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Effects of an Enhanced Heart Rate Reserve on Aerobic Performance in Patients with a Heart Transplant

ABSTRACT


Objective: The aim of this study was to investigate whether a high-intensity warm-up at the start of a graded, symptom-limited exercise test would enhance heart rate reserve and thus improve the aerobic performance of orthotopic heart transplant patients.

Design: Adrenal and cardiorespiratory responses were compared in 10 orthotopic heart transplant patients who performed two graded, symptom-limited exercise tests on an ergocycle.

Results: At the start of the graded, symptom-limited exercise test, high intensity increased the norepinephrine level more than usual intensity between rest and the third minute of exercise. This higher norepinephrine level was followed by a higher heart rate response from the fourth minute of exercise. Heart rate reserve was enhanced during high-intensity exercise, without any significant change in peak oxygen uptake.

Conclusions: This specific warm-up enhanced heart rate reserve during a graded, symptom-limited exercise test on an ergocycle. Mechanisms more important than limited heart rate reserve are involved in the limitation of exercise tolerance in orthotopic heart transplant patients.

Key Words: Cardiac Transplantation, Oxygen Uptake, Chronotropic Response, Exercise
Altered resting\(^1\,^2\) and exercise\(^1\) hemodynamics caused by cardiac de
ervation are a common finding after orthotopic heart transplantation (OHT). Heart rate reserve (HRR), which is peak heart rate (HR) minus
the resting HR,\(^3\) is the most de
creased cardiac parameter\(^4\) because
of a high resting HR and a low peak
HR. Moreover, it has been shown that
the percentage of change in HR from
rest to peak exercise is correlated
with peak oxygen uptake (\(V\dot{O}_2\); \(r = 0.60\)).\(^5\) Thus, HRR may affect aerobic
power after OHT, but no causal rela
tionship has been demonstrated to
date. The factors that limit the exer
cise tolerance of heart transplant re
cipients are not yet well understood,
but abnormal chronotropic response
is generally cited as one of the expla
nations for the peak \(V\dot{O}_2\) limitation.\(^6\,^7\)

Because HR response to exercise
is delayed and reduced after heart
transplantation,\(^6\,^8\,^9\,^10\) we hypothe
sized that a high workload (50 W) at
the start of an incremental exercise
test allowing the assessment of HRR
and peak \(V\dot{O}_2\) would increase cate
cholamine levels rapidly and mark
edly. We further speculated that after
6 min of exercising at this workload,
the effects would be nearly optimal in
terms of chronotropic response. The
aim of this study was thus to investi
gate the ability of a specific warm-up
(50 W) to enhance adrenal response,
HR increase, and HRR during a
symptom-limited exercise test and
then to assess the effect on aerobic
power.

METHODS

Subjects

Ten male OHT patients (age, 55
\(\pm\) 2 yr; weight, 74.5 \(\pm\) 2.8 kg; height,
173.6 \(\pm\) 1.2 cm; postsurgery time,
31.6 \(\pm\) 6.6 mo) volunteered to par
ticipate in the study. None was in
volved in a rehabilitation program.
Before surgery, their clinical status
was class IV according to the New
York Heart Association, with etio
logies including dilated cardiomyopa
thy (\(n = 3\)) and ischemic cardiopathy
(\(n = 7\)). After surgery, all patients
were considered to be class I and
were receiving triple-drug immuno
-suppressive therapy (cyclosporine,
azathioprine, and steroid [average
dose, 10 mg/day]). None was receiv
ing \(\beta\)-blocker agents or other therape
tries that could affect the chronotro
pic response. All were free of acute
rejection, systemic infection, coro
nary artery disease, and peripheral
vascular disease. Informed written
consent was obtained from all pa
tients, and the study was accepted by
the hospital ethics committee (Co
mité de protection des personnes pour
la recherche biologique No. 950187).

Materials

Exercise Testing. Each subject per
formed two different graded, symp
tom-limited exercise tests in random
order on an electromagnetic cycle er
gometer (Ergo-Metrics 900; Ergoline,
Bitz, West Germany). Respiratory
variables and gas exchanges were
measured with a breath-by-breath
automated metabolic system (CPX,
Cardio2, Breeze; Medical Graphics,
St. Paul, MN).\(^11\) During exercise, ox
ygen saturation was continuously de
termined with a pulse oximeter (Da
tex, Helsinki, Finland), and a 12-lead
electrocardiograph (CPX, Cardio2,
Breeze) was monitored for the mea
surement of HR. Finally, systolic and
diastolic blood pressure were mea
sured with a cuff blood pressure
transducer (Ergoline).

