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Functional Results in Aortic Root Enlargement

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ABSTRACT

Background: The hemodynamically efficient valves with effective orifice areas that are used in aortic valve replacement have been positively determined to affect postoperative exercise capacity. The aim of this study was to evaluate the functional effects of aortic root enlargement in the late postoperative period for patients with a small effective orifice area.

Methods: Nineteen patients with a small effective orifice area were included in the study. The study group comprised 9 patients who underwent isolated aortic valve replacement with 23-mm St. Jude Medical prosthetic valves and posterior aortic root enlargement. The control group comprised 10 patients in whom 19-mm and 21-mm St. Jude Medical prosthetic valves were implanted without aortic root enlargement. The patients were evaluated in the late postoperative period with echocardiography and cardiopulmonary exercise testing.

Results: The 2 groups were similar in anthropometric parameter values, follow-up periods, echocardiographic findings, and the gradients at the prosthetic aortic valve at rest; however, the anaerobic threshold, peak oxygen uptake, minute ventilation volume, and walk time were significantly higher in the study group ($P < .05$).

Conclusion: The choice of aortic root enlargement for the implantation of a valve with a larger effective orifice area is preferred by most of the surgeons over the implantation of a valve with a smaller effective orifice area. The late postoperative functional capacity of the patient is significantly improved with root enlargement. Surgeons should be encouraged to perform root enlargement in patients with a small effective orifice area, and such surgery may even be performed routinely in these patients.

INTRODUCTION

The choice of a valve with an effective orifice area matching the body surface area and providing efficient hemodynamics is an important factor affecting mortality and morbidity in patients undergoing aortic valve replacement. Patient-prosthesis mismatch is defined as a disproportion between the size of the prosthesis and the patient's body surface area. Patient-prosthesis mismatch when smaller-sized valves are used causes various complications in patients who undergo aortic valve replacement [Pibarot 1999]. Persistent left ventricular dysfunction, left ventricular hypertrophy, hemolysis, mechanical valve thrombosis, and sudden death are the major complications [Kratz 1994].

Effective orifice area for mechanical valves is calculated by dividing the geometric valve area in centimeters by the body surface area in meters. For patients with an aortic valve prosthesis, the factors of effective valve area and postoperative exercise capacity are predictors of prosthesis-patient mismatch [Pibarot 1999]. The mismatch of the prosthetic valve and body surface area has been suggested to affect the exercise capacity in the postoperative period [Wiseth 1993]. A low exercise capacity in the postoperative period is an indicator of patient-prosthesis mismatch [Tatineni 1989].

Measuring the oxygen uptake (VO_2) value during peak exercise is a noninvasive method for determining cardiac output. If the anaerobic threshold represents tiredness, a lower threshold means that the patient will get tired earlier. The measurement of oxygen consumption and other parameters with the cardiopulmonary exercise test is of prognostic value with respect to left ventricular dysfunction and valvular diseases [Lehmann 1996]. The muscles, lungs, and heart should work together to provide the oxygen necessary for our activities. Maximal oxygen uptake (VO_2max) is a good index of exercise capacity and is used for evaluating prognosis in cardiac disease [Stelken 1996, Chaitman 1997].

This study used the cardiopulmonary exercise test to compare the postoperative functional capacities of a group of patients who underwent posterior aortic root enlargement and received an aortic valve replacement prosthesis with a larger effective orifice area with a control group of patients who received an aortic valve replacement prosthesis with a small effective orifice area without undergoing aortic root enlargement.

MATERIALS AND METHODS

Between November 1987 and July 2002, 33 patients underwent aortic root enlargement at our center. Nine of the patients included in the study were in follow-up. The clinical follow-up periods were between 13 months and 62 months

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Table 1. Patient Characteristics*

	Aortic Root Enlargement +	Aortic Root Enlargement −	*P*
Age, y	41.67 ± 8.59	46.56 ± 12.56	NS
BSA, m^2	1.70 ± 0.15	1.65 ± 0.13	NS
GOA, cm^2	2.55 ± 0.0	1.96 ± 0.2	.01
EOA, cm^2/m^2	1.50 ± 0.12	1.18 ± 0.09	.02
Follow-up, mo	26.33 ± 16.77	49.33 ± 37.82	NS

*Data are presented as the mean ± SD. NS indicates nonsignificant; BSA, body surface area; GOA, geometric orifice area; EOA, effective orifice area.

