AORTIC STENOSIS

A POST-MORTEM CINEPHOTOGRAPHIC STUDY OF VALVE ACTION

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In a previous communication (McMillan *et al.*, 1952) we described a method of studying the behaviour of aortic and pulmonary valves post-mortem in an apparatus designed to simulate the natural conditions of pulsatile flow. In this way a photographic record is obtained of the action of normal and abnormal valves and the effects of surgical procedures can be evaluated.

Aortic valvotomy has been performed in this country and in the United States for the last two years (Bailey, 1950, 1952, 1954; Brock, 1954; and Logan and Turner, 1954). The object of this communication is to present the information obtained by this method which is relevant to the selection of cases for this operation.

Method. The apparatus described in the previous paper has been considerably improved (Fig. 1). Water was found to be the most satisfactory perfusion fluid for photographic purposes. The water is pumped from a reservoir (fluid tank) to the heart via a solenoid magnetic valve (1 inch diameter) which allows a continuous flow of about 25 litres a minute or a pulsatile flow of 10–12 litres a minute by the method previously described. After passing into the ventricle and up through the aortic valve, the water is led through a compressible rubber tube, which in conjunction with an air chamber (similar in principle to that used in the standard Starling heart-lung machine, Knowlton and Starling, 1912) allows variations in out-flow and elastic resistance. The water then returns via a rotameter to the reservoir.

In this way the aortic valve can be perfused at a flow equivalent to that in life. The photography is as previously described. It must be emphasized that the results recorded are based on studying the working specimen and cinefilms made from it, and only a few stills taken from them have been used as illustrations.

RESULTS

Fig. 2 shows one cycle of a normal valve. Thirty specimens of stenosed aortic valves have been studied. Each specimen has been placed in the machine and, if the data were available, exposed to conditions as near as possible to those obtaining in life. During continuous and pulsatile flow the valves were studied and photographed. In some cases pressures were recorded with a Sanborn electromanometer, above and below the valve, and in a few cases the valve orifice was measured. The first pressure corresponds to the aortic and the second to the left ventricular pressure.

Attempts were made to split the commissures as far as the aortic wall. When the maximum possible split had been obtained, the specimens were studied again. Of the 30 specimens studied only 3 were not calcified. The distribution of calcification varied from small spicules to large masses and the ability to split the commissure depended directly on the amount of calcification

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FIG. 1.—The apparatus used for studying heart valve function.

FIG. 2.—A cycle of normal aortic valve movements showing the opening and subsequent closure.

present as it was usually densest in the region of the commissure. Of the three fibrous valves, one had early peripheral commissural fusion with little stenosis (Fig. 3), while the second had severe eccentric stenosis (Fig. 4), and the third central stenosis with all commissures fused (Fig. 5).

Six specimens were examined after the patient had had an aortic valvotomy in life but had died shortly afterwards.

The shape of the orifice varied in every case, but fell into certain groups.

(1) Early peripheral fusion with good function centrally (3 cases)	..	Fig. 3
(2) Peripheral calcification not affecting function (1 case)		Fig. 6
(3) Fusion of one commissure (14 cases)		Fig. 7 and 11
(4) Partial or complete fusion of two commissures (5 cases)		Fig. 8
(5) Partial or complete fusion of three commissures, often with incompetence (5 cases)		Fig. 9
(6) Cone-shaped valve with an ellipsoid orifice at the apex, and no sign of former commissures (2 cases)		Fig. 10

Types 1 and 2 were presumably degenerative and were accompanied by severe atheroma of the ascending aorta. In Type 3 one-quarter were rheumatic and the ætiology of the remainder was unknown. Types 4 and 5 usually had an associated mitral valve lesion and were presumed to be rheumatic. The type in some cases depended on the ætiology and Type 6 was usually considered to be congenital and known to be in the specimen shown in Fig. 10. This was very difficult to split and was comparable to the cone-shaped congenital pulmonary valve.

RESULTS OF VALVOTOMY POST MORTEM

In the first fibrous case (Fig. 3) the lesion was not clinically detectable and no treatment would have been required, in the second (Fig. 4) one commissure split easily with the finger and the other with the knife, and in the third (Fig. 5) they split easily with the Bailey dilator. If these last two cases could have been accurately diagnosed in life, a very good surgical result would have been possible as in the first the flow through the valve increased from 1.9 to 5.5 litres after valvotomy and the pressure difference across the valve decreased from 70 to 20 mm. Hg.

The results in the calcified valves were on the whole disappointing, as in most cases there was considerable calcification in the fused commissures and even if a split was made with a knife, the rigidity of the valves was such that neither movement nor flow were greatly increased (Fig. 8). If an elective valvotomy could be performed on the commissure mainly affected a good result could be achieved (Fig. 11).

