

The anatomy of the mitral valve and its associated structures

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Since the development of mitral valve surgery the previously conventional descriptions of the valve have been reappraised, and many publications have appeared dealing with its detailed anatomy (Davila and Palmer, 1962; Bailey, Zimmerman, and Likoff, 1960; van der Spuy, 1958; Morris, 1960; Frater and Ellis, 1961; Rusted, Scheifley, and Edwards, 1952; Harken, Ellis, Ware, and Norman, 1948; Brock, 1952; and Gould, 1953). Open-heart operations for correction of mitral incompetence and for treatment of the grossly diseased stenosed valve are becoming commonplace, and the results of valve replacement are now promising. This advance is in part due to the surgeon's improved anatomical knowledge, but some details of the structural relations of the valve are not widely known, and there is still a need for standardization of terminology. An effort is made in this paper to systematize the description of this complex valve and to orientate it in relation to the surrounding structures that must be avoided at operation. We also present data of the dimensions of the valve, which may be of interest to anatomists and surgeons. Familiarity with the normal measurements of the component parts of the valve will, at operation, help the surgeon to assess the exact mechanical reason for valve insufficiency.

MATERIALS AND METHODS

The following descriptions are based upon observations made during intra-cardiac operations and dissections of fresh human hearts which were later preserved in diglycerol stearate by the method described by Kramer (1938). These specimens, if correctly prepared, retain their true features and relationships and can be conveniently studied or used for teaching purposes.

The dimensions of the valve were taken from 10 normal hearts. The mitral leaflets with the annulus, chordae, and papillary muscles were removed, and the valve was flattened out in a

single plane by dividing its ring at the lateral commissure and by half splitting the medial papillary muscle mass. The opened-out valves were then pinned to cork boards during fixation in formalin and were finally waxed with diglycerol stearate.

Measurements were made with point dividers and an ordinary metric ruler. To determine the surface areas, the leaflets were traced on graph paper and the enclosed squares were counted.

ANATOMY

Various names have been given to the leaflet of the mitral valve that is related to the aorta. It has been called the aortic, the septal, the ventral, the antero-medial or the anterior leaflet. Multiple names have also been given to the commissures and papillary muscles. The terminology we suggest, whilst neither original nor absolutely precise, is simple and descriptive. Figure 1 shows the four valves orientated to the saggital plane of the body. The mitral leaflet nearest the aortic valve is the anterior leaflet, and the one opposite is the posterior leaflet. The commissure pointing towards the mid-line is the medial, and the one opposite is the lateral. The papillary muscles, being related to the commissures, are also referred to as medial and lateral.

The fibrous skeleton of the heart provides the key to understanding the anatomical relationships of the mitral valve. Its keystone is the aortic root, which is the extension of the aorta below the aortic valves, and is the thickest most rigid part of the skeleton. Fibrous extensions from the aortic root form the scaffold for the pulmonary, tricuspid, and mitral rings. Figure 2 is a diagram of the fibrous skeleton based on Fig. 3, which shows the dissected aortic root and fibrous skeleton. At the base of the non-coronary cusp, the aortic root is continuous with the interventricular septum, and its downward extension forms the

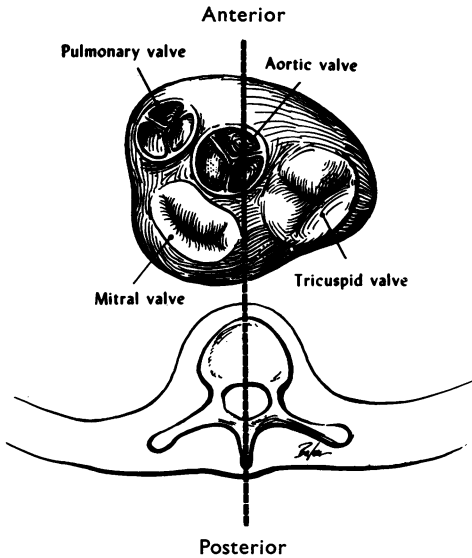


FIG. 1. The four valves of the heart orientated to the saggital plane of the body. The mitral valve nearest the aortic valve is the anterior leaflet, and the one opposite is the posterior leaflet. The commissure pointing towards the mid-line is the medial, and the one opposite is the lateral.

