Hemodynamic Performance on Exercise: Comparison of a Stentless and Stented Biological Aortic Valve Replacement

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Background and aim of the study: **Although stentless valves are expected to be hemodynamically superior to stented valves, the results of comparative trials have been inconsistent. The study aim was to compare hemodynamic function at rest and on exercise in 50 stentless and stented biological replacement aortic valves**

Methods: **Twenty-one patients with a Toronto™ stentless porcine valve and 29 with a Perimount™ stented bovine pericardial valve were exercised using a bicycle ergometer. Echocardiography was performed before, and during exercise testing.**

Results: **Patients with either valve type were exercised to a similar degree. Transaortic resistance was slightly lower in the Perimount compared with the Toronto at rest (p = 0.03) and at peak exercise (p = 0.04), and flow was higher in the Perimount at rest (p = 0.007), but not at peak exercise. There were no significant differences between the valve types in peak velocity, mean pressure difference or effective orifice area either at rest or on peak exercise.**

Conclusion: **There were no clinically significant differences in hemodynamic function between the stented and stentless biological valves chosen for comparison either at rest or during bicycle exercise.**

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Stented biological replacement valves are relatively obstructive compared with a normal native aortic valve (1). Stentless valves are expected to be less obstructive since, in the absence of a stent and sewing cuff, more of the orifice should be available for flow. Some (2,3) but not all (4) early non-randomized studies appeared to confirm this situation. Randomized studies have also shown contradictory results, with some in favor of stentless valves (5,6), while others showed no significant difference in hemodynamic function (7,8). One major reason for this discrepancy is likely to be the choice of comparator valve. However, it is also possible that cardiac output affects stentless and stented valves differently, and that hemodynamic differences between the valves may be most apparent on exercise (9).

The aim of the present study was to compare stentless and bovine pericardial valves on exercise, as no previous investigation has been made in this respect.

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Clinical material and methods

Patients

A total of 160 patients from a long-term, randomized comparison of the stentless Toronto and stented Perimount valves was eligible if surgery had been performed between one and five years previously. A period of one year was allowed for maximum postoperative recovery, and the five-year limit was to ensure that early valve failure was unlikely. The Toronto valves were sized using the sinotubular junction, as recommended at the time of surgery. The Perimount valves were placed in a supra-annular position, as was routine at the authors' institution. Among 114 patients at between one and five years after implantation, 61 were excluded because of living too far from the hospital (n = 21), refusal (n = 26), atrial fibrillation (n = 8), or logistical problems (e.g. machine not available) (n = 6). In addition, three patients had poor signals on exercise. Hence, the total group comprised 50 patients, of whom 21 had received a Toronto valve and 29 a Perimount valve. The mean patient age was 70.0 years (range: 54 to 85 years), and the male to female ratio was 28:22 (Table I). There were no differences between the total population of 160 patients and the 50 exercise study patients in terms of valve size, body surface area, or age. The study was approved by

Table I: Demographic data for patients after Toronto or Perimount valve implantation.

Parameter	Toronto (n = 21)	Perimount (n = 29)	p-value
Age (years)*	69 (54-82)	72 (62-85)	0.12
Gender ratio (M:F)	12:9	16:13	
BSA (m^2)+	1.81 ± 0.23	1.83 ± 0.20	0.77
Time after surgery (years)+	2.9 ± 1.4	3.0 ± 1.4	0.67
LVEF (%)+	63 ± 10	61 ± 12	0.48

*Values are mean (range).
+Values are mean ± SD.
BSA: Body surface area; LVEF: Left ventricular ejection fraction.

the local committee on ethical practice, and the patients provided their written consent.

Echocardiography

Measurements were made as recommended by the American Society of Echocardiography (10) and the British Society of Echocardiography (11). The maximum of three measurements of left ventricular outflow tract diameter was taken over three frames frozen in systole from the trailing edge of the left septal echo to the leading edge of the anterior mitral leaflet echo. Subaortic pulsed recordings were made in the apical five-chamber view, with the sample placed just below the level of significant flow acceleration. Peak velocity, mean pressure drop, and velocity integral were recorded. Steerable continuous-wave Doppler recordings were made from the apex. Peak velocity, mean pressure drop, and velocity integral were recorded. Measurements were made over three cycles at rest and at each stage of the bicycle exercise.

Exercise

Exercise was performed with a semi-supine bicycle ergometer (Vision Fitness R2200, USA), starting at 25 W and increasing in 25-W increments every 3 min. The electrocardiogram was monitored continuously and blood pressure measured at the end of each stage.

Calculations

The following calculations were performed:
Effective orifice area (EOA, in cm^2) by the continuity equation = [CSA × VTI_1/VTI_2], where CSA is the left ventricular outflow cross-sectional area (cm^2) calculated from the diameter assuming a circular cross-section, VTI_1 is the subaortic velocity integral (cm), and VTI_2 is the aortic velocity integral (cm).
Peak pressure difference across the aortic valve (peak ΔP in mmHg) = $[4 (v_2^2 - v_1^2)]$, where v_2 is transaortic peak velocity (m/s) and v_1 is subaortic peak velocity (m/s).
Mean pressure difference across the aortic valve (mean ΔP in mmHg) = [aortic mean ΔP - subaortic mean ΔP].
Resistance (dynes.s.cm^{-5}) = 1.333 × mean ΔP × ejection time/CSA × VTI_1.
Flow (ml/s) = CSA × VTI_1/ejection time.