FIG. 3.—Peripheral fusion. (a) and (b) Open and shut.

FIG. 4.—Fibrous fusion with excentric stenosis. (a) and (b) Open and shut. (c) and (d) Open and shut after post-mortem valvotomy.

FIG. 5.—Fibrous fusion with three commissures fused. (a) and (b) Open and shut. (c) and (d) Open and shut after post mortem valvotomy.

FIG. 6.—Peripheral calcification, not affecting function. Shut.

FIG. 7.—Bicuspid valve, heavily calcified. (a) and (b) Open and shut.

FIG. 8.—Aortic stenosis and incompetence with one normal and two fused commissures. (a) and (b) Open and shut. (c) and (d) After post-mortem valvotomy showing immobility of divided commissure.

FIG. 9.—Aortic stenosis and incompetence with three commissures fused (a). (b) Showing no improvement after valvotomy.

FIG. 10.—Congenital aortic stenosis. (a) and (b) Open and shut.

FIG. 11.—Bicuspid aortic stenosis. (a) and (b) Open and shut. (c) Showing good result of elective post-mortem valvotomy.

FIG. 12.—Bicuspid aortic stenosis after valvotomy in life (split at lower right-hand corner). (a) and (b) Open and shut.

FIG. 13.—Calcific aortic stenosis after valvotomy in life. (a) and (b) Open and shut. (c) and (d) With Bailey dilator *in situ*, open and closed. (e) and (f) Showing result of post-mortem valvotomy with Bailey dilator.

FIG. 14.—Normal mitral valve seen from left auricle with aortic cusp on right. (a) and (b) Open and shut.

FIG. 15.—Calcific mitral stenosis with aortic cusp on right. (a) and (b) Open and shut. (c) and (d) After post-mortem valvotomy to show optimal result.

FIG. 16.—Aortic stenosis and incompetence with rough edges of the valve. (a) and (b) Shut and open.

Fig. 12 shows the effect of dilating a bicuspid valve in life. Here the fused commissure has split to the aortic wall and some mobility has been restored.

Insertion of a dilator either produced no commissurotomy, or splitting of one or two of the commissures, but in no instance was a tri-radiate split obtained by dilation. Selective splitting of the third commissure was only possible with the knife, a method as yet impracticable in life. Fig. 13 shows that with the Bailey dilator (Bailey, 1954) results can be very disappointing, as this specimen had a valvotomy in life. It also shows the Bailey dilator in the same calcified valve performing valvotomy post mortem (c and d) and the results of its action after full opening (e and f). In no case was a calcified valve split except in the region of the commissure. But if one commissure was normal and the rim of the cusp soft, this latter was seen to tear in several cases rather than the calcified area split (indicated by the arrow in Fig. 13b).

Fig. 5 shows a fibrous valve, and an optimal result after post-mortem valvotomy with a Bailey dilator. Fig. 8 shows calcification on one side and mobility on the other. Here splitting of one commissure helped a little but as the calcification occupied half of the fused cusps, attempted dilatation through the pliable part merely pushed the solid part laterally without splitting any further.

TABLE OF RESULTS OF AORTIC VALVOTOMY

No.	Valve type	Calcification	Valvotomy	Result
1	Bicuspid	++	1 commissure	Poor
2	"	+++	"	No record
3	"	+++	"	Some improvement
4	"	+	—	
5	"	++	1 commissure	No improvement
6	" (Fig. 8)	+++	"	Slight improvement
7	" (Fig. 11)	+++	"	Good
8	" (Fig. 7)	++	—	
9	"	+++	—	
10	Congenital bicuspid	+++	1 commissure	Much improvement
11	Bicuspid	++	—	
12	Round hole (Fig. 16)	+++	—	
13	"	+++	—	
14	" (Fig. 9)	+++	3 commissures	No improvement, increased in-competence
15	"	++	—	
16	"	++	—	
17	1 commissure normal—2 partly fused	+++	—	
18	" "	++	(a) 1 commissure split (b) 2 commissures split	Slight improvement No further improvement
19	" "	++	—	
20	2 commissures completely fused; 1 normal (Fig. 4)	0	2 commissures	Much improvement
21	Partial fusion 3 commissures	+	—	(Fig. 3)
22	Partial fusion 3 commissures and incompetence	0	—	
23	Peripheral calcification but no fusion (Fig. 6)	+	—	
24	1 commissure completely fused; 2 partly (Fig. 5)	0	2 commissures split with Bailey dilator	Much improvement
25	Bicuspid	++	Commissurotomy during life	No split
26	" (Fig. 12)	++	in vivo	Small split
27	"	+++	"	Fair
28	Congenital, cone-shape	+	"	Minimal split
29	" (Fig. 10)	++	"	"
30	2 commissures completely fused; 1 normal (Fig. 13)	++	"	Little improvement

DISCUSSION

Leonardo da Vinci (1513) first demonstrated that the normal aortic valve opened to give a triangular orifice and this has been amply confirmed (Fig. 2). It follows, therefore, that the normal orifice is considerably less than the cross-sectional area of the aorta: this is approximately 5.3 sq. cm. (Quain) and the calculated area of the triangle is 2.6–3.5 sq. cm. approximately.