membranous septum. Immediately above the junction of the ventricular septum and the tricuspid ring the aortic root is extremely thin, and this is named the undefended area. Occasionally this area is deficient, and blood will then shunt from the left ventricle directly into the right atrium. Posteriorly and to the left, the aortic root expands into a broad membranous structure, the intervalvular space, to which the anterior third of the mitral annulus attaches. The intervalvular space therefore lies between the bases of the left and non-coronary aortic cusps and the mitral annulus. Posteriorly and to the right, the aortic root thickens to form the right fibrous trigone which separates the mitral and tricuspid rings and forms the base of the inter-atrial septum. A tendinous extension from the right fibrous trigone, the tendon of Todaro (Grant, 1958), extends between the layers of the inter-atrial septum. On the left side the aortic root again thickens to form the left fibrous trigone. This trigone is closely related to the left coronary artery and forms part of the base of the transverse sinus of the heart.

The pulmonary valve ring is anterior and to the left of the aortic valve ring. It is set in a plane almost at right angles to that of the aortic valve and is attached to the base of the aorta by a flimsy fibrous extension of the aortic root called

the tendon of the conus. The rest of the pulmonary valve ring is supported by the base of the right ventricle and the interventricular septum. The tricuspid and pulmonary valves occupy two openings within the right ventricle separated by a band of myocardium, the crista supraventricularis. On the other hand, the mitral and aortic valves share a common opening in the base of the left ventricle (Fig. 4). Although the aortic and mitral valves occupy the same opening in the myocardium, they lie at an angle of 40° to each other so that the anterior leaflet of the mitral valve forms a watershed between the inflow and outflow streams of the left ventricle (Fig. 5).

Considerable controversy centres around the exact position and even the existence of that part of the mitral annulus related to the anterior leaflet.

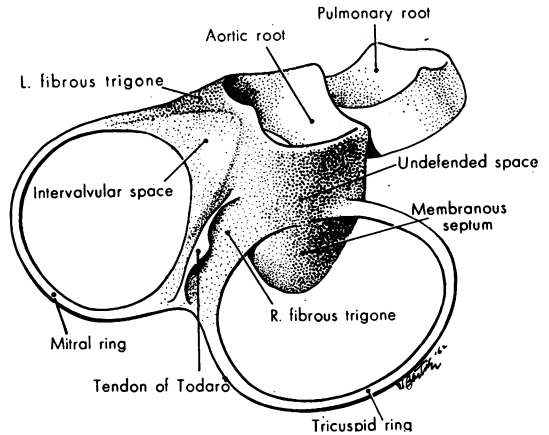


FIG. 2. Diagram of the fibrous skeleton of the heart.

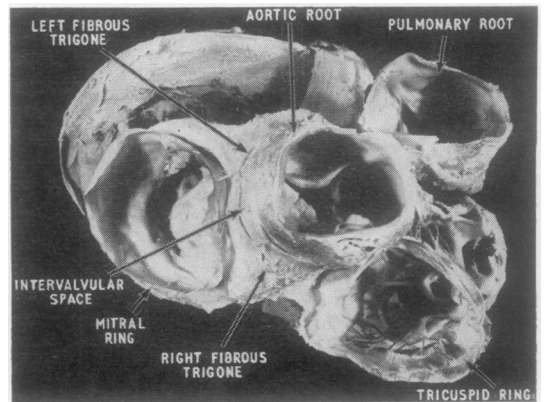


FIG. 3. Dissected aortic root and fibrous skeleton of the heart. The valve leaflets and part of the left ventricle have been retained.

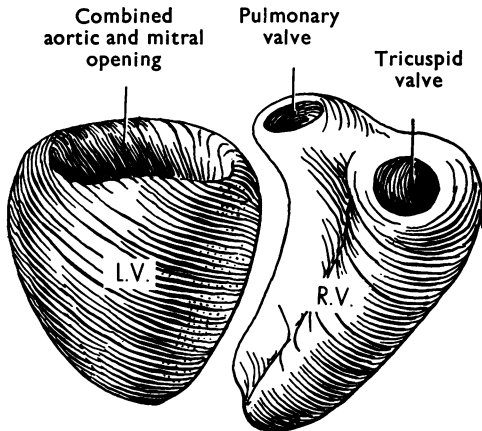


FIG. 4. Diagram to show that the tricuspid and pulmonary valves occupy separate openings within the right ventricle whereas the mitral and aortic valves share a common opening in the base of the left ventricle.

