CONSIDERATIONS IN THE PROSTHETIC CONSTRUCTION OF A COMPLETELY ANATOMICAL WHOLE MITRAL VALVE FROM AUTOGENOUS TISSUES

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O Lord, how manifold are thy works! in wisdom hast thou made them all.
Psalm 104:24.

When one examines the various mitral valve prostheses in common use today, one tends to think that the normal mitral valve is believed to function in much the same way as would a mechanical valve with but an opening and a closing mechanism. It is certain, however, that the mitral valve forms as integral a part in the function of the heart as a whole as does the papillary muscle in the function of the mitral valve as a unit.[1-3]

Its only function is to direct the flow of blood from the lungs to the heart—the only two organs with functions so vital that the complete cessation of the function of either for but a few minutes will inevitably lead to immediate death. It is therefore imperative that a valve of such great importance should function persistently well even in the presence of adverse haemodynamic influences.

Anatomy and Dynamics

Anatomically the mitral valve is by far the most complicated valve. Its many and varied anatomical features alone should serve to indicate that there are many complex aspects upon which the continued successful function of the valve depends.

Like the tricuspid valve it guards an atrioventricular opening. It is most important, however, to realize that the tricuspid valve, unlike the mitral valve, has a dual function. Whereas incompetence under stress is its most important function—competent closure under normal conditions is its usual function—incompetence of the mitral valve leads to most serious cardiopulmonary complications, especially when of an acute nature. That the left atrioventricular valve is bicuspid and the right tricuspid must therefore be significant. The tricuspid valve is attached at its periphery to the entire circumference of the base of the right ventricle. The construction of the tricuspid valve is such that dilatation of the right ventricle with, therefore, dilatation of the tricuspid ring, will readily cause valvular incompetence. Had the root of the pulmonary artery and the tricuspid ring both occupied the base of the right ventricle, then a dilated pulmonary artery root would have encroached upon the tricuspid valve. In instances of severe pulmonary hypertension the beneficial outcome of engorging the systemic venous system by transferring the adverse effects of hyperpressure in the pulmonary arterial system to the peripheral and portal venous systems through tricuspid incompetence would have been seriously interfered with. The outflow tract of the right ventricle is therefore merely an anatomical expression of the absolute necessity of having the pulmonary root some distance away from the tricuspid valve. In view of the above it seems quite wrong to replace a diseased tricuspid valve with a non-anatomical prosthesis, particularly in cases with associated pulmonary hypertension and/or atrial fibrillation, because of the possible development of right heart failure.

The base of the left ventricle, on the other hand, accommodates both the aortic root and the mitral ring, a fact of the greatest functional importance. The antero-medial (anterior) half of the root of the aorta is attached to the membranous part of the interventricular septum. The short postero-lateral (posterior) cusp of the mitral valve is attached to the remaining posterior half of the base of the left ventricle. The postero-lateral (posterior) half of the root of the aorta and the long, and very much more important, antero-medial (anterior) cusp of the mitral valve are, however, not attached to the base of the ventricle at all, but instead have a common tendinous attachment, with the major part of 2 adjacent aortic cusps, to form the antero-medial (anterior) half of the mitral ring. Whereas one half of the root of the aorta is attached to the base of the left ventricle via the membranous portion of the interventricular septum, the remaining half is attached to the wall of the left ventricle, on either side of and proximal to its apex, via the anterior mitral cusp, its chordae tendineae and both sets of papillary muscles. During systole the tension on the chordae which results from the upward excursion of the cusps causes upward displacement of the apices of the papillary muscles. This must necessarily imply either systolic stretching of the papillary muscles or upward displacement of their bases, i.e. of the left ventricular wall, or both. In either case it is clear that the cusps, chordae tendineae and papillary muscles support the left ventricular wall during systole. Since the anterior mitral cusp is attached to the posteriorly convex root of the posterior half of the aorta and since the body of this long cusp lies opposite the anteriorly concave posterior cusp, as it is attached to the base of the posterior half of the left ventricle, the convexity of the anterior cusp during systole closes against the concavity of the posterior cusp, giving complete valve closure.

The mitral valve has a relatively large closing surface—the entire length of the posterior cusp. It also has a large closing reserve. Because of the length of the cusps, particularly of the anterior cusp, and the chordae tendineae and because of the extensibility of the papillary muscles, systolic excursions of the cusps are possible well beyond the normal requirements of valve closure. For this reason the absence of incompetence at operation is often found in spite of marked thickening of the cusps, chordal shortening and gumming together of the papillary muscles.

During systole there is a reduction in the diameter of the base of the left ventricle with at the same time maximal expansion of the root of the aorta by the ejected blood. Because the oval mitral valve lies between the posterior half of the base of the left ventricle (behind) and the posterior half of the root of the aorta (in front), the cusps are approximated, i.e. the valve flattened, by ventricular systole. Dilatation of the aortic root will further enhance this beneficial flattening effect during systole and so compensate to some extent for the adverse effects of left ventricular dilatation with downward displacement of the papillary muscle bases, which will tend to produce mitral incompetence, as for instance in the case of aortic regurgitation. In such a case, however, compensatory lengthening of the extensile papillary muscles probably plays a more significant role.