This in practice means that as long as the free borders of the cusps are mobile and shut well, there may be considerable calcification in the peripheral parts of the cusps and walls of the sinuses of Valsalva without limitation of flow in the valve area (Fig. 6). It may be difficult to distinguish the various sites of calcification on radiological evidence alone.

Some fusion of the peripheral parts of the commissures can occur without causing symptoms (Fig. 3). The maximum aortic orifice is much greater than the normal requirement and this combined with the compensatory hypertrophy of the left ventricle provides an explanation for the advanced pathological change often seen post mortem compared with a relatively short disability. It is intended to present data on the critical orifice size and their pressure relationships elsewhere.

Experience with mitral valvotomy suggests that the bivalve structure of the mitral valve can be split with the finger or knife even when calcified (Fig. 14 and 15). But the surgeon has the inestimable advantage of being able to feel the valve and know where the commissures should be, whereas aortic valvotomy at present has to be done blindly by an instrument, so that chance plays a bigger part in deciding the site of the valvotomy. The aortic approach is an advance but the finger can only guide the instrument to the orifice and not select the commissure to be split (Brock, 1950; Bailey, 1954). As mentioned previously valvotomy usually splits the weakest commissure and rarely more than two commissures. In some cases the valve may have been a congenital bicuspid type with a fused raphe representing the third commissure, but even where three commissures were present the third was very difficult to split.

The ventricular approach, however, is the one most commonly used. Attempted blind dilatation of a calcified ring from some distance above the valve may lead to a separation of the aortic wall from the calcified valve which may have dire results as was seen in one case. Another disturbing factor was the roughness of the valve surface, even before splitting, with fibrin and calcified particles only loosely attached. This is much worse after splitting in all except the fibrous valves and makes only too obvious the possibility of peripheral systemic embolism as a result of valvotomy (Fig. 16).

Where one commissure is unaffected a relatively normal cusp may be torn and aortic incompetence result. An early degree of this is shown in Fig. 13b and is marked by an arrow. This hazard can only be eliminated by direct palpation or inspection of the valve. Fig. 13f shows how the damage is increased after repeated post-mortem dilatation of the same specimen.

The chances of a recurrence of the stenosis by fusion of the divided commissure would appear to be high owing to their rough edges and frequent limitation of mobility of the cusps due to calcification, even after splitting (e.g. Fig. 8). The best results would be anticipated in fibrous valves without gross calcification. An accurate method of determining the presence or absence of calcification and of its distribution is urgently needed to improve the selection of cases for operation. In patients with much calcification, exploration is worthwhile if the circumstances justify the risk, as a proportion of such patients may have a commissure amenable to splitting, or the calcification may be outside the critical orifice area.

The orifice size, measured from films taken of the valve working under conditions simulating those in life, was smaller than that obtained by direct measurement with the finger. This was due to the fact that the examining finger post mortem can exert a relatively enormous pressure compared to that produced by the contracting ventricle in life. This would account for what appears to be a good split producing a poor functional result and is correlated exactly with the degree of rigidity of the valve and particularly with calcification.

The method as described in this paper gives very useful information in determining valve action and the effect of surgical procedures on the valves, and by cinematography allows permanent

records to be made. This study has been devoted purely to valve function and no attempt has been made to analyse the differences due to differing ætiology.

CONCLUSIONS

Thirty stenosed aortic valves were studied post mortem in an artificial perfusion system. Of these 27 showed various degrees of calcification.

The effect of post-mortem valvotomy was studied in 25 specimens, and the results of valvotomy in life in a further 6 specimens.

Many valves after valvotomy were still relatively immobile. Usually it was only possible to split one or two commissures, even with tri-radiate dilators. Unlike mitral valvotomy, large increases of valve area were not easily obtained, except in the uncalcified specimens.

When two commissures were fused, forcible dilatation in some instances damaged the remaining mobile cusp. This could lead to the production of incompetence in life.

The uncalcified stenosed aortic valve is the most suitable for aortic valvotomy as it can be easily divided.

A method of direct inspection of the valves is urgently needed to assess operability, as this cannot be done accurately by existing clinical methods.

The presence of gross calcification seriously militates against a successful functional operative result, but the existing methods of determining the degree and distribution of calcification in life are too imprecise to forbid operation if the circumstances justify the risk.

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