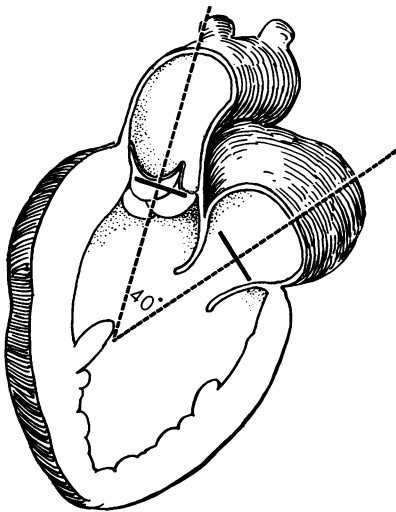


FIG. 5. Diagram illustrating that the mitral and aortic valves, although occupying the same opening in the left ventricle, are set at an angle of 40° to each other. The anterior mitral leaflet thus forms a watershed between the left ventricular inflow and outflow streams.

Frater and Ellis (1961) state that the anterior leaflet of the mitral valve is attached to the base of the non-coronary and most of the base of the left coronary cusp of the aortic valve. Van der Spuy (1958) states that the anterior mitral leaflet 'is a hinged extension into the cavity of the left ventricle of the postero-lateral aortic root and

that the hinge is formed by the common fibrous origins of the postero-lateral half of the aortic root, of the antero-medial mitral leaflet and the major part of two aortic cusps'. Bailey *et al.* (1960) maintain that this part of the mitral ring is deficient. They describe the annulus as a horseshoe-shaped fibrous thickening of the upper edge of the left ventricular myocardium, which extends from the right fibrous trigone around to the left fibrous trigone and is deficient antero-medially. These three opinions are really different ways of saying the same thing—namely, that the anterior leaflet shares a common origin with parts of two aortic cusps. We do not agree with this view.

It is convenient to describe the mitral ring by dividing it into an anterior third, to which the base of the anterior leaflet is attached and a posterior two-thirds, from which the posterior leaflet arises. The posterior two-thirds of the ring is a fibrous thickening at the base of the left ventricle extending from the right to the left fibrous trigone. The anterior third of the mitral ring is closely related to the aortic root. It is a well-defined fibrous cord extending from the one trigone to the other and into which the base of the left atrium also inserts (Figs. 6, 7, and 8). The part of the aortic root enclosed by the mitral annulus and the bases of the left and non-coronary leaflets of the aortic valves is the intervalvular space. We do not believe that this space can be described as part of the mitral valve because it lies above the hinge of the anterior leaflet (point *y* of Fig. 8). According to van der Spuy's contention, point *x* in Fig. 8, *i.e.*, at the bases of the aortic leaflets, is the hinge of the anterior leaflet. However, the left atrial muscle attaches at point *y*, and during atrial contraction this point is drawn inwards whilst the leaflet flaps open, so that the intervalvular space does not move with the mitral curtain. The left atrial attachment at *y* must anchor the anterior leaflet, which must therefore hinge here. We agree with Brock (1952) that this is the mitral annulus. It is a substantial structure which provides adequate bulk to hold the sutures of a prosthetic ring.

The mitral valve leaflets form a continuous veil attached as a muff to the circumference of the mitral ring. The free edge of this veil hangs into the left ventricle and is split by indentations, none of which reaches to the mitral ring. The specimen shown in Fig. 9 is representative of the average valve. It shows the accentuated anterior part of the valve curtain which is attached to the anterior third of the mitral annulus. The anterior leaflet is roughly triangular in shape. The base of the

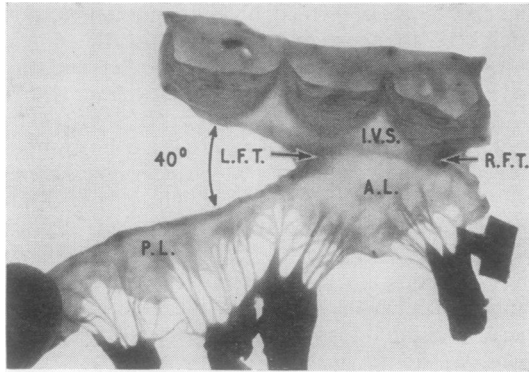


FIG. 6. Transilluminated opened-out mitral and aortic valves seen from the ventricular aspect. Note (a) the two aortic cusps are separated from the anterior mitral leaflet (A.L.) by the intervalvular space (I.V.S.); (b) the anterior part of the mitral annulus extends between the two fibrous trigones (L.F.T. and R.F.T.); (c) the central portion of the anterior mitral leaflet is free of chordal attachments. Chordae tendineae are attached to the whole ventricular surface of the posterior leaflet; (d) the angle formed by the planes of the aortic and mitral valves is approximately 40° ; (e) the anterior part of the mitral annulus is half the length of its posterior portion; and (f) the depth of the anterior leaflet is twice that of the posterior leaflet.

