Exercise Conditioning in Older Coronary Patients
Submaximal Lactate Response and Endurance Capacity

Philip A. Ades, MD; Mary L. Waldmann, BSN; Eric T. Poehlman, PhD; Peter Gray, MD; Elizabeth D. Horton, BS; Edward S. Horton, MD; Martin M. LeWinter, MD

Background. Older coronary patients are at high risk of cardiac disability. Exercise conditioning programs have been demonstrated to improve functional capacity, particularly in younger coronary patients. In this study, the effects of aerobic conditioning on submaximal and maximal indicators of exercise performance were examined in 45 older coronary patients.

Methods and Results. Forty-five patients (mean age, 69±6 years; range, 62 to 82 years) entered 3-month and 12-month (n=11) endurance training programs. Training effects were assessed during an exhaustive submaximal exercise protocol with measurement of endurance time, serum lactate, perceived exertion, and expired ventilatory measures. Exhaustive endurance time increased by more than 40% (30±10 to 41±10 minutes), with associated decreases in serum lactate, perceived exertion, minute ventilation, heart rate, and systolic blood pressure during steady-state exercise. Respiratory exchange ratio during steady-state exercise, an indicator of substrate utilization, decreased, indicating a shift toward greater use of free fatty acids as a metabolic fuel. In a subset of 10 patients, percent body fat was decreased (32±8% to 29±10%) over a period of 3 months.

Conclusions. Older coronary patients respond to aerobic conditioning with remarkable improvements in submaximal endurance capacity, out of proportion to the more modest increases in VO2 max. Activities that were exhaustive before training became sustainable for extended periods of time at a lower perceived exertion. Measurements of serum lactate, respiratory exchange ratio, and ventilation during steady-state exercise document that at an identical absolute work load after conditioning, exercise is performed using aerobic substrate to a greater degree, and ventilatory response to a given work load is lessened.

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Key Words • exercise • coronary artery disease • aging

Clinical evidence of coronary artery disease is present in >25% of persons ≥65 years old and is associated with a significant limitation of functional independence in 70% of men and 45% of women.1,2 Of disabled elders living at home, 20% indicate that heart disease is a major component of their disability.3 Exercise-based cardiac rehabilitation programs have come to play an important role in minimizing the disability of myocardial infarction and coronary bypass surgery.4-6 After 3 to 12 months of exercise conditioning, improvements in maximal aerobic capacity ranging from 16% to 42% have been demonstrated in both younger4,5 and older coronary patients.6 The mean age of hospitalized myocardial infarction and coronary bypass patients is now >65 and >63 years, respectively, in the United States.7,8 Since older coronary patients are significantly less fit after a coronary event than younger coronary patients,9 many are unable to perform their daily activities free from significant dyspnea, angina, or fatigue. Despite the demonstrated ability of exercise rehabilitation programs to improve maximal exercise capacity and the magnitude of disability in middle-aged coronary patients, there has been little study of the effect of exercise training on submaximal performance indicators, particularly in older coronary patients.

Accordingly, in this study of 45 older post–coronary event patients, the effects of short-term (3 months) and longer-term (12 months) conditioning on submaximal and maximal indices of exercise performance were evaluated. Lactate response and respiratory exchange ratio (RER) during matched absolute work loads of exhaustive submaximal exercise were used as indices of skeletal muscle metabolism and substrate utilization. The effect of short-term conditioning on body composition was also evaluated in a subset of patients.

Methods

Conditioning effects of a 12-week, 36-session aerobic conditioning program were determined in 45 older coronary patients with a mean age of 69±6 years (range, 62 to 82 years); 30 were men (age, 68±5 years), and 15 were women (age, 69±6 years). Patients had all had a recent coronary event (mean, 8±5 weeks): myocardial infarction in 21 and coronary bypass surgery in 24. Before entering the conditioning program, all candi-
dates underwent a familiarization symptom-limited treadmill test with ECG monitoring and expired gas analysis. All subjects underwent a resting radionuclide ventriculogram with determination of left ventricular ejection fraction. Subjects were excluded from the study if resting left ventricular ejection fraction was <30% or if they had a noncardiopulmonary limiting factor to exercise (eg, arthritis, claudication, hemiparesis). All candidates gave informed consent. The protocol was approved by the University of Vermont Committee on Human Research.