Data analysis

Values were expressed as mean ± SD. Comparisons

Table II: Hemodynamic results for the Toronto and Perimount valves at rest and peak exercise.

Parameter	Toronto			Perimount		
	Rest	Peak	p-value	Rest	Peak	p-value
Peak velocity (m/s)	1.9 ± 0.5	2.4 ± 0.6	0.004	1.8 ± 0.3	2.2 ± 0.4	<0.0001
Peak ΔP (mmHg)	15.9 ± 8.3	23.7 ± 10.7	<0.0001	13.8 ± 4.3	19.1 ± 6.9	<0.0001
Mean ΔP (mmHg)	7.0 ± 3.9	9.5 ± 4.7	<0.0001	5.6 ± 2.2	8.0 ± 3.5	<0.0001
Resistance (dynes·s·cm^{-5})	48 ± 29	53 ± 31	NS	34 ± 15.6	38 ± 17.9	0.01
EOA (cm^2)	1.65 ± 0.59	1.74 ± 0.74	NS	1.85 ± 0.51	1.90 ± 0.46	NS
CO (l/min)	4.27 ± 1.27	7.41 ± 3.23	0.0002	4.82 ± 1.03	7.84 ± 1.51	<0.0001
Flow rate (ml/s)	207 ± 61	273 ± 94	<0.0001	239 ± 45	289 ± 56	<0.0001

Values are mean ± SD.
ΔP: Pressure difference; CO: Cardiac output; EOA: Effective orifice area; NS: Not significant.

Table III: Toronto valve: Hemodynamic results by valve label size.*

Label size (mm)	Flow (ml/s)		Resistance (dynes.s.cm^{-5})		EOA (cm^2)		Mean ΔP (mmHg)		Peak ΔP (mmHg)	
	Rest	Peak	Rest	Peak	Rest	Peak	Rest	Peak	Rest	Peak
21 (n = 2)	199	218	66	92	1.2	1.1	10.1	15.1	27.1	37.5
23 (n = 5)	186 ± 35	218 ± 34	67 ± 23	73 ± 28	1.2 ± 0.2	1.2 ± 0.2	9.6 ± 4.8	12.0 ± 5.5	21.9 ± 11.1	28.8 ± 12.9
25 (n = 10)	196 ± 40	281 ± 109	48 ± 29	49 ± 25	1.6 ± 0.4	1.7 ± 0.6	6.5 ± 3.1	9.2 ± 3.5	14.6 ± 4.9	21.2 ± 6.8
27	-	-	-	-	-	-	-	-	-	- -
29 (n = 4)	266 ± 29	352 ± 72	16 ± 6.6	17 ± 5.5	2.6 ± 0.3	2.9 ± 0.2	3.3 ± 1.4	4.5 ± 1.9	7.8 ± 2.8	11.6 ± 3.4

*Values are mean ± SD.
Abbreviations as Table II.

were made between valve types using an unpaired *t*-test, and between resting and peak values using a paired *t*-test. Selection bias was excluded by comparison of valve labeled size in the subpopulation of 50 patients with the parent population of 160 patients.

Results

The mean label size for the Toronto valve was 24.9 ± 2.4, and for the Perimount was 24.9 ± 2.5. The proportion of small valves (19-22 mm) was 12% in the present study compared with 12% in the main population, the proportion of medium valves (23 and 25 mm) was 60% compared with 63%, and the proportion of large valves (27 and 29 mm) was 28% compared with 25%.

Patients with Toronto valves exercised for 6.7 ± 2.8 min to a peak energy of 55 ± 23 W, and those with Perimount valves exercised for 6.5 ± 2.8 min to a peak energy of 53 ± 20 W. The heart rate increased from 70 ± 10 bpm at rest to 103 ± 21 bpm at peak for the Toronto valve, and from 72 ± 12 to 107 ± 16 bpm for the Perimount valve. Blood pressure was also similar at rest (139/78 versus 145/79 mmHg) and on peak exercise (170/84 versus 173/78 mmHg).

The echocardiographic results at rest and on peak exercise for the Toronto and Perimount valves are listed in Table II. The transaortic resistance was slightly lower in the Perimount compared with the Toronto at rest ($p = 0.03$) and at peak exercise ($p = 0.04$), and flow was higher in the Perimount at rest ($p = 0.007$), but not at peak exercise ($p = 0.5$). There were no significant differences between the valve types in peak velocity, mean pressure difference or EOA either at rest or at peak exercise. In both valve types, the peak velocity, pressure difference and EOA increased with exercise.