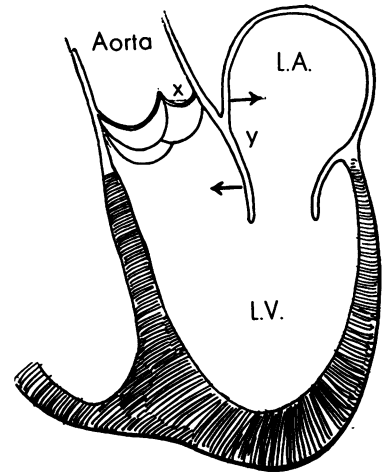


FIG. 8. Diagram illustrating that the point of hinging of the anterior mitral leaflet (y) corresponds to the attachment of the base of the left atrium to the posterior aortic root. This is the anterior part of the mitral annulus.

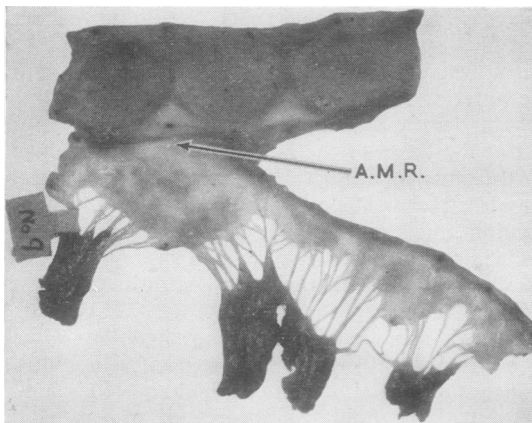


FIG. 7. Splayed open mitral and aortic valves seen from the atrial surface of the mitral valve. Note that the anterior part of the mitral ring (A.M.R.) is a definite structure to which part of the base of the left atrium is attached.

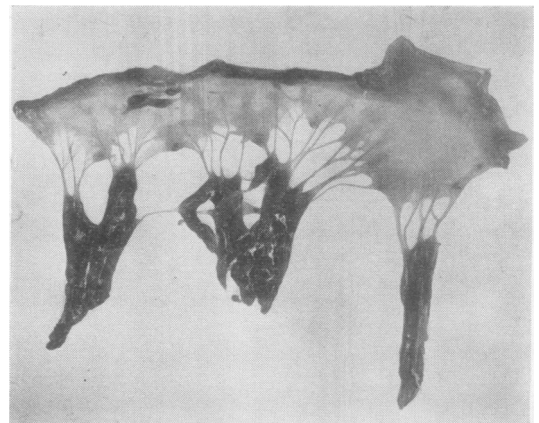


FIG. 9. Splayed open mitral valve. Note (a) the triangular shape of the anterior leaflet and the rectangular shape of the posterior leaflet; (b) the mitral valve curtain is shortest at the fibrous trigones.

triangle is attached to the annulus, and the apex is the free edge which is devoid of chordal attachments. The two sides of the triangle give attachment to chordae of the first order, and these are responsible for the scalloped appearance of the leaflet edge. The atrial surface of the anterior

leaflet is smooth and flat but the ventricular surface is ridged by the insertion of chordae of the second order which, however, spare the central portion of the valve leaflet. The posterior leaflet is roughly rectangular in shape, and its free edge is usually more deeply scalloped than that of the

anterior leaflet. At the centre of its free edge there is also a small area devoid of chordal attachments. This site marks the separation between the chordae rising from the two papillary muscles. Unlike the anterior leaflet, the ventricular surface of the posterior leaflet is covered with chordal attachments. Apart from chordae of the first and second order, chordae of the third order are attached to this surface (Brock, 1952).

The valve curtain is shortest near the two points of attachment of the mitral annulus to the left and right fibrous trigones. This is the junctional area between the anterior and posterior leaflets. In some specimens (Fig. 10) the scallops in the free edge of the ventricular curtain may be exaggerated and may nearly reach the annulus to give the appearance of separate leaflets, called accessory leaflets by some authors (Chiechi, Lees, and Thompson, 1956). In rare cases the scallops in the junctional area are so deep that they reach the annulus, and mitral regurgitation results.