Maximal Exercise Capacity

Maximal exercise capacity was determined by repeating the symptom-limited treadmill test using a single metabolic equivalent increment Balke protocol with subjects breathing into a Hans-Rudolph mouthpiece for collection of expired gas. Patients took their prescribed medications, including 20 patients who were receiving β-adrenergic blockers. Medications were not altered during the conditioning and testing program. Expired gas was analyzed with a Sensormedics Horizon metabolic measurement cart (Sensormedics Corp, Yorba Linda, Calif) with oxygen consumption (V̇O₂), minute ventilation, CO₂ production, and RER (RER=CO₂ production/V̇O₂) determined at 30-second intervals. Exercise was terminated because of fatigue (n=43) or progressive angina (n=2).

Submaximal Exhaustive Endurance Capacity

Submaximal exhaustive endurance capacity was determined on the treadmill on a separate day before and after the 3-month and 12-month exercise conditioning programs. After resting data were collected, subjects exercised for 5 minutes at 50% of their previously determined peak V̇O₂. Without interruption, the exercise intensity was then increased such that by 10 minutes they were exercising at 80% of the peak preconditioning peak V̇O₂. Exercise was continued until exhaustion or until a duration of 45 minutes had elapsed. Data were collected at 5-minute intervals and included oxygen consumption, venous lactate levels, CO₂ production, RER, heart rate, blood pressure, and perceived exertion score (Borg scale 6 to 20). Blood samples for lactate determinations were drawn from a plastic catheter in an antecubital vein, and serum was immediately deproteinized with perchloric acid and refrigerated. Duration of exhaustive submaximal exercise was specifically determined for 35 of the 45 patients. In 10 patients, exercise at 80% V̇O₂ max was not exhaustive by 45 minutes and was terminated. After the conditioning program, patients were restudied during submaximal exercise on the treadmill using the same absolute work loads as preconditioning.

Training Protocol

Patients then entered a 12-week, 3-hour-per-week protocol of telemetry-monitored treadmill, stationary bicycle, and rowing ergometer exercise with intensity levels guided by exercise heart rate, which initially was monitored at 75% to 85% of maximal heart rate. Because older coronary patients frequently do not reach a true physiologically maximal effort during post-coronary event exercise testing, training intensity was increased to 85% to 90% of maximal heart rate attained during the preconditioning stress test after the initial 2 weeks of training rather than the more commonly recommended range of 70% to 85% of maximal heart rate. Treadmill exercise lasted 25 minutes per session, bicycle exercise 15 minutes, and rowing ergometer 10 minutes per session, preceded and followed by warm-up, stretching, and cool-down. Modifications of the program for particularly unfit patients (n=3) were minor and included more intermittent bouts of exercise on an apparatus rather than continuous exercise. Patients with hip or knee arthritis performed a greater proportion of their exercise on the cycle and rowing ergometers. A subset of 11 patients agreed to continue their exercise program for an additional 9 months and were then retested as at baseline and 3 months. The age and baseline peak V̇O₂ of these patients did not differ from the patients who trained just for 3 months; age was 68.1±5.9 versus 68.5±5.6 years (P=.82), and peak V̇O₂ was 20.2±6.9 versus 19.0±4.8 mL·kg⁻¹·min⁻¹ (P=.51). No coronary events occurred in this group during the 9-month period.

Body Composition

Body composition was determined by the skin-fold technique in a subset of 10 patients before and after 3 months of conditioning with calculation of percent body fat, fat weight, and fat-free weight. Skin-folds were taken from the triceps, subscapular, biceps, and abdominal sites. All skin-fold measurements were taken by the same investigator according to recent recommendations. The reliability coefficient and the coefficient of variation for repeated measurements of skin-folds in our laboratory in 18 older women (55 to 75 years) are 0.98 and 3.4%, respectively.

Statistical Analysis

Paired t tests were used to compare baseline data with those after 3 months’ training. A one-way repeated ANOVA was used to analyze baseline, 3-month, and 12-month data. All data are reported as mean±SD. A value of P<.05 was considered to indicate a statistically significant difference.

Results

The 3-month exercise program was completed by 43 of the 45 entrants. One subject dropped out after a hospitalization for congestive heart failure, and one person discontinued participation because of back arthritis. Body weight was unaltered by the conditioning program (75.6±12.1 to 74.8±13.3 kg, P=NS). Estimated percent body fat decreased after 12 weeks of conditioning, 31.7±8% to 29.1±10% (P<.05). Estimated total fat mass decreased from 24.5±7 to 22.5±9 kg (P<.05), and fat-free weight increased from 52.4±8 to 53.6±8 kg (P<.05).

