47.

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