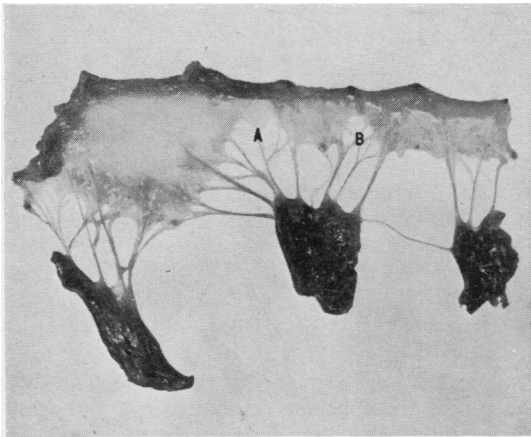


FIG. 10. Ventricular aspect of the mitral valve. Note that exaggerated scalloping in the mitral valve curtain (A and B) can give the appearance of a separate commissural leaflet, sometimes called accessory leaflets.

OTHER STRUCTURES RELATED TO THE MITRAL VALVE ANNULUS Figure 11 shows four important structures related to the annulus which have to be avoided during replacement of the prosthetic valve. These are:

(1) The intervalvular space (Figs. 6 and 7). This space affords a certain margin of safety when inserting a prosthetic valve, but, even so, carelessly placed sutures may transfix the bases of the left and non-coronary aortic cusps and cause aortic insufficiency.

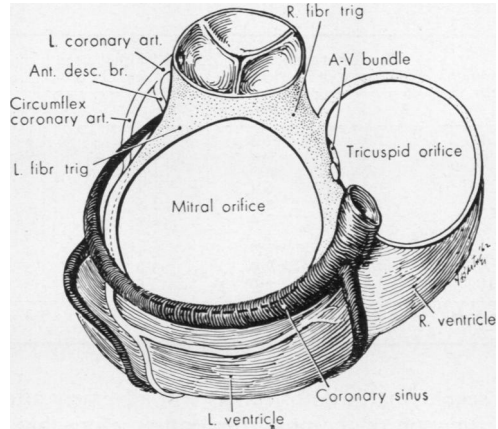


FIG. 11. Diagram illustrating the structures related to the mitral valve annulus which must be avoided during insertion of the prosthetic valve.

(2) Coronary vessels. Where the lateral commissure abuts against the left fibrous trigone, the great cardiac vein and the circumflex branch of the left coronary artery are endangered by deep sutures.

(3) Bundle of His. Where the medial commissure meets the right fibrous trigone the atrio-ventricular bundle may be injured.

(4) The coronary sinus. The opening of the coronary sinus into the right atrium is slightly behind the site of the atrio-ventricular bundle. Along the posterior two-thirds of the mitral annulus the coronary sinus and left coronary vein may be incorporated in careless suturing.

The annulus provides sufficient strong fibrous tissue in which to place sutures for anchoring a prosthetic valve ring. Good exposure and careful suturing will avoid damage to related structures.

DIMENSIONAL DATA

Table I lists the dimensions of the annulus and of the leaflet depth of 10 normal valves. It will be seen that the length of the annular attachment of the anterior leaflet is half that of the posterior leaflet. The maximum depth of the anterior leaflet, measured from its annular attachment to its apex, is approximately twice that of the posterior leaflet. In rheumatic fever the inflammatory process and the subsequent fibrosis is very often concentrated at the free edges of the valve leaflets, particularly at the points of insertion of the chordae tendineae. As the depth of the posterior leaflet is half that of the anterior leaflet, equivalent contraction of

TABLE I

Specimen No.	Length of Annular Attachment of Leaflet (cm.)		Maximal Length of Leaflet (cm.)	
	Anterior	Posterior	Anterior	Posterior
1	3.9	7.2	2.8	1.8
2	3.0	6.4	2.2	1.0
3	3.9	6.7	2.6	1.4
4	3.2	6.4	3.2	1.2
5	2.9	6.9	2.5	1.3
6	3.1	5.4	2.4	1.2
7	3.4	5.1	2.5	1.3
8	4.1	8.7	2.9	1.4
9	4.5	7.9	3.0	1.5
10	3.2	6.0	2.6	1.3
Averages	3.5	6.7	2.7	1.3

the scar tissue in both leaflets will adversely affect the function of the posterior leaflet before that of the anterior leaflet. This explains why shortening of the posterior leaflet is the most common cause of rheumatic mitral regurgitation.