Maximal Exercise Capacity

At baseline, maximal aerobic capacity (V̇O₂ max) was 19.4±5 mL·kg⁻¹·min⁻¹. It increased by 16% at 3 months to 22.5±8 mL·kg⁻¹·min⁻¹ (P<.05) and increased by 19% at 1 year to 23.9±6 mL·kg⁻¹·min⁻¹ (P<.01) in the subset of 11 patients who trained for 1 year. The duration of maximal treadmill exercise increased 54% (9±4 to 14±4 minutes, P<.05) at 3 months and 44% (10±3 to 15±4 minutes, P<.05) at 1 year. At
Table 1. Training Response by Age and Sex

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Age (years)</th>
<th>Baseline VO₂max (mL · kg⁻¹ · min⁻¹)</th>
<th>Training effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Young-old&quot; (&lt;70 years)</td>
<td>29</td>
<td>65±2 (62-69)</td>
<td>21.5±4</td>
<td>23.7±5 (+10%)</td>
</tr>
<tr>
<td>&quot;Older-old&quot; (≥70 years)</td>
<td>16</td>
<td>75±4 (70-82)</td>
<td>15.9±4*</td>
<td>19.2±4 (+21%)</td>
</tr>
<tr>
<td>Men</td>
<td>30</td>
<td>68±5 (62-80)</td>
<td>20.5±5</td>
<td>23.4±3 (+17%)</td>
</tr>
<tr>
<td>Women</td>
<td>15</td>
<td>69±6 (62-82)</td>
<td>16.9±5*</td>
<td>19.6±5 (+16%)</td>
</tr>
</tbody>
</table>

Values are mean±SD. *P<.05 older vs younger and men vs women. †P<.05 vs baseline.

Baseline, peak exercise RER exceeded 1.00 in 31 of the 45 subjects, whereas after 3 months of conditioning, 35 of 43 subjects exercised to RER ≥1.00 (P=NS). Mean peak exercise RER did not change (1.07±0.13 to 1.10±0.16, P=NS). Resting left ventricular ejection fraction was 50±11% before conditioning (range, 30% to 76%), 50±12% after 3 months, and 47±14% at 12 months of conditioning (P=NS).

The maximal data were then analyzed by dividing the group into patients <70 years old (n=29; mean age, 65±2 years; range, 62 to 69 years) and patients ≥70 years old (n=16; mean age, 75±4 years; range, 70 to 82 years). The older group was less fit at baseline (15.9±4 versus 21.5±4 mL · kg⁻¹ · min⁻¹, P<.05) but had a tendency to display a greater increase in VO₂max after 3 months' training compared with the younger group (21% versus 10%, P=.16) (Table 1). Thus, the ability to respond to a conditioning program was maintained in the oldest age group. Preconditioning VO₂max was slightly higher in male patients (n=30) compared with female patients (n=15): 20.5±5 versus 16.9±5 mL · kg⁻¹ · min⁻¹ (P<.05) (Table 1). However, both groups improved VO₂max similarly with conditioning, increasing 17% in men and 16% in women (P=NS).

Submaximal Exercise

The 3-month exercise program resulted in marked changes in exercise performance during the exhaustive submaximal exercise protocol. At baseline, mean exercise time to exhaustion was 30±10 minutes, with only 10 of 45 patients completing the entire 45-minute protocol. At 3 months' conditioning, mean exercise time was 41±10 minutes (P<.001), including 33 of 43 subjects who were stopped arbitrarily at 45 minutes, before exhaustion (P<.05 versus baseline). Thus, the percent improvement in submaximal endurance time after training is underestimated. At 1 year of conditioning, 10 of 11 subjects completed the entire protocol without exhausting; mean exercise time was 43±7 minutes (P<.001 versus preconditioning, P=NS versus after 3 months' conditioning). Preconditioning endurance capacity did not differ between men and women; the men (n=30) exercised for 28.5±11 minutes until exhaustion, compared with 27.4±13 minutes for the women (P=NS). Both men and women improved their endurance capacity similarly with training: 12.3±9 minutes for men, 10.3 minutes for women (P=NS). Thus, because there was no sex effect on endurance training, the data are pooled.

