Aortic ball valve resistance

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After the introduction of the Starr-Edwards ball valve prosthesis for use in the aortic orifice (Starr, Edwards, McCord, and Griswold, 1963) more than one hundred implantations of such ball valves have been done in cases of aortic insufficiency and stenosis at the Clinic of Thoracic Surgery in Uppsala. In 1964 Björk reported the results of the first 74 patients in this series. In 12 of these patients cardiac output was determined during the operation before and after correction, *i.e.*, before and after the bypass procedure. In connexion with the cardiac output determinations pressure measurements were made. The ball valve resistance has been estimated from these data.

METHOD

Cardiac output was determined by the dye dilution technique or the direct Fick method or both, according to a technique described elsewhere (Grenvik, Björk, Herzog, and Holmdahl, 1966). The relative length of the systolic period was determined and the cardiac output was counted as a systolic mean flow.

The duration of the systolic period in per cent. of the cardiac cycle was estimated from the arterial pressure curves (from the brachial artery), starting at the point of sudden rise in pressure (representing the opening of the aortic valves) and ending at the dicrotic incisure (representing approximately the closure of the aortic valves), and the systolic mean flow was calculated.

Since all patients had aortic insufficiency there was a back flow during the diastole before correction. We were not able to measure the amount of back flow by our technique. Our values of the cardiac output are thus the same as the forward flow in systole minus the backward flow in diastole. The systolic mean flow before correction is therefore called the effective systolic mean flow.

Ventricular and arterial pressures were determined simultaneously before and after correction, the ventricular pressure by direct puncture of the left ventricle and the arterial pressure through an indwelling polyethylene catheter in the brachial artery. The gradient in millimetres of mercury divided by the systolic mean flow in litres per minute is taken as an index of the resistance.

MATERIAL

The 12 investigated patients were all men between 19 and 54 years old (mean age 38 years). Five patients had a combination of aortic insufficiency and aortic stenosis; in six there was an aortic insufficiency without any signs of aortic stenosis, and one patient had a combination of aortic insufficiency with mitral insufficiency and stenosis. This last patient had a replacement of both the aortic and mitral valves by ball valves.

As is shown in the Table, the total heart size varied between 1,200 and 1,820 ml., with a mean of 1,500 ml. The relative heart size had a range of 640 to 980 ml./m.² body surface and a mean value of 800 ml./m.² body surface.

RESULTS

The results are presented in detail in the Table. Before correction the mean cardiac output in the 12 patients was 5.8 l./min., and after correction it was slightly less, 5.3 l./min. The mean value of the heart frequency increased from 79 to 83 beats per minute and the duration of the systolic part of the heart cycle decreased from 42% before correction to 34% after correction. Due to the aortic insufficiency with backward flow during the diastole it is obvious that the systolic flow must have been greater before implantation of the ball valve. This may be one reason why the systolic part of the cardiac cycle was longer before correction than after.

Before correction the systolic pressure gradient across the aortic valve had a mean value of 19 mm. Hg. After correction the value was 15 mm. Hg. The highest gradient was found in case 3, a boy of 19 with a combination of aortic insufficiency and stenosis. The pressure gradient over his prosthesis (size 10) was 40 mm. Hg and the resistance index 2.9. This boy died 26 days after the operation with signs of a low cardiac output.

Case 6, a man of 34 with aortic insufficiency combined with mitral insufficiency and mitral stenosis, had a replacement of both the mitral and

TABLE
CLINICAL DATA OF 12 PATIENTS UNDERGOING AORTIC VALVE REPLACEMENT

Case No.	Diagnosis	Age	Body Surface Area (m. ²)	Heart Size		Before Correction					
				Total (ml.)	Relative (ml./m. ²)	Cardiac Output (l./min.)	Duration of Systole (% of heart cycle)	Heart Frequency Rhythm (beats/min.)	E.S.M.F. (l./min.)	Aortic Valve Gradient (mm. Hg)	Resistance Index (mm. Hg/l./min.)
1	A.I.	41	1.76	1,530	860	4.9	37	64 sinus	13.2	2	0.2
2	A.I.	34	1.86	1,820	980	5.7	39	89 sinus	14.6	4	0.3
3	A.I.+A.S.	19	1.80	1,490	820	5.9	48	89 sinus	12.3	68	5.5
4	A.I.+A.S.	52	1.84	1,200	640	3.2	37	64 sinus	8.6	34	4.0
5	A.I.+A.S.	45	2.05	1,620	820	5.2	36	69 sinus	14.4	22	1.5
6	A.I.+M.I.+M.S.	34	1.82	1,640	910	4.5	43	72 atrial fibrillation	10.5	0	0
7	A.I.	25	1.76	1,600	820	5.9	35	88 sinus	16.9	9	0.5
8	A.I.	40	1.80	1,710	940	4.3	49	80 sinus	8.8	0	0
9	A.I.+A.S.	40	1.76	1,270	700	7.9	46	72 sinus	17.2	15	0.9
10	A.I.	37	1.86	1,230	710	6.7	46	98 sinus	14.6	11	0.8
11	A.I.	54	2.24	1,510	670	9.7	43	88 sinus	22.6	40	1.8
12	A.I.+A.S.	34	1.85	1,330	720	6.0	39	77 sinus	15.4	85	5.5
Mean		38	1.87	1,500	800	5.8	42	79	14.1	19	1.8
Range		19-54	1.76-2.24	1,200-1,820	640-980	3.2-9.7	35-49	64-98	8.6-22.6	0-85	0-5.5