The mitral valve ring is on average 1.1 cm. longer than the free edge of the valve curtain (Table II). This is the reason why the mitral valve is conical in shape with a larger inlet than outlet. As the anterior and posterior leaflets are not equally deep, the plane of the outlet orifice does not correspond with that of the annulus. To some extent this compensates for the smaller size of the outlet orifice (Fig. 12). Although the anterior and posterior leaflets differ in shape, annular attachments, and depth, their individual surface areas are approximately equal (Table II). The mitral annulus is not a perfect circle and its surface area can only be estimated approximately. The average length of the mitral ring in the 10 specimens examined was 10.2 cm., and from this the average surface area is calculated to be 8.1 cm.² The average surface area of the anterior leaflets was 4.9 cm.² and of the posterior leaflets 5 cm.² (Table II). The average surface area of both leaflets therefore is 10 cm.², which is greater than the

TABLE II

Specimen No.	Total Length of Valve Ring (cm.)	Length of Free Edge of Valve Curtain (cm.)	Surface Area of Leaflet (cm.)	
			Anterior	Posterior
1	11.1	10.5	5.2	5.3
2	9.4	8.5	4.0	4.5
3	10.6	9.5	5.5	4.8
4	9.6	8.5	4.5	4.8
5	9.8	8.4	4.3	4.6
6	8.5	8.0	4.4	4.5
7	8.5	7.9	4.5	4.2
8	12.8	11.7	5.9	6.5
9	12.4	9.3	5.6	5.8
10	9.2	8.3	5.0	5.0
Averages	10.2	9.1	4.9	5.0

surface area of the mitral annulus. In the cadaveric heart, the surface area of the valve orifice is therefore four-fifths that of the combined leaflet area. In addition, in life the mitral valve orifice narrows during ventricular systole so further reducing its surface area and leaving relatively even more valve leaflet surface available to close the atrio-ventricular orifice. The normal mitral valve thus closes not only by marginal contact but by liberal leaflet surface apposition. This is an important concept in the recognition of the mechanisms causing mitral regurgitation where leaflet shortening, leaflet rigidity, or dilatation of the mitral annulus are present.

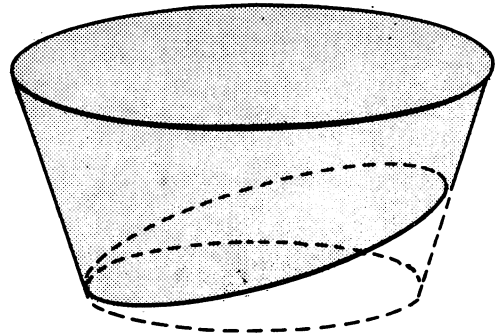


FIG. 12. Diagram showing the conical shape of the mitral valve. Because the anterior part of the valve curtain is deeper than the posterior, the outlet orifice lies at an oblique plane to the inlet (see text).

SUMMARY

Standardization is sought for the nomenclature of the mitral valve leaflets, commissures, and papillary muscles. We offer support for the use of the terms 'anterior' and 'posterior' for the leaflets and 'lateral' and 'medial' for the commissures. As the papillary muscles are related to the commissures they should also be referred to as 'lateral' and 'medial'.

The fibrous skeleton of the heart is described with particular reference to its relation to the anterior part of the mitral valve annulus.

The shape, chordal attachments, and inlet and outlet orifices of the mitral valve curtain are described. The mitral valve is a continuous veil of tissue, but indentations at the fibrous trigones divide it into a triangular anterior and rectangular posterior leaflet. The central part of the ventricular surface of the anterior leaflet is free from chordal attachments, whereas the whole of the

corresponding surface of the posterior leaflet gives attachment to chordae tendineae.

The mitral valve inlet is larger than its outlet, but an oblique setting of the plane of the outlet orifice to some extent compensates for the discrepancy in size.

The proximity of the bundle of His, the coronary sinus, the aortic cusps, and other coronary vessels to various parts of the mitral annulus is described. These structures may be damaged by careless suturing during total valve replacement.

Certain dimensional data concerning the mitral valve are presented. The annular attachment of the anterior leaflet is half that of the posterior leaflet; the anterior leaflet is twice as deep as the posterior one. Although the leaflets differ in shape, their surface areas are similar. The surface area of both leaflets is greater than that of the mitral valve ring. This has an important bearing on the closure of the mitral valve.

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