Cardiorespiratory Measurements. We
were principally interested in HR,
which allowed the calculation of HRR
(peak exercise HR − resting HR) and
\(V\dot{O}_2\). We also measured \(CO_2\) output
(\(V\dot{CO}_2\)) to determine the respira
tory exchange ratio (\(V\dot{CO}_2/O_2\)).

Circulating Catecholamine Analysis.
One of the 10 subjects did not agree
to venous sampling. So in nine sub
jects, a venous catheter was inserted
in a superficial forearm vein to allow
sampling for measurement of epi
nephrine and norepinephrine con
centrations. A three-way tap was
placed on the catheter to allow rins
ing with a syringe containing a mix
ture of heparin and physiologic saline
(250 IU/ml) and blood sampling with
a dry syringe after the catheter had
been cleared of saline. Approximately
3 ml of blood was placed in a tube
(lithium heparin) containing reduced
glutathione (1.2 mg/ml) to control
catecholamine oxidation, centrifuged
(3000 rpm for 10 min) and stored at
−80°C for catecholamine analysis.
Plasma catecholamine concentra
tions were determined by high-per
formance liquid chromatography
(HPLC).\(^12\) The catecholamines were
extracted by selective absorption to
aluminum oxide (Chromsystems
HPLC-Kit; Waters Corp., Milford,
MA) before the HPLC run. Aluminum
oxide was briefly shaken up in extrac
tion buffer (50 \(\mu\)l) and then 1 ml of
plasma was added with 50 \(\mu\)l of in
ternal standard solution (600 pg of
dihydroxybenzylamine). The alumi
num oxide was washed three times,
with brief centrifugation between
washes. The catecholamines were ex
tracted with 120 \(\mu\)l of elution buffer
with brief shaking and then centri
fuged (final centrifugation) at 2000
rpm for 1 min. Then 50 \(\mu\)l of sample
eluent was injected into the HPLC
column (Resolve 5-\(\mu\)l spherical C18
HPLC column; Waters Corp.) and
eluted with mobile phase. The flow
rate was 1 ml/min at 2000 psi with
a potential of 0.60 V. The chromato
gram was analyzed by computer inte
gration (Baseline 815; Waters Corp.).
Three assays were made for each
sample, and the mean of these assays
was taken for statistics. The error of
measurement within sample was sat
isfactory (less than 5%), similar to
that found in a previous study of our group.13

Protocol

The order of the two exercise tests was randomized, and the subjects performed the two tests within a 2-wk period. On the days of the experiment, patients arrived at the laboratory at the same hour in the morning and received standardized instructions as to the testing procedure. On day 1, they underwent a complete physical examination and a resting electrocardiogram. Each patient then performed a graded, symptom-limited cycle exercise test. The second exercise test was performed on day 2. One of the tests had a usual intensity (UI) for warm-up (i.e., 20 W).11 The patient rested for 3 min while seated on the cycle and then, after a warm-up at 20 W for 3 min, loads were increased 10 W each minute until exhaustion. The other test, with a high intensity (HI) warm-up, was similar in that the patient rested for 3 min on the cycle. But the warm-up consisted of cycling at 50 W for 6 min, with loads then increased 10 W each minute (in such a way that at the seventh minute, all patients were exercising at 60 W) until exhaustion.

All cardiorespiratory values were recorded at rest, up to peak exercise, and during recovery, for the last 20 sec of every minute. Systolic and diastolic blood pressure were measured every 3 min up to the end of exercise.

Samples for catecholamines were taken at rest, at the third minute (which corresponded to the end of the usual starting workload), and at the sixth minute (which corresponded to the end of the HI starting workload) of the exercise test and at peak exercise. To minimize the inter-subject variation, as seen in some studies,7,14 the concentrations of norepinephrine and epinephrine at the third and sixth minute of exercise were expressed by using the third- or sixth-minute exercise values minus resting value. ΔCatecholamines was also calculated between rest and peak exercise (peak exercise − resting values).

Indications for halting the exercise test before the appearance of a plateau VO₂ were as follows: (1) adverse symptoms: severe dyspnea, light-headedness and faintness, confusion, severe fatigue, or inability to maintain the pedaling frequency; (2) adverse signs: facial pallor, HR or blood pressure decrease (or failure of either to increase with increasing effort), or a rapid increase in systolic or diastolic blood pressure, or both, exceeding 210/115 mm Hg for a moderate intensity of exercise (<60 W); and (3) adverse electrocardiographic changes: frequent complex ventricular extrasystoles, ventricular tachycardia, sustained supraventricular tachycardia, second- or third-degree heart block, severe ST depression (horizontal or down sloping greater than 2 mm).13 A respiratory exchange ratio >1.1 and the inability to maintain the pedaling frequency despite the standardized encouragements of the experimenters were the criteria for verifying that the exercise tests were really symptom limited.11,15

