Total prosthetic replacement of atrioventricular valves in the dog

Part II. Development of a tilting cone mitral prosthesis

G. DEN OTTER

From the Laboratory for Experimental Surgery of the Free University at Amsterdam and the Department of Applied Physiology of the State University at Leyden

The free-floating cone and cage valve, described in a previous study as being successful as a substitute for the right atrioventricular valve, does not perform well when it is inserted in the mitral ostium. A tilting cone or disc was constructed and tested in a series of 15 dogs. This prosthesis gave excellent results in 12 animals. The reasons for its failure in the remaining three is discussed. The prosthesis presented has advantages over any ball and cage valve, mainly because of its smaller volume.

Of the many different types of mitral prosthesis that have been developed in recent years (Ellis and Bulbulian, 1958; Akutsu, Dreyer, and Kolff, 1959; Akutsu, Mirkovitch, and Kolff, 1961; Braunwald, Cooper, and Morrow, 1960; Howard, Willman, and Hanlon, 1960; Starr, 1960; Starr and Edwards, 1961; Esmond, Attar, Braley, McGrigor, and Cowley, 1961; Stuckey, Newman, Berg, Goodman, and Dennis, 1961; Ellis, McGoon, Brandenburg, and Kirklin, 1963; McKenzie and Ellis, 1963; Starr, Edwards, and Griswold, 1962) the Starr-Edwards ball valve has been the most widely used in human surgery. This has temporarily tipped the scale in favour of prostheses consisting of a rigid ring or cage equipped with an opening and closing device of an equally rigid material over leaflet valves made of pliable substances such as Dacron, Teflon, polyurethane, Silastic, and others.

This cage and ball valve device carries disadvantages. It has a large volume, since its height is related directly to the diameter of the left atrioventricular ring. This may be of little consequence when the left ventricle is dilated; but if the dilatation is not so pronounced the prosthesis fills it almost completely, thus reducing its diastolic filling volume. Moreover, the prosthesis may protrude into the aortic outflow tract, hindering the emptying of the ventricle. Turbulence of the blood and a high-velocity outflow jet are other undesirable effects of this valve which are the more important if the dilatation of the ventricle is small or moderate.

For these reasons we have found experimental work in animals (*i.e.*, dogs) difficult using this ball and cage valve. It can hardly be placed in the

narrow left ventricle, and its mass is such that frequently the heart cannot maintain a normal systemic blood-pressure afterwards.

Some investigators have constructed mitral prostheses with a smaller volume while retaining the rigid circular insertion ring (Barnard, Goosen, Holmgren, and Schrire, 1962; Barnard and Schrire, 1963; Barnard, Schrire, Frater, and Goosen, 1965; Alvarez-Díaz, Melrose, Bentall, McMillan, Nahas, and Atamanyuk, 1964; Cross and Jones, 1965). The U.C.T. prosthesis of Barnard is still rather large and seems to evoke clotting; the Alvarez valve is a hinging device which carries the risk of wearing, becoming loose, or blocking; and the Cross-Jones lenticular valve has free-ending legs on which, according to our experience with similar types, the myocardium may impale itself.

We submit that it is doubtful whether these valves will prove to be improvements over the Starr-Edwards prosthesis.

In a previous article (this journal, p. 173) we described a free-floating cone valve (Fig. 1) which has been successful as a substitute for the right atrioventricular valve of the dog. This prosthesis, however, did not perform satisfactorily when it was inserted in the mitral ostium. This might have been expected, since the left atrioventricular ring and the lumen of the left ventricle have the form of an oval slit, and the available space inside the ventricle is limited so that this prosthesis protrudes into the aortic outflow tract and often rests against the ventricular septum. The

¹All valves shown in this report were manufactured by Mr. R. P. de Graaf and Mr. A. Kroon, of the Laboratory of Physiology, State University, Leyden

FIG. 1. Free-floating cone valve.

main reason for its failure is that the powerful muscles of the left ventricle, especially those of the left lateral wall of the heart, wedge themselves inside the cage, thereby blocking the free movements of the cone (Fig. 2). One may prevent this by shielding the cage, but a semi-circular defect has to be created in the shield exactly opposite the aortic outflow (Fig. 3). Such a prosthesis is difficult to insert in exactly the right position. A better guarantee for a free outflow towards the aortic ostium is shown in Figure 4. Here the atrial and ventricular rings of the original prosthesis meet at an angle of 30° . The closed side of the cage comes to rest against the lateral wall of the left ventricle and prevents contact of the myocardium with the moving part of the prosthesis. Its open side does not reach the septum and, although it protrudes into the aortic cone, it does not obstruct the bloodstream to the aorta when the prosthesis is closed during systole.

