Maximal Workload and Oxygen Uptake During Exercise After Aortic-Valve Replacement

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Context: It is more feasible to assess functional capacity with an exercise test than to measure peak-exercise VO$_2$. Objective: To assess whether maximal workload reliably predicts peak VO$_2$. Patients: Thirty-six patients after aortic-valve replacement during routine follow-up. Design: Incremental symptom-limited cycle exercise test in the upright position with increments of 20 W/min. Setting: Out-clinic patients, university hospital. Main Outcome Measures: Maximal workload, ventilatory threshold, and peak VO$_2$. Results: Maximal workload was 151 ± 39 W, and peak VO$_2$ 1649 ± 486 ml/min. The correlation coefficient between maximal workload and peak VO$_2$ was $r = .92$ ($P < .0001$). The regression equation for the estimation of peak VO$_2$ was $y = 11.7$ (maximal workload in watts) – 110.7. Peak VO$_2$ calculated with this equation was 1657 ± 451 ml/min. Conclusions: Maximal workload during ergometry in the upright position reliably predicted peak VO$_2$. Key Words: exercise capacity, cycle ergometry, peak oxygen uptake

Gated cardiac pool imaging, exercise Doppler echocardiography, right-heart catheterization, and peak-VO$_2$ determination are the methods commonly used in research to assess cardiac performance during exercise in patients after aortic-valve replacement. These methods have several disadvantages in the everyday evaluation of routine patients, such as high cost, limited availability, and the need for trained laboratory staff. It is more feasible to measure functional capacity with a symptom-limited exercise test, because cycle ergometry is easy to perform, relatively inexpensive, and widely available.

The best indicator of functional capacity during ergometry is the maximal ability to consume oxygen. Peak-exercise minute oxygen uptake (VO$_2$) is determined by the analysis of inspired and expired air and describes the VO$_2$ value at maximal exercise effort. We assumed that a symptom-limited exercise test without VO$_2$ measurements could also accurately assess functional capacity if it is able to predict peak-exercise VO$_2$ from the maximal workload.

The aim of the present study was to evaluate whether maximal workload reliably predicts measured peak VO₂ in patients after aortic-valve replacement.

**Methods**

**Patient Population**

The study included 36 ambulatory patients who had undergone aortic-valve replacement. The patients had a routine follow-up visit at least 1 year after replacement, with mean follow-up at 4.7 ± 4.8 years postoperatively. Indications for aortic-valve replacement were aortic stenosis in 28 patients and aortic regurgitation in 8 patients. Thirty patients were men and 6 were women. The average age was 53 ± 15 years (range 23–82). Mean weight was 80 ± 14 kg, and height, 173 ± 6 cm. Twenty-four patients had received mechanical prostheses, 10 had tissue valves, and 2 had homograft valves. The follow-up assessment included an echocardiogram at rest, which revealed normal aortic-valve morphology and function (pressure gradient 30 ± 13/17 ± 8 mmHg, no relevant aortic regurgitation) in all patients. The left-ventricular function assessed by echocardiography was normal in 31 patients and slightly impaired in 5.

**Study Protocol**

The exercise test was performed on an electrically braked cycle ergometer (Seca Cardiotest, Hamburg, Germany) in the upright position. The workload started at 20 W and increased by 20 W every minute until the patients developed symptoms that caused them to stop exercising. The length of the exercise test was 7.8 ± 1.9 minutes. Ventilatory threshold and peak-exercise VO₂ measurements were performed during the test. The patients' cardiac function during the test was monitored by continuous electrocardiography, and their blood pressure was measured every minute.

The gas analyzers (MedGraphics, Minneapolis, Minn) were calibrated before each test. The breath was collected through a face mask. Resting measurements were taken with the patient seated on the ergometer. The V-slope and ventilatory-equivalent methods were used to determine the ventilatory threshold. When these 2 criteria identified different ventilatory thresholds, the results were averaged. Peak-exercise VO₂ was defined as the maximal VO₂ level when the patient stopped the exercise test.

