Studies of the Mitral Valve. I. Anatomic Features of the Normal Mitral Valve and Associated Structures

By Ian E. Rusted, M.D., Charles H. Scheifley, M.D., and Jesse E. Edwards, M.D.

This study attempts to bring into focus certain details which have not been described adequately in textbooks of anatomy. This information is now of considerable significance because of its role in the genesis and surgical treatment of mitral stenosis. Variations in the size and shape of the mitral valve are described, with particular reference to the fact that valve commissures, or junctional zones between the leaflets, occur in the normal valve. Measurements of commissures, chordae tendineae and valve leaflets are presented, with a discussion of the significance of some of these measurements.

UNTIL recent years, descriptions of the mitral valve in anatomic textbooks were entirely adequate. With the impetus provided by the work of Murray,1 of Bailey2 and of Harken and associates,3 operations for the relief of mitral stenosis are becoming commonplace. Because of this, any anatomic factors which might affect the indications for operation, the technic used, or the postoperative prognosis would seem worthy of more careful consideration. The nature of such anatomic factors and a discussion of their significance form the basis of this communication.

MATERIALS AND METHODS

Fifty normal hearts were examined. The specimens, which had been fixed in formalin following necropsy, were selected from cases in which there was no evidence of cardiac disease. In some cases there were moderate degrees of coronary atherosclerosis but where there was any evidence of myocardial infarction the specimen was excluded. There were 25 men and 25 women, five men and five women from each decade between the ages of 30 and 79 years.

Measurements were made of the following structures constituting or associated with the mitral valve: (1) the anterior cusp of the mitral valve from its central portion, or apex, along a perpendicular line to its base; (2) the posterior cusp, at a corresponding site; (3) the diameter of the valve from anterolateral to posteromedial commissure, that is, the greatest diameter of the orifice; (4) circumference of the valve ring, with the heart opened; (5) the depth of the junctional tissue, or commissures, between the two cusps, measured from their free edges to the valve ring; (6) the length and thickness of certain chordae tendineae. In measuring thickness of chordae, main stems, that is, origins of these structures, were avoided, their branches being measured.

A pair of dividers with fine points and an ordinary ruler with subdivisions of 0.1 cm. were used, in a conscious effort to use a simple, practical method of making measurements. If a structure, usually a chorda tendinea, was inaccessible it was excised and placed across the ruler in order to obtain a more accurate measurement. In general, therefore, measurements were probably not in error by more than 0.02 or 0.03 cm.

Before considering the results obtained, our discussion of their significance will be made easier by quoting from Cunningham’s Text-book of Anatomy.4 Of several standard texts that were examined, this was found to contain the most detailed description of the mitral valve. This description reads, in part, as follows: “The two cusps [of the mitral valve] are triangular and of unequal size. The bases of the cusps are either continuous with each other at their attachments to the fibrous ring around the mitral orifice, or they are separated by small secondary cusps of irregular form and size.” It should be noted that the reference to the continuity of the cusps at their bases suggests that there is little or no valvular tissue separating them, unless a secondary type of cusp exists. In other words, one might be justified in assuming that the point of contiguity could be at the valve ring. Grant5 referred briefly to “a short cuff” of tissue at this site, but we have no details as to the frequency of its occurrence, its size or its significance.

Figure 1 shows a normal mitral valve which has

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been opened by an incision which passes through the posterior cusp. Where the anterior cusp ends there is a small junctional zone of valvular tissue which merges with the posterior cusp. The term "commissure" has never been applied to this area, although a standard definition of the word "commissure" is given as "a junctional zone." Another definition refers to "areas joined together," and this seems to have been the one intended by Glover, Bailey and O'Neill when they stated that mitral disease causes the commissures to become an anatomic reality. For reasons which will be made clearer later, we believe that the commissures, the tissue joining the two mitral leaflets, should be considered as anatomic realities in the normal valve. In a modified sense, the area of fusion of leaflet edges caused by rheumatic disease may also be called an artificial or pathologic commissure.

Fig. 1. A normal mitral valve, opened by an incision through the middle of the posterior cusp. Arrows indicate the junctional zones or commissures between the two cusps of the valve.