FIG. 2. Free-floating cone valve in mitral ostium seen from the left ventricle. It protrudes into the outflow tract and becomes blocked by the myocardium.

FIG. 3. Shielded mitral prosthesis with semilunar defect to ensure a free aortic outflow tract.

FIG. 4. Tilting cone mitral prosthesis.

THE TILTING CONE VALVE

The other parameters of a size 24 of this valve are:

Internal diameter on atrial side	24 mm.
External diameter on atrial side	30.5 mm.
Surface of inflow plane	4.5 cm. ²
Surface of outflow plane	6.5 cm. ²
Height of cone	7.6 mm.
Diameter of cone	26.8 mm.
Angle at tope of cone	114°
Total weight of prosthesis	9 g.

The cone has a central air chamber and a peripheral flat rim 2 mm. wide. It is made of Lucite and tilts inside the cage. This is shown in Fig. 5, where the cage is equipped with a Teflon rim. In some cases we replaced the cone by a tilting disc, as shown in Fig. 6, which also demonstrates the difference in volume between comparable sizes of a tilting disc or cone valve and a ball valve.

The tilting cone valve was used in 15 adult mongrel dogs weighing between 18 and 25 kg. They were

FIG. 5

FIG. 6

FIG. 5. *The same as in Fig. 4 but equipped with a Teflon rim.*

FIG. 6. *Tilting disc mitral prosthesis and Starr-Edwards valve of the same size.*

anaesthetized with intravenous thiopentone sodium, intubated with a cuffed endotracheal tube, and placed on a mechanical respirator, using nitrous oxide, halothane, and oxygen with succinylcholine as a muscle relaxant. The left chest was entered through the bed of the fifth rib. The pericardium was opened widely and 2.5 mg. of heparin per kg. bodyweight was given intravenously. A single plastic catheter (size 26 to 30) was inserted into the right femoral artery, and venous blood was drained by gravity from the right atrium into a Rygg-Kyvsgaard bubble-oxygenator and returned through the right femoral artery by an occlusive roller pump (Pemco). The left atrium was drained by gravity and/or suction into the oxygenator, which also received the blood lost through the cardiectomy. The animal was placed on total perfusion by fibrillating the heart with shocks of 3 to 6 volts 50 cycles AC through two closely spaced electrodes. The temperature of the blood was lowered to about 32° C. by means of a heat exchanger. Pump flows were kept at 70-90 ml./kg. bodyweight in order to maintain the mean arterial blood pressure above 100 mm. Hg.

The left auricle was opened and the mitral valve and its chordae were completely excised, except for a small area adjacent to the aorta. The prosthesis was then placed with the open side of the cage directed towards the aortic valve and was anchored with 10 to 12 interrupted 3-0 atraumatic silk sutures. Figures 7 and 8 show the prosthesis as seen from the atrium and from the ventricle. With the valve in situ the left auricle and the left ventricle were allowed to fill with blood; the aortic valve area was then distorted to allow blood to flow retrogradely into the left ventricle to displace residual air. The left auricle was closed with a running 5-0 atraumatic silk suture, while the Melrose drain evacuated any remaining air and prevented distension of the left atrium.

Defibrillation was accomplished with one or two shocks of 200 volts 2 ampères of 0.1 second duration,

FIG. 7. *Tilting cone prosthesis in mitral ostium as seen from the left ventricle.*

FIG. 8. *Tilting cone prosthesis in mitral ostium as seen from the left atrium.*

and perfusion was discontinued after the temperature of the blood had been raised to 35° or 36° C.

The arterial, venous, left atrial, and left ventricular pressures were recorded with Sanborn pressure transducers on a Sanborn Poly-Viso. Biochemical controls were made at frequent intervals and adjustments were made as indicated. At the end of the operation protamine titrations were done to determine the amount of protamine sulphate required to neutralize the heparin present.

Figure 9 shows the pressure recordings and the electrocardiogram obtained two hours after the end of the operation. Long-term results will be published separately, as will the analysis of the pressure curves themselves. This tilting cone prosthesis performed very well in 12 out of 15 dogs. In three cases there was a rapid rise in left atrial pressure and pulmonary oedema developed shortly after discontinuing the perfusion, because of a complication that is, I think, typical of any rigid cage valve mounted near the aortic valve. Since the mitral ostium has the form of an oval slit, it becomes grossly deformed by any

FIG. 9. Blood pressure in carotid artery. Pressures of left atrium and left ventricle and electrocardiogram of dog with tilting cone mitral prosthesis two hours after finishing extracorporeal circulation.