Maximal workload and heart rate were compared. The directly measured peak-exercise VO₂ was correlated with the ventilatory threshold, as well as with the maximum workload and the heart rate at the maximum workload. Thereafter, the equation that best described the relationship between maximal workload and peak-exercise VO₂ was developed.
Statistical Methods

Data are expressed as mean ± SD. The 2-sided Student t test and the Wilcoxon-Mann-Whitney test were used to assess the statistical significance of the differences. The relationships between the different variables were analyzed using the Pearson correlation coefficient. P values <.05 were considered statistically significant.

Results

The most frequent reason to terminate ergometry was fatigue, which occurred in 24 patients. Other reasons for exercise termination were breathlessness in 8 and leg fatigue in 4 patients. Maximal workload was 151 ± 39 W, and the heart rate at the maximal workload was 137 ± 22 beats/min. The correlation coefficient between the 2 variables was $r = .49$.

Three patients were unable to exercise to the level of the ventilatory threshold. The ventilatory threshold of the other 33 patients was 1210 ± 307 ml/min and was expressed as 15.5 ± 4.2 ml · min · kg$^{-1}$ body weight. Peak-exercise VO$_2$ was 1649 ± 486 ml/min, and the body-weight-adapted value was 20.7 ± 5.9 ml · min · kg$^{-1}$. Both variables significantly correlated with one another at $r = .91$ ($P < .0001$).

The correlation coefficient between peak-exercise VO$_2$ and maximal workload was $r = .92$ ($P < .0001$; Figure 1), and between peak-exercise VO$_2$ and the heart rate at the maximal workload, was $r = .49$ ($P < .0001$). The regression equation to calculate peak VO$_2$ from maximal workload was $[y = 11.7 \times \text{(maximal workload in watts)} - 110.7]$. The peak VO$_2$ calculated with this regression equation was 1657 ± 451 ml/min.

![Figure 1](image_url)  
**Figure 1** Correlation ($r = .92$) between maximal workload and measured peak oxygen uptake.
Comment

Numerous equations have been developed for predicting peak VO$_2$ from treadmill graded exercise tests or cycle ergometry.\textsuperscript{10-15} These equations were developed in healthy subjects, and only 1 equation has been established for patients after myocardial infarction.\textsuperscript{14} Peak VO$_2$ estimated with this formula was 1858 ± 474 ml/min and overestimated the measured peak VO$_2$ observed in the present study by 13%. The other approach is to predict peak VO$_2$ from anthropometric variables. Fairbarn et al\textsuperscript{12} developed prediction equations based on a large patient group. Peak VO$_2$ calculated with these equations was 2780 ± 663 ml/min and overestimated the peak VO$_2$ measured in our study by 67%.

The observed differences between the measured peak VO$_2$ and previously predicted peak VO$_2$ indicate that equations for patients without valvular disease are not applicable to patients who have undergone aortic-valve replacement. The patients we studied had normal or only slightly impaired left-ventricular function at rest, and most of them terminated the exercise test because of fatigue. The main reason for the specific behavior during exercise of patients after aortic-valve replacement seems to be related to abnormalities in left-ventricular filling, whereby the impairment of the left-ventricular diastolic function becomes evident only under the stress of dynamic exercise.\textsuperscript{16,17} Another reason could be an unexpected increase of the pressure gradient during exercise, which—as a limitation—was not determined in the present study.\textsuperscript{17}

The exercise capacity during symptom-limited exercise on a cycle ergometer in the upright position was closely related to the measured peak-exercise VO$_2$. As a consequence, the assessment of maximal workload seems to be sufficient in this group of patients to describe their cardiopulmonary capacity. It should be considered that the measured peak-exercise VO$_2$ might not be equal to the maximal VO$_{2\text{max}}$, which is defined as the VO$_2$ at which increasing levels of supramaximal work fail to increase VO$_2$ any further.\textsuperscript{9} The observed close relationship between the ventilatory threshold and peak VO$_{2\text{max}}$, however, indicates that the measured values seem to be very close to the maximal VO$_{2\text{max}}$.

In summary, the present investigation described a close relationship between the maximal workload during upright cycle ergometry with 1-minute increments of the workload and peak-exercise VO$_2$ for patients after aortic-valve replacement.

References