TABLE—continued

Case No.	After Implantation of Ball Valve							Comments
	Starr Ball Valve No.	Cardiac Output (l./min.)	Duration of Systole (% of heart cycle)	Heart Frequency Rhythm (beats/min.)	S.M.F. (l./min.)	Ball Valve Gradient (mm. Hg)	Resistance Index (mm. Hg/l./min.)	
1	12	5.6	33	83 sinus	17.0	15	0.9	Prolapsing cusps
2	12	4.9	33	93 sinus	14.8	12	0.8	Prolapsing cusps
3	10	5.2	38	103 sinus	13.7	40	2.9	Coarctation of the aorta; operation 1960; very narrow orifice; prolapsing cusps. Dead (low cardiac output)
4	11	4.2	26	68 AV block	16.2	27	1.7	Calcifications ++ prolapsing cusps. Post-op. AV block
5	11	5.3	26	57 AV block	20.4	16	0.8	Calcifications +++ post-op. AV block. Dead (anuria)
6	10	2.0	47	100 atrial fibrillation	4.3	20	4.7	Prolapsing cusps; aortic and mitral ball valves. Dead (low cardiac output)
7	11	5.7	34	100 sinus	16.8	0	0	Perforation of cusp; prolapsing cusp. Dead (pulmonary embolism)
8	11	5.8	30	65 sinus	19.3	19	1.0	Prolapsing cusps
9	11	4.7	32	64 sinus	14.7	4	0.3	Calcifications + prolapsing cusps
10	13	6.6	37	97 sinus	17.8	2	0.1	Prolapsing cusps
11	12	7.8	36	94 sinus	21.7	9	0.4	Prolapsing cusps
12	11	5.4	30	67 sinus	18.0	11	0.6	Calcifications ++
Mean		5.3	34	83	16.2	15	1.2	
Range		2.0-7.8	26-47	57-103	4.3-21.7	0-40	0.4-7	

S.M.F.=systolic mean flow. E.S.M.F.=effective systolic mean flow. A.I.=aortic insufficiency. A.S.=aortic stenosis. M.I.=mitral insufficiency. M.S.=mitral stenosis.

the aortic valves by ball valves. After correction the pressure gradient over the aortic ball valve (size 10) was 20 mm. Hg. The patient had an extremely low cardiac output of 2.0 l./min. after implantation of the artificial valves and his resistance index over the aortic ball valve was 4.7. He died on the first post-operative day.

The remaining 10 patients all had a lower resistance index than the two patients who died with signs of a low cardiac output. Of these 10 patients, eight survived; case 5 died from renal tubular necrosis with anuria and case 7 from pulmonary embolism. These patients received valves of sizes 11 to 13.

DISCUSSION

The pressure gradient over the aortic orifice has been estimated as the difference between the left ventricular and the arterial peak pressures. The resistance index was calculated as this peak pressure difference divided by the effective systolic mean flow. The resistance index is not a true flow resistance value for several reasons. It may still have some clinical interest, as in this investigation in which the two patients who died with signs of low cardiac output had considerably higher resistance indices over the ball valves than the others. It was also observed that the systolic part of the

cardiac cycle, estimated from arterial pressure curves, was significantly shortened after introduction of the ball valve. This may be due to the decrease in left ventricular stroke volume caused by the prosthesis, which prevents the diastolic back flow and thereby decreases forward flow in systole.

SUMMARY

A report is given of 12 operated cases with ball valve replacement of the aortic valve. An index of the resistance of the ball valves was estimated by measuring the pressure gradient and the effec-

tive systolic mean flow. Two patients succumbed with signs of a low cardiac output, and they had the highest ball valve resistance indices. The remaining 10 patients had considerably lower resistance indices. Of these patients, two died, one from anuria and one from pulmonary embolism, but none had signs of low cardiac output.

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