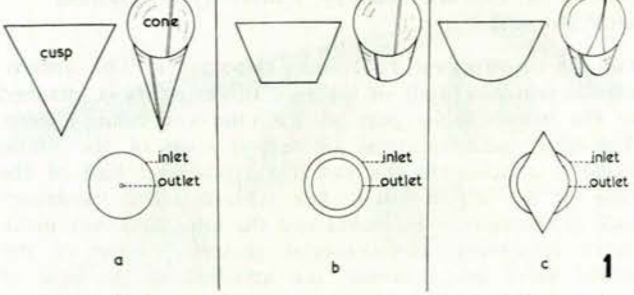

Fig. 1a. If the mitral cusps were triangular and the mitral ring annular, then the inlet of the truly cone-shaped valve would be large and the outlet small. *(1b)* Amputation of the apices of the cusps increases the size of the outlet of the cone. The shorter the cusps, the larger the outlet. *(1c)* When the free margins of the cusps are round or triangular the outlet becomes larger still and obstruction to blood-flow at this level is eliminated.

The mitral valve consists of 2 cusps which are very roughly triangular. Their apical margins correspond. If the cusps had been truly triangular and of equal size, and if the mitral ring was annular, then the mitral valve would have been a regular cone with a large inlet and a minute outlet (Fig. 1a). Amputation of the apical zone of a cone increases the size of its outlet; and the shallower the cone the larger its outlet (Fig. 1b). To produce minimal outlet obstruction, a cone-shaped valve must therefore be of minimal vertical depth. This seems to be the reason why the posterior mitral cusp is short. When the apical margins of the cusps of such a valve are

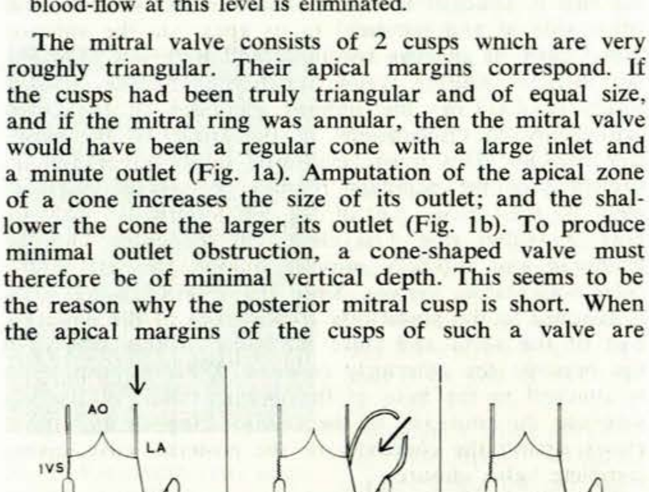

Fig. 2a. The obliquely placed mitral ring as seen from above (arrow) is concavo-convex. *(2b)* As seen by the surgeon from the left atrium (arrow), the mitral ring is oval because the anterior half of the left atrium is attached across the base of the anterior cusp close to its attachment to the biconvex root of the posterior half of the aorta. *(2c)* The anterior half of the true mitral ring is formed by the common attachments of the major part of 2 adjacent aortic cusps, the base of the anterior mitral cusp, and the posterior half of the aortic root. As seen from the left ventricle (arrow) the anterior half of the mitral valve is biconcave.

AO=Aorta, IVS=interventricular septum, LA=left atrium, LV=left ventricle, MR=mitral ring.

rounded the outlet of the cone becomes larger still and the outlet obstruction completely avoided (Fig. 1c). In such a shallow cone with a circular inlet, complete valve closure would entail complete flattening of the entire valve, including the circular inlet and therefore, in the case of the mitral valve, very considerable reduction in the diameter of the base of the left ventricle during systole and also very considerable backward and forward excursions of the cusps during systole and diastole. A flattened—oval—valve inlet, by approximating the cusp bases would largely reduce the degree of cusp excursion required to produce valve closure. Because the mitral ring occupies the complete lateral extent of the base of the left ventricle and because the aortic root and mitral ring together occupy its antero-posterior extent, the mitral ring is flattened in an antero-posterior direction. A flattened or oval valve inlet will, however, produce valve-inlet obstruction. But when this oval valve inlet is set obliquely, its shape can become more circular, its size much larger and flattening of the valve itself maintained. For the valve inlet to be placed obliquely the cusps must be of unequal length. As the shorter posterior cusp is attached to the base of the left ventricle and as the longer anterior cusp is attached to the root of the aorta, the latter must lie at a more cranial level than the former. Because the remaining half of the root of the aorta is attached to the interventricular septum, the base of the left ventricle must be oblique too. This obliquity is due to the membranous portion of the interventricular septum which extends between the root of the anterior half of the aorta and the

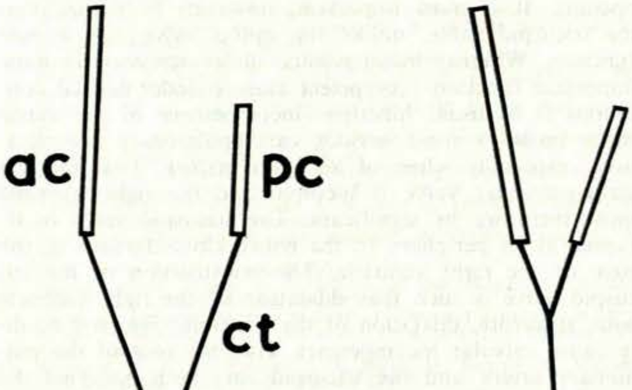

Fig. 3a. The chordae tendineae normally arise as several separate stems from the apical zones of the papillary muscles to allow the cusps maximal separation during diastole. *(3b)* Chordae anatomically fused but of the same length will cause valve outlet obstruction.

ac=anterior cusp, pc=posterior cusp, ct=chorda tendinea, pm=papillary muscle.