Statistical Analysis

Values of all variables are expressed by the mean ± SEM. Paired Student’s t-tests were performed on resting HR and HRR. Resting and peak VO₂ were compared for statistical difference by using the same procedure. Submaximal HR time courses were compared by using a fully factorial repeated-measures design. When the F ratio was significant, the Tukey test was performed to identify differences. In addition, catecholamine values at rest and during exercise (norepinephrine and epinephrine values at 3 and 6 min) and Δnorepinephrine and Δepinephrine (peak exercise − resting values) were compared with the Wilcoxon’s signed rank test. SigmaStat (Jandel Scientific, Costa Madre, CA) and SYSTAT (SPSS Inc., Chicago, IL) software was used for these statistical analyses. The level of significance for all analyses was P ≤ 0.05.

RESULTS

During the graded exercise tests, none of the OHT patients developed decreases in oxygen saturation of more than 4%, adverse signs or symptoms, or electrocardiogram changes such as severe ST segment depression, tachycardia, or atrial fibrillation. All stopped the exercise test because of leg fatigue and pain. The duration of the two tests was not significantly different (12.4 ± 1 min and 12.3 ± 0.9 min for HI and UI, respectively), and most of the patients were able to exercise longer after the HI warm-up; only two patients exercised for less than 10 min.

There was no significant difference for epinephrine response during exercise (at 3 and 6 min) or for Δepinephrine (112.3 ± 37.9 pg/ml for HI vs. 54.9 ± 43.6 pg/ml for UI). Concerning norepinephrine concentration, during HI, norepinephrine values at 3 and 6 min were significantly lower than Δnorepinephrine (peak − resting value; P < 0.05). During UI, norepinephrine at 3 min was significantly lower than norepinephrine at 6 min (P < 0.05), but it was not significantly different from Δnorepinephrine. Norepinephrine at 3 min was significantly higher during HI vs. UI (P < 0.05; Fig. 1). There was no significant difference for Δnorepinephrine between HI and UI (Fig. 1).

At rest, cardiorespiratory values were similar for the two tests (Table 1). HR was significantly higher in HI than in UI from the fourth to sixth minute of exercise (Fig. 2). HRR was significantly higher during HI vs. UI (P < 0.05), in contrast to peak VO₂ (Fig. 3).

DISCUSSION

This study shows that, during a symptom-limited exercise test, a spe-
Specific warm-up enhances the submaximal HR and HRR in OHT patients. This enhancement of HRR is not associated with a significant enhancement of peak $V_\dot{O}_2$.

The HR values at rest and during submaximal and peak exercise in the UI condition are typical of the denervated heart, i.e., a delayed and gradual increase in HR with the onset of exercise$^{6,8,9}$ and a low peak HR$^{6,9}$ attaining only $78.1 \pm 3.2\%$ of predicted maximal HR. In normal subjects, the HR increase observed at the onset of exercise is initially caused by the withdrawal of vagal tone.$^{16,17}$ The literature notes that during exercise in heart transplant patients, the observed HR change is closely linked to the level of circulating catecholamines,$^{2,14}$ with a linear relationship during constant-load exercise between HR and norepinephrine increments.$^{14}$ Nevertheless, during HI, because of the higher and longer starting workload compared with UI, the increase in norepinephrine was significantly higher at the third minute of exercise, whereas the HR response was significantly increased from the fourth to sixth minute.

First, because norepinephrine at 3 and 6 min during HI were not different, we can speculate that the norepinephrine concentration was stable because it was adapted to the level of the intensity (50 W). In UI, in contrast, the norepinephrine level increased between the third and sixth minute of exercise proportionally to the increase in exercise intensity. Indeed, at the sixth minute of exercise, the workload was the same in HI and UI (50 W), and there was no difference in norepinephrine concentrations between the two tests at this moment. Second, concerning the chronotropic response, at the third minute of HI, HR showed only a tendency to be higher than in UI. Moreover, at the sixth minute of HI, HR was significantly higher. This result can be explained by a delay between the release of norepinephrine, its fixation on the endomyocardial $\beta$-receptors, and the subsequent chronotropic response. This hypothesis would explain in part why, during the first phases of recovery, a rapid decrease in norepinephrine concentration was observed without the same change in HR in OHT patients.$^{14}$ Furthermore, the gain in HR at the start of exercise during HI seemed to persist until the end of exercise, as indicated by the significantly higher HRR in HI vs. UI.