Table 1.—Measurements (in Cm.) of Normal Mitral Valves (50 Hearts)

<table>
<thead>
<tr>
<th>Structures measured</th>
<th>Men (25 subjects)</th>
<th>Women (25 subjects)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Range</td>
</tr>
<tr>
<td>Anterior cusp</td>
<td>2.3</td>
<td>1.6-2.9</td>
</tr>
<tr>
<td>Posterior cusp</td>
<td>1.3</td>
<td>0.8-1.8</td>
</tr>
<tr>
<td>Anterolateral commissure</td>
<td>0.8</td>
<td>0.5-1.3</td>
</tr>
<tr>
<td>Posteromedial commissure</td>
<td>0.8</td>
<td>0.5-1.3</td>
</tr>
<tr>
<td>Intercommissural diameter</td>
<td>2.5</td>
<td>1.9-3.7</td>
</tr>
<tr>
<td>Circumference of valve ring</td>
<td>9.9</td>
<td>8.5-11.0</td>
</tr>
</tbody>
</table>

Results

Table 1 contains details of the measurements made in the manner described under Materials and Methods. In none of the hearts examined did the valve orifice extend all the way to the ring; that is, there was always some junctional or commissural tissue between the two cusps of the mitral valve in this series of cases. With very few exceptions the depth of this tissue ranged between 0.5 and 1.0 cm. The figures representing the intercommissural diameter of the valve, with the heart held in the closed position, show a considerable range above and below the equivalent of two fingerbreadths (roughly 2.5 to 3.5 cm.). Thus, a valve less than two fingerbreadths from commissure to commissure is not necessarily stenotic, while one that admits two fingers may be mildly stenosed. In half of the cases the anteroposterior diameter of the orifice averaged 1.5 cm., but the manner in which most of the specimens had been opened made this measurement difficult and the results are therefore not accurate.

It has been our experience that accessory cusps between the two major leaflets are seldom seen (approximately 5 per cent of cases). Frequently the posterior cusp was notched, and it is possible that other observers have considered one of these subdivisions of the posterior cusp as separating the main portions of the anterior and posterior cusps. In doubtful cases we have used the papillary muscles and chordae tendineae to designate the site of the commissure, thus helping to make clear where the posterior cusp begins.*

In table 2 are seen the measurements of chordae tendineae extending from each papillary muscle to the corresponding commissure. In one case there was an anomalous absence of chordae from the anterolateral muscle to the region of the commissure. In another instance this commissure was attached directly to the apex of the papillary muscle, thus accounting for the zero figure in table 2. The other groups of chordae tendineae measured were those which are so important in main-

* See Addendum.
taining the competency of the mitral valve: that is, those chordae going from the papillary muscles to the apex or central portion of the anterior cusp.

It is convenient to remember that the thickness of all individual chordae was less than 0.1 cm. In two thirds of the cases there was a thicker chorda from each muscle (or group of muscles) inserting near the central portion may flow into the aorta. We are able to see in this photograph a fibrous band within the endocardial layers of the valve, running along its line of closure. Most of the chordae tendineae appear to insert into this fibrous band. That this is not always the case is shown in figure 2b, where the chordal insertions into the anterior cusp can be seen to pass through the substance of the leaflet for a considerable distance. Many

<table>
<thead>
<tr>
<th>Location</th>
<th>Men (25 subjects)</th>
<th>Women (25 subjects)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length</td>
<td>Thickness</td>
</tr>
<tr>
<td>To anterolateral commissure</td>
<td>1.4 0.3-2.5</td>
<td>0.05 0.02-0.07</td>
</tr>
<tr>
<td>To posteromedial commissure</td>
<td>1.7 0.8-2.5</td>
<td>0.05 0.02-0.07</td>
</tr>
<tr>
<td>From anterolateral muscle to apex of anterior cusp</td>
<td>2.1 1.3-3.0</td>
<td>0.05 0.02-0.09</td>
</tr>
<tr>
<td>From posteromedial muscle to apex of anterior cusp</td>
<td>2.2 1.3-3.2</td>
<td>0.04 0.02-0.07</td>
</tr>
</tbody>
</table>

**Fig. 2a.** A normal mitral valve with the anterior cusp transilluminated to show that most of the chordae tendineae insert at or near the free edge of the valve. Arrows point to the fibrous band referred to in the text. (b) Transillumination of the anterior cusp of a normal mitral valve to show that many of the chordae tendineae from both papillary muscles pass through most of the valve cusp, in some cases as far as the valve ring.

of the anterior cusp, its diameter averaging 0.09 cm. and ranging from 0.06 to 0.16 cm.