Table 2. Echocardiographic Findings*

	Aortic Root Enlargement +	Aortic Root Enlargement −	*P*
LVEDD, cm	4.63 ± 0.63	4.48 ± 0.65	NS
LVESD, cm	3.38 ± 0.54	3.14 ± 0.72	NS
Ejection fraction, %	63.33 ± 5.16	66 ± 4.66	NS
AV max G at rest, mm Hg	28.17 ± 3.82	34.33 ± 8.59	NS
AV mean G at rest, mm Hg	14.33 ± 2.94	20.33 ± 8.92	NS

*Data are presented as the mean ± SD. LVEDD indicates left ventricular end-diastolic diameter; NS, nonsignificant; LVESD, left ventricular end-systolic diameter; AV max G at rest, aortic valve maximal gradient at rest.

following the surgical procedures. The study group comprised 9 patients who underwent isolated aortic valve replacement with 23-mm prosthetic valves (St. Jude Medical, St. Paul, MN, USA) with posterior aortic root enlargement (with the Nicks procedure in 5 patients and the Manouguian procedure in 4 patients). The control group comprised 10 patients in whom 19-mm and 21-mm St. Jude Medical prosthetic valves (4 with 19-mm valves, 6 with 21-mm valves) were implanted without aortic root enlargement. Nine of these 19 patients were women, and the mean age ± SD was 44.6 ± 11.08 years. The other demographic data for the 2 groups were similar. The patients included in the study had no chronic obstructive pulmonary disease, vascular disease, anemia, orthopedic defects, or neurologic defects that would preclude performing an effort test. All patients were in sinus rhythm.

The effective orifice areas (cm^2/m^2) of the valves were calculated and standardized. All of the patients were evaluated by echocardiography for left ventricular and prosthetic valve functions. All of the patients underwent cardiopulmonary exercise tests in the late postoperative period (a minimum of 1 year after surgery). We did not conduct cardiopulmonary exercise testing before surgery because such testing is classically contraindicated in cases of aortic stenosis.

The study was performed with the approval of the Institutional Human Investigation Committee.

Echocardiography

A complete echocardiographic examination was performed with the patient in the left lateral decubitis position, and standard parasternal and apical views were obtained with an HP Sonos 1500 (Hewlett-Packard, Palo Alto, CA, USA) and an electronic transducer. Two-dimensional measurements and M-mode recordings were used to evaluate the interventricular septum, posterior wall thickness, left ventricular end-systolic and end-diastolic diameters, ejection fraction, and diameter of the left atrium. Mechanical aortic valves were examined with continuous wave Doppler, and maximal systolic velocities were recorded. Mean and maximal aortic gradients were calculated by means of the modified Bernoulli equation.

Cardiopulmonary Exercise Test

Exercise tests were performed with the patient's heart rate, blood pressure, and electrocardiogram monitored every 3 minutes under the supervision of a physician. Expired flow and oxygen and carbon dioxide partial pressures were monitored on a breath-by-breath basis during cardiopulmonary exercise testing.

At 0 to 3 days after an echocardiographic examination, the patients underwent a symptom-limited cardiopulmonary exercise test with Quinton 5000 treadmill exercise equipment (Quinton, Bothell, WA, USA) and a Cortex Metalyzer 3B (Cortex Biophysik, Leipzig, Germany) to measure VO_2 and carbon dioxide production (VCO_2) from breath to breath. Calibration was performed before every test. The respiratory gas exchange ratio (VCO_2/VO_2) and the ventilatory equivalents for oxygen and carbon dioxide were also measured.

Peak VO_2 (maximum oxygen uptake value during the test), the VO_2 value at the anaerobic threshold, minute ventilation volume (VE), and VE/VO_2 were recorded. The method chosen for the exercise test was the Bruce protocol, which has been determined to be more valuable for the determination of the anaerobic threshold [Clyne 1991]. In all patients, tests were completed with complete exhaustion. The Weber classification was used to determine functional capacity. Classification into 4 groups (A, B, C, and D) was carried out with respect to oxygen uptake (>20 mL/min per kg, 16-20 mL/min per kg, 10-16 mL/min per kg, and <10 mL/min per kg).