As expected, the mean pressure difference was

Table IV: Perimount valve: Hemodynamic results by valve label size.*

Label size (mm)	Flow (ml/s)		Resistance (dynes.s.cm^{-5})		EOA (cm^2)		Mean ΔP (mmHg)		Peak ΔP (mmHg)	
	Rest	Peak	Rest	Peak	Rest	Peak	Rest	Peak	Rest	Peak
21 (n = 4)	201 ± 43	227 ± 35	49 ± 22	52 ± 27	1.4 ± 0.4	1.5 ± 0.6	7.0 ± 2.4	8.4 ± 3.8	15.9 ± 4.5	18.1 ± 6.3
23 (n = 10)	224 ± 68	277 ± 50	39 ± 8.4	46 ± 13	1.6 ± 0.4	1.7 ± 0.2	6.3 ± 0.9	9.6 ± 3.6	15.5 ± 2.9	21.9 ± 7.5
25 (n = 5)	253 ± 51	321 ± 56	34 ± 19	29 ± 22	1.9 ± 0.6	2.2 ± 0.6	6.6 ± 3.5	6.9 ± 4.4	13.7 ± 3.5	16.4 ± 5.7
27 (n = 7)	263 ± 39	296 ± 43	25 ± 10	41 ± 9	2.0 ± 0.4	2.0 ± 0.1	4.8 ± 2.2	7.1 ± 2.7	12.8 ± 5.4	17.0 ± 9.8
29 (n = 3)	256 ± 110	339 ± 158	15 ± 4.7	23 ± 7.7	2.5 ± 0.2	2.4 ± 0.2	3.0 ± 0.1	6.0 ± 2.2	7.9 ± 2.0	15.3 ± 5.5

*Values are mean ± SD.
Abbreviations as Table II.

inversely related to valve labeled size, and EOA was directly related to labeled size for both valve types (Tables III and IV). The effect of flow was not more obvious for the small valves. In view of the small numbers of each valve size, these parameters were not compared between the two valve types.

Discussion

The effect of exercise on hemodynamic function has not been studied extensively. In 25 patients with small tilting-disk, bileaflet mechanical or stented biological valves, bicycle exercise produced a modest increase in mean gradient from 16 mmHg at rest to 24 mmHg at peak (12), while in a study of Medtronic Hall valves, the mean gradient rose from 2.9 to 6.8 mmHg (13). In small-sized Medtronic Hall or St. Jude Medical standard mechanical valves, the gradient increased from 21 mmHg at rest to 33 mmHg with exercise (14-16) or dobutamine stress testing (17). In 23 mm supra-annular CarboMedics valves, the mean gradient was increased from 11.4 to 19.1 mmHg (18).

A small number of studies have included stentless valves. In these, the increase in mean gradient with stress was small, usually from approximately 6 mmHg at rest to 9 mmHg with stress, whether the valve was an allograft (19), stentless Biocor (20,21) or Medtronic Freestyle (22). The results of the present study were in agreement with those of previous investigations. However, the comparator valve is usually associated with higher increases in gradient. For the stented St. Jude Medical valve (21), the mean gradient was increased from 16.5 mmHg at rest to 27.5 mmHg after exercise, while in the Carpentier-Edwards supra-annular porcine valve, the increase was from 12 to 22 mmHg (22) and for the Intact stented porcine valve, from 19.3 to 27.8 mmHg (19). By comparison, in the present study the mean gradient for the Perimount stented valve rose from only 5.6 mmHg to 8.0 mmHg.

This similarity to the Toronto valve was in contradistinction to the findings of previous studies. One possible - but invalid - explanation was that the present elderly patients exercised less than those in other studies. Both of the present groups exercised to a peak of about 55 W, compared with 63 W for the Medtronic Freestyle and 70 W for the Carpentier-Edwards in another study (22), and about 90-100 W in a further study with younger patients (19). However, cardiac output in the present patients was similar to that in other studies, at ~4 l/min at rest and 8 l/min during exercise (18,20). In the present study, the most likely explanation for an inability to show hemodynamic superiority for the Toronto valve was that the comparator valve was a pericardial rather than a porcine valve, and was placed in a supra-annular position. Hence, it had better hemodynamic function than previously studied comparator valves (1).

Effect of differences in gradient

It is difficult to assess the actual benefit of a rise in gradient with exercise. Valve size or gradient do not closely relate to exercise capacity. In one study, despite an increase in gradient in Medtronic Hall or St. Jude Medical valves by a factor of 1.5 to a mean of 33 mmHg, there was no difference in exercise capacity compared with control subjects matched for age and gender (16). There is also contradictory evidence linking high gradients with a higher risk of death and other complications (23,24) or the surrogate end-point of regression of left ventricular hypertrophy. Some studies comparing different valves have reported a faster and more complete regression of hypertrophy in stentless valves compared with mechanical or stented biological valves (5,6,25), but others have not found this to be the case (3,7,8,26,27). However, the assessment of left ventricular mass by echocardiography is not accurate, and there may also be many factors determining left ventricular regression, including genetic status, systemic hypertension and the duration of hypertrophy before surgery (28).

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