In Cunningham's textbook it is pointed out that the ventricular surfaces of the valve leaflets are roughened by the attachments of the chordae tendineae. In Gray's textbook it is stated that "nearly all the chordae tendineae which reach [the anterior cusp] are attached near the margin of this cusp which, therefore, is smooth on both its surfaces..." Figure 2a shows the latter arrangement, which is said to provide a smooth surface over which blood variations of both patterns have been observed. In the posterior cusp, the chordae usually traverse most of the distance through the cusp toward its base. In both leaflets the majority of chordae tendineae insert into the free edge and have been called "chordae of the first order" to distinguish them from the chordae of the second order, which end in endocardial folds on the ventricular aspect of the leaflets 0.3 to 0.6 cm. from the free edge. The chordae of the first order are best seen in figure 1 while those of the second order are
shown in figure 3. The latter are usually larger in diameter than the former. Between them there may be no other chordae or there may be one or more branches that originate from one or both of the two major groups of chordae. Sometimes these intermediate groups of chordae arise independently from the papillary muscles.

Concerning papillary muscles, the textbooks state simply that they are two in number, one superior and one inferior. We have observed that papillary muscles have a consistent relationship to the valve commissures and therefore suggest that they be similarly designated, that is, anterior (or anterolateral) and posterior (or posteromedial). Following a study of 200 normal hearts, we have already reported that the anterior papillary muscle was usually single and that in more than 70 per cent of cases it contained a groove which led in the direction of the commissure immediately above the apex of the muscle. At the posteromedial location there were two or three muscles (or one muscle with two or three heads) in more than 60 per cent of the cases. In almost every instance there was a close relationship between the muscles and the adjacent commissure.

Figure 4 illustrates the way, in this instance in a heart with mitral stenosis, in which chordae tendineae may form a pathway to guide a palpating finger to the commissure. In normal hearts this guiding feature is encountered less frequently at the posteromedial than at the anterolateral site, a fact which may be related to the slightly greater distance between the muscles and the commissure. (See table 2.) Also, multiple muscles at the posteromedial location tend to cause gaps between the groups of chordae arising from them, and these gaps are larger than when a single muscle is present.

Additional Measurements. The thickness of the left atrium, in areas away from the thinner portions surrounding the entry of the pulmonary veins and excluding fatty epicardium, averaged 0.18 cm. (range: 0.1 to 0.3 cm.) as compared with the figure of 0.3 cm. quoted in Gray's textbook. The thickness of the midportion of the left ventricle averaged 1.3 cm. in women (range: 1.0 to 1.6 cm.), and 1.5 cm. in men (range: 1.2 to 1.8 cm.). The 1.8 cm. reading was obtained in a 30 year old man with normal blood pressure. The depth of the left ventricle was measured from the base of the posterior (noncoronary) cusp of the aortic valve to the apex of the left ventricular cavity. In women the measurements averaged 6.7 cm. (range: 5.4 to 8.5 cm.) and in men 7.3 cm. (range: 5.6 to 9.5 cm.).

Comment

In discussing the significance of the structures and muscles referred to, possibly the first question that might be asked would be:
Why is it important to consider mitral commissures as special parts of the mitral valve? Also, Why is it desirable to differentiate between the commissure which is present normally and the additional artificial commissure that may be produced by fusion of the cusp edges?

Almost all the surgeons doing operations on the mitral valve have stressed the importance of avoiding incisions or tears at any region other than at the commissures. If the method of "finger fracture" is employed, the fact has to be accepted that the weakest point will be the one to separate. If it were possible to predict whether a thickened commissure would separate with ease or only with difficulty a considerable contribution would be made to the equanimity of surgeon and patient. Depending on the severity and the distribution of the rheumatic changes, there may be a small amount of fusion of the cusps (causing a fish-mouth type of stenosis) or there may be a great deal of fusion, reducing the orifice to a buttonhole shape. Remembering that the depth of the commissure in the normal valve averaged 0.7 to 0.8 cm. and was never more than 1.3 cm. in our series, the surgeon palpating a stenosed mitral valve may conclude that a commissure deeper than 1 cm. is made up partly of fused cusps. It seems logical that a commissure made up partly of fused cusps might separate more easily than a thickened commissure with no fusion of cusps. In a number of necropsy specimens we have observed that this supposition is usually defensible, and this is one reason for distinguishing between the normally existing commissure and the deeper pathologic commissure.