Patients who underwent the root enlargement procedure with larger-sized prosthetic valves were compared with patients who received implants of smaller-sized valves without root enlargement. The late postoperative functional capacities of these patients were compared.

Statistical Analysis

All data are expressed as the mean ± SD. The Student t test for independent samples was used for statistical analyses. Statistical significance was determined by a P value of less than .05.

RESULTS

There were no statistically significant differences between the 2 patient groups with respect to anthropometric parameters (age, body surface area) and follow-up period. Geometric orifice area and the effective orifice area of the prosthetic valve were significantly different between the 2 groups (Table 1).

The left ventricular end-diastolic and end-systolic diameters, the left ventricular ejection fractions, and the maximal

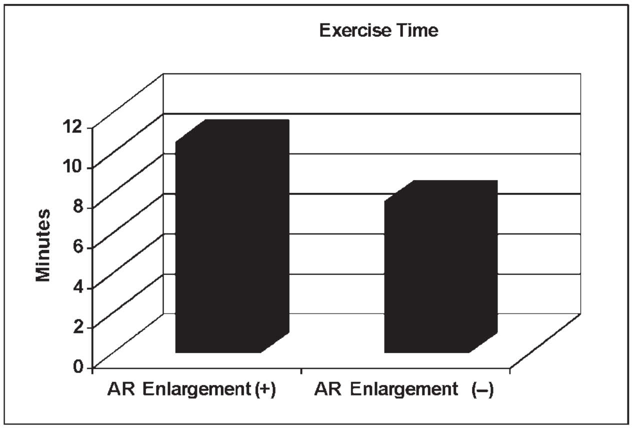

Figure 1. Comparison of exercise times for the 2 patient groups. AR indicates aortic root.

Table 3. Cardiopulmonary Exercise Test Results*

	Aortic Root Enlargement		
	+	–	*P*
AT, L/min	1.34 ± 0.31	0.88 ± 0.18	.007
Peak VO_2, L/min	2.29 ± 0.18	1.45 ± 0.37	.001
VE, L/min	22.78 ± 7.11	31.82 ± 5.03	.01
Exercise time, min	10.46 ± 1.09	7.47 ± 2.81	.01
VO_2max, mL/min per kg	28.67 ± 2.93	22.41 ± 5.82	.03
Functional capacity†	A	A	
HR at rest, beats/min	90.33 ± 6.65	87.11 ± 17.79	NS
Maximal HR, beats/min	147.67 ± 7.34	168.11 ± 9.55	.01

*Data are presented as the mean ± SD. AT indicates anaerobic threshold; VO_2, oxygen uptake; VE, minute ventilation volume; VO_2max, maximal oxygen uptake; HR, heart rate; NS, nonsignificant.

†Weber classification. A indicates oxygen uptake >20 mL/min per kg.

and mean gradients of the prosthetic valve at rest were not significantly different between the 2 groups by echocardiography before cardiopulmonary exercise testing. None of the patients had any dysfunction of the prosthetic aortic valve. Mild mitral valve regurgitation without any clinical symptoms was determined in 3 of the patients with aortic root enlargement (Table 2).

Comparison of the exercise test results for the 2 patient groups showed that the values for anaerobic threshold, peak VO_2, exercise duration, and functional capacity were higher in patients with aortic root enlargement (Figures 1 and 2). VE and maximal heart rate during exercise in the root enlargement group were lower. These findings were all found to be statistically significant (Table 3).

DISCUSSION

The measurement of VO_2 and the other parameters with the cardiopulmonary exercise test is of diagnostic and prognostic value in cases of left ventricular dysfunctions and valve disease [Chaitman 1997]. Maximal exercise testing provides an objective assessment of the capacity of the patient's circulatory system to perfuse skeletal muscle [Clyne 1991]. Peak VO_2 is an important prognostic value in cases of valvular disease [Mudge 1993]. VO_2 measurement at maximal exercise is a noninvasive method of determining cardiac output, and this parameter best reflects exercise capacity. Several studies have shown that an increase in the effective orifice area of the prosthetic valve may produce an increase in cardiac output [Theo 1987, De Paulis 1994].