FIG. 10. Relation between mitral prosthesis and aortic valve as seen from the left ventricle.

FIG. 11. Relation between mitral prosthesis and aortic ostium as seen from the aorta.

round and rigid cage. This may have consequences for the aortic ostium, to which the prosthesis lies so close (Figs 10 and 11) that it may become distorted, too, thereby causing incompetence of the aortic valve. Aortic blood then squirts back during the ventricle's diastole and, since the cage protrudes into the aortic cone, this blood may depress the cone of the prosthesis, keep it opened, and flow into the left atrium (Fig. 12). This may cause serious pulmonary congestion, which may be rapidly fatal, as was the case in the three animals we lost.

FIG. 12. Mechanism of backflow into left atrium caused by aortic insufficiency.

The tilting cone prosthesis presented in this paper is a good replacement for the left atrio-ventricular valve in the dog. Its use in man seems justified, since it offers advantages over the presently used ball valves, mainly because its volume is smaller and its height is not related to the diameter of the ostium into which it must fit.

REFERENCES

- Akutsu, T., Dreyer, B., and Kolff, W. J. (1959). Polyurethane artificial heart valves in animals. *J. appl. Physiol.*, **14**, 1045.
- Mirkovitch, V., and Kolff, W. J. (1961). Teflon as experimental replacement for mitral and tricuspid valves. *J. surg. Res.*, **1**, 188.
- Alvarez-Diaz, F., Melrose, D. G., Bentall, H. H., McMillan, K. R., Nahas, R., and Atamanyuk, M. (1964). Nueva prótesis mitral. Comunicación preliminar. *Rev. Clin. esp.*, **93**, 322.
- Barnard, C. N., Goosen, C. C., Holmgren, L. V., and Schrire, V. (1962). Prosthetic replacement of the mitral valve. *Lancet*, **2**, 1087.
- and Schrire, V. (1963). Surgical correction of Ebstein's malformation with prosthetic tricuspid valve. *Surgery*, **54**, 302.
- Frater, R. W. M., and Goosen, C. C. (1965). Further experiences with the U.C.T. mitral, tricuspid and aortic prostheses. *Ibid.*, **57**, 211.
- Braunwald, N. S., Cooper, T., and Morrow, A. G. (1960). Complete replacement of the mitral valve. Successful clinical application of a flexible polyurethane prosthesis. *J. thorac. cardiovasc. Surg.*, **40**, 1.
- Cross, F. S., and Jones R. D. (1965). Caged-lens prosthesis for replacement of the mitral and aortic valves. *Circulation*, **31-32**, suppl. no. II, p. 72.
- Ellis, F. H., and Bulbulian, A. H. (1958). Prosthesis replacement of the mitral valve. I. Preliminary experimental observations. *Proc. Mayo Clin.*, **33**, 532.
- McGoon, D. C., Brandenburg, R. O., and Kirklin, J. W. (1963). Clinical experience with total valve replacement with prosthetic valves. *J. thorac. cardiovasc. Surg.*, **46**, 482.
- Esmond, W. G., Attar, S., Braley, S., McGrigor, R. R., and Cowley, R. A. (1961). Design and implantation trials of prosthetic silastic-dacron (or teflon) ivalon mitral heart valves. in *Prosthetic Valves for Cardiac Surgery*, ed. K. A. Merendino, p. 340. Thomas, Springfield, Illinois.
- Howard, H. S., Willman, V. L., and Hanlon, C. R. (1960). Mitral valve replacement. *Surg. Forum*, **11**, 256.
- McKenzie, M. B., and Ellis, F. H. (1963). Current concepts in surgical correction of acquired mitral insufficiency. *Circulation*, **28**, 603.
- Starr, A. (1960). Total mitral valve replacement: Fixation and thrombosis. *Surg. Forum*, **11**, 258.
- and Edwards, M. L. (1961). Mitral replacement: Clinical experience with a ball-valve prosthesis. *Ann. Surg.*, **154**, 726.
- and Griswold, H. (1962). Mitral replacement: Late results with a ball-valve prosthesis. *Progr. cardiovasc. Dis.*, **5**, 298.
- Stuckey, J. H., Newman, M. M., Berg, E., Goodman, S., and Dennis, C. (1961). Design and placement of prosthetic valves to fit in the mitral ring of the dog after excision of the leaflets. In *Prosthetic Valves for Cardiac Surgery*, ed. K. A. Merendino, p. 266. Thomas, Springfield, Illinois.