Whether or not a thickened commissure, with no fusion of cusps, can be broken will depend on the severity and distribution of the rheumatic changes. Very often it is the more severely involved valve with brittle commissural tissue that can be "fractured" rather than the valve with nonbrittle, fibrous commissural tissue.

If the commissure is relatively normal there is obviously no necessity for incising or "fracturing" it. This may seem a superfluous con-

![Fig. 5a. A stenosed mitral valve, as seen from above. (b) The valve shown in a after the heart had been opened. Note the thickening of the chordae of the first order. The stiffness of these chordae made it difficult for the valve to open. The anterolateral commissure, at the left, has been incised to help demonstrate its normal appearance.](image)

sideration and one would wonder how there can be any stenosis of the mitral valve if the commissures are normal.

Figure 5a shows the stenosed mitral valve in an adult in whom there had been rheumatic fever in childhood. On physical examination there were presystolic and systolic apical murmurs and the patient also had auricular fibrillation. Cardiac decompensation developed gradually and increased until death occurred from congestive cardiac failure.

Figure 5b shows the appearance of the opened valve in this case and demonstrates the fact that considerable stenosis of the mitral valve can exist in the presence of commissures that are normal. The valvular dysfunction seemed to have been caused by chordal
changes. The thickening of the chordae of the first order prevented normal excursion of the valve leaflets and therefore was the basis for mitral stenosis. In this instance the chordae of the second order were only mildly affected, but other cases have been observed in which these chordae were the most severely involved, others in which both sets were equally involved and still others in which all groups of chordae were fused in a solid sheet of stiff fibrous tissue, constituting the main source of valvular dysfunction. Such cases, therefore, belong to the group—fortunately in the minority—in which operations on the commissures would be unsuitable and they present another reason for recognizing the presence of commissures in normal mitral valves and the role which they may or may not play in the genesis of mitral stenosis.

**SUMMARY**

1. Measurements have been made of the component parts of the normal mitral valve and its associated structures in 50 human hearts.

2. The significance of certain of these structures and their measurements is discussed, with special reference to the normal occurrence and size of the valve commissures.

3. Commissural tissue between the major cusps of the mitral valve averages 0.7 to 0.8 cm. in depth. In mitral stenosis this tissue may remain essentially normal; it may contribute to the stenosis by becoming thick and stiff, or its depth may be artificially increased by fusion of the adjacent margins of the leaflets. It is suggested that this last cause of dysfunction may be suspected if the commissural zones are more than 1.0 cm. in depth.

**ADDENDUM**

Shortly after the presentation of this material there appeared a communication by Harken and associates. In this they stated on the basis of observations made on 35 normal hearts, that “two additional triangular projections are commonly found that might be called the ‘anterior and posterior commissural leaflets.’ Four triangular leaflets, arranged circumferentially, constitute the mitral valve.” Of the two smaller leaflets they say that “their function in maintaining the integrity of the redundant portions of the two larger valve leaflets in systolic closure would seem to be considerable.” The foregoing pattern was seen in 75 per cent of their cases and in the remaining cases any variation was “principally in the size and shape of the ventricular leaflet in relation to the two commissural leaflets.”

The foregoing findings led us to examine 50 additional hearts for the presence of accessory cusps. The results, based on the combined total of 100 cases, remain essentially unchanged from our brief statement in the text. In 5 of the 100 normal hearts there were very tiny projections which conceivably could be called “accessory cusps” at one or both commissural sites. In 50 cases the posterior (or “ventricular”) cusp was not significantly notched. However, 14 per cent of the cases showed two projections in the portions of the posterior cusp adjacent to the commissures. There was one such projection in an additional 28 cases. In 13 of these 28 cases the notching existed at the anterolateral portion of the posterior cusp and in the other 15 at the posteromedial portion. In three cases the indentation was at the central portion of the cusp so that if the two projections were called “commissural leaflets” there would be nothing to designate as the posterior or “ventricular” cusp in these cases. In each of five cases four so-called cusps constituted the posterior leaflet.

In many of the valves there were no actual indentations but the valve tissue was folded, or actually pleated, so as to create redundant portions. It does seem that such redundant portions and so-called accessory cusps would add to the integrity of the mitral valve during systole. However, these features were absent or inconspicuous in half of our cases even though these hearts apparently functioned as well as the others. For this reason and because of the additional variations encountered we feel it is sufficient to remember that there are two major cusps in the mitral valve, the posterior of which may be regular or irregular along its free margin. It is unusual for an accessory cusp to separate the two major cusps.
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