This study shows that it was possible to increase HRR in heart transplant patients. This enhanced HRR was not followed by higher aerobic power, because peak $V_\dot{O}_2$ was not statistically different between HI and UI. However, HRR may still be linked to the limitation in aerobic performance, because the percentage of change in HR from rest to peak exercise is correlated with peak $V_\dot{O}_2$, and patients with a high percentage of

![Figure 1: Norepinephrine concentration changes from rest to the third minute of exercise ([NE]$_3$ = third minute of exercise value - resting value) to the sixth minute of exercise ([NE]$_6$ = sixth minute of exercise value - resting value) and to peak exercise (Delta [NE] = peak exercise value - resting value) for the high-intensity warm-up test (HI warm-up = 50 W for 6 min) and the usual-intensity warm-up test (UI warm-up = 20 W for 3 min). *$P < 0.05$ between HI and UI; #$P < 0.05$ within the group. The other compared values were not significantly different.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Cardiorespiratory values for the two tests</th>
<th>Rest</th>
<th>Peak Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HI</td>
<td>UI</td>
<td>HI</td>
</tr>
<tr>
<td>HR (beats·min$^{-1}$)</td>
<td>101.1 ± 3</td>
<td>101.1 ± 3</td>
<td>143 ± 5</td>
</tr>
<tr>
<td>$V_\dot{O}_2$ (ml·kg$^{-1}$·min$^{-1}$)</td>
<td>4.8 ± 0.4</td>
<td>5 ± 0.2</td>
<td>23.2 ± 1.6</td>
</tr>
</tbody>
</table>

HI, high-intensity workload; UI, usual-intensity workload; HR, heart rate; $V_\dot{O}_2$, oxygen uptake.
change in HR (>40%) have a higher peak VO₂ than patients with a low percentage of change (<40%). Because OHT patients generally have a low HRR, in our study the mean increase in this variable during HI (7 beats/min) was high when expressed as a relative value, i.e., as a percentage (20%). These results are in agreement with previous data from our group that were obtained during a longitudinal study, which found a peak HR increase with postsurgery time, without an increase in peak VO₂. This peak VO₂ was symptom limited in the two exercise conditions, at 77.4 ± 3.2% and 76.4 ± 5.7% of predicted in HI vs. UI. Because the relation between cardiac output and oxygen consumption is linear in OHT patients, this indicates that whatever the HR, cardiac output remained unchanged. Some studies have suggested that the inability of the denervated heart to achieve the same HR level as the innervated heart may be responsible for the decreased oxygen uptake observed in OHT patients. Our data, in agreement with a study by Jensen et al., indicate that factors other than the limited and sluggish increase in HR may influence the exercise limitation in OHT patients. First, we and other authors recently demonstrated that the abnormal pulmonary diffusion capacity found in many OHT patients was associated with the peak VO₂. Second, the exaggerated skeletal deconditioning of OHT patients caused by extended periods of inactivity both before and after surgery may be implicated. Third, a detrimental effect of immunosuppressive therapy on mitochondrial skeletal muscle respiration has been reported in rats. A detrimental effect of immunosuppressive therapy on vasodilatory capacity (already impaired in humans after heart transplantation) has also been suggested. Fourth, Jensen et al. showed that OHT patients are able to maintain their oxygen-carrying capacity within normal range, and persistent skeletal muscle abnormalities have been found in these patients. Furthermore, the maximal arteriovenous oxygen difference seems to be low in heart transplant recipients. These last studies seem to indicate a peripheral limitation during exercise. In our study, all patients stopped exercise because of leg limitations. Figure 2: Time course of heart rate during submaximal exercise. *P < 0.05 and **P < 0.01 between the high-intensity warm-up test (HI warm-up = 50 W for 6 min) and the usual-intensity warm-up test (UI warm-up = 20 W for 3 min). Figure 3: Peak oxygen uptake (VO₂) and heart rate reserve (peak exercise – resting heart rate) for the high-intensity warm-up test (HI warm-up = 50 W for 6 min) and the usual-intensity warm-up test (UI warm-up = 20 W for 3 min). *P < 0.05 between HI and UI.
pain and fatigue. Moreover, because our results indicate a cardiac output response adapted to the level of exercise, the hypothesis of a peripheral limitation seems to be increasingly pertinent.

In conclusion, our study clearly demonstrates that a specific warm-up can enhance HRR during a graded, symptom-limited exercise test in OHT patients. This warm-up resulted in a higher increase in catecholamine levels during submaximal exercise, which was followed, after a slight delay, by an enhancement of HR. However, because aerobic power, as determined by peak VO₂ values, was similar between the high warm-up protocol and the usual one, whereas the HRR was 20% enhanced with the HI, more important mechanisms are probably involved in the limitation of exercise tolerance in these patients. Although it is worthwhile in itself to try to normalize HR response to exercise by using a specific warm-up, studies are needed to further investigate the role of pulmonary and especially peripheral factors that limit exercise capacity. A better understanding of these factors is essential for the prescription of physical training programs that can optimize exercise tolerance.

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