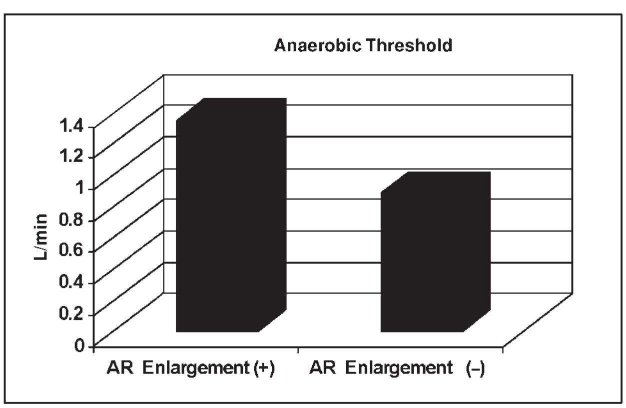

Figure 2. Degrees of tiredness (anaerobic threshold) in the 2 groups. AR indicates aortic root.

Hirooka et al determined that patients with small-sized prosthetic aortic valves had a lower exercise capacity [Hirooka 1994]. Parameters related to ejection fraction and left ventricular function were not associated with the exercise capacity of patients with aortic prosthetic valves. Age and prosthetic valve size were determined to be independent risk factors for exercise intolerance. The mismatch between prosthetic valve area and body surface area has been determined to affect exercise capacity in the postoperative period [Tatineni 1989]. Becassis et al compared healthy people with patients with small-sized prosthetic aortic valves and determined that small-sized valves do not cause exercise intolerance [Becassis 2000]. On the other hand, a residual stenosis that restricts the effort capacity occurs in patients with small-sized aortic valves [Theo 1987]. The findings of our study show that the patients who underwent implantation of large-sized valves after aortic root enlargement had higher VO_2 levels, indicating that these patients had a higher cardiac output.

Theoretically, the anaerobic threshold is the value at which muscles during dynamic exercise start to provide energy by anaerobic metabolism. In the healthy body, lactic acid starts to accumulate in the blood at a level of 50% to 60% of the aerobic metabolic rate and increases as exercise continues. Metabolic acidosis occurs as a result. This acidosis is tamponaded in the blood, and carbon dioxide extraction increases with the hyperventilation reflex. A lower anaerobic threshold is an expected finding in cases of chronic heart diseases [Chaitman 1997].

If the anaerobic threshold symbolizes tiredness, then patients with small-sized aortic prosthetic valves get tired earlier than patients with large-sized valves after aortic root enlargement, because the former have lower anaerobic threshold levels.

The respiratory response to exercise was found to be lower in patients with small-sized valves. Our study shows that the patients with small-sized valves had a lower effort capacity and a lower ventilation volume.

In addition, we determined that the patients who received implants of large-sized valves with aortic root enlargement had significantly higher values in walking duration and maximal VO_2 at the anaerobic threshold and significantly lower values of VE/VO_2, minute heart rate, and ventilation volume during comparable maximal efforts than patients who received implants of smaller-sized valves.

These findings allow us to conclude that a larger effective orifice area is associated with a greater effort capacity and that patients with a larger effective orifice area reach the equal effort capacity of patients with a small effective orifice area with a ventilation rate and a heart rate that are more efficient.

Our study shows that patients who received larger-sized valves with aortic root enlargement procedures endured a longer walking time with higher resultant VO_2 values during the test and lower anaerobic thresholds than the group without aortic annular enlargement. These results also showed significantly lower values for cardiac rates, ventilatory volume, and VE/VO_2 during the highest comparable effort. These findings indicate that patients with larger effective orifice areas have better functional capacities and a better economy of ventilatory and hemodynamic functions at similar end points of effort than patients without aortic annular enlargement.

Aortic root enlargement and the selection of a valve with a large effective orifice area seem to improve the quality of life for the patient. We conclude that aortic root enlargement should be routinely performed in patients with a small effective orifice area to achieve a better postoperative functional capacity.

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