At rest, heart rate, systolic blood pressure, and serum lactate were unaltered after 3 months of conditioning, whereas after 12 months of conditioning, resting heart rate and systolic pressure were lowered compared with baseline (Table 2). During the preconditioning submaximal exercise protocol, actual exercise intensity at 5 minutes of exercise was measured at a mean work load of 58±17% peak VO₂. At 3 months' conditioning, the identical absolute work load corresponded to 50±8% of the postconditioning peak VO₂, and at 12 months' conditioning, the same absolute work load corresponded to 46±7% of the peak VO₂ at 1 year. At 3 and 12 months' conditioning, heart rate, serum lactate, and perceived exertion scores were all lower at the identical low submaximal work load (P<.05). Submaximal systolic blood pressure at this work load was unaltered. Similarly, at 10 minutes of exercise at a work intensity of 79±14% of preconditioning peak VO₂ and at each 5-minute data collection interval until exhaustion, heart rate, serum lactate, and perceived exertion scores were lower at 3 months' and 12 months' conditioning compared with baseline (P<.05; Table 2, Figures 1 and 2).

RER, oxygen consumption, CO₂ production, and minute ventilation were measured in all patients at 15 minutes of the steady-state submaximal protocol before and after the conditioning program (Table 3). A lower RER during steady-state exercise after 3 and 12 months' conditioning reflects a shift toward increased utilization of free fatty acids as metabolic fuel during endurance exercise. Both CO₂ production and minute ventilation were reduced at identical work loads after conditioning, as was oxygen consumption (Table 3).

Discussion

Previous studies have shown that older coronary patients enrolled in a cardiac rehabilitation program are capable of improving their maximal aerobic capacity in response to a graded exercise conditioning program.6-16 Previous studies, however, have not focused on submaximal exercise parameters, which are most relevant to the ability to carry out daily activities. The results of this study demonstrate that, in older coronary patients, when exercise capacity is assessed during an exhaustive submaximal exercise protocol, training benefits are amplified. Whereas maximal oxygen consumption, measured during a graded treadmill protocol, increased by 16% at 3 months of conditioning, exhaustive submaximal endurance capacity measured at a steady-state intensity of 80% of preconditioning VO₂max increased by more than 40%. Furthermore, at every level of submaximal exercise, work was performed at a lower perceived exertion, a lower blood lactate level, and a lower heart rate. Substrate utilization was altered toward a greater use of free fatty acids at steady-state exercise, as demonstrated by a lower RER. For most patients, a preconditioning work load that was exhaus-
TABLE 2. Submaximal Exercise Data

<table>
<thead>
<tr>
<th></th>
<th>Baseline (n=45)</th>
<th>3 Months' conditioning (n=43)</th>
<th>12 Months' conditioning (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR</td>
<td>70±16</td>
<td>68±14</td>
<td>68±1*</td>
</tr>
<tr>
<td>Systolic BP</td>
<td>135±25</td>
<td>134±21</td>
<td>122±20*</td>
</tr>
<tr>
<td>Serum lactate</td>
<td>1.47±0.68</td>
<td>1.49±4.6</td>
<td>1.51±0.39</td>
</tr>
<tr>
<td>Low submaximal exercise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity (% (\dot{V}O_2) max)</td>
<td>58±17%</td>
<td>50±8*</td>
<td>46±7*</td>
</tr>
<tr>
<td>HR</td>
<td>94±16</td>
<td>84±12*</td>
<td>84±10*</td>
</tr>
<tr>
<td>Systolic BP</td>
<td>143±26</td>
<td>140±24</td>
<td>131±27</td>
</tr>
<tr>
<td>Serum lactate</td>
<td>1.85±0.96</td>
<td>1.44±0.46*</td>
<td>1.39±0.26*</td>
</tr>
<tr>
<td>Perceived exertion</td>
<td>9.9±2.6</td>
<td>8.7±2.2*</td>
<td>7.9±1.2*</td>
</tr>
<tr>
<td>High submaximal exercise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity (% (\dot{V}O_2) max)</td>
<td>79±14%</td>
<td>67±10%*</td>
<td>55±12+*</td>
</tr>
<tr>
<td>HR</td>
<td>108±16</td>
<td>97±16*</td>
<td>97±10*</td>
</tr>
<tr>
<td>Systolic BP</td>
<td>153±27</td>
<td>148±24</td>
<td>141±26</td>
</tr>
<tr>
<td>Serum lactate</td>
<td>2.30±1.08</td>
<td>1.60±0.43*</td>
<td>1.60±0.41*</td>
</tr>
<tr>
<td>Perceived exertion</td>
<td>14.0±2.2</td>
<td>11.7±2.2*</td>
<td>11.5±2.5*</td>
</tr>
<tr>
<td>Submaximal exercise duration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean exercise time (min)</td>
<td>30±10</td>
<td>41±10*</td>
<td>43±7*</td>
</tr>
<tr>
<td>Complete 45-min protocol</td>
<td>10/45 (22%)</td>
<td>33/43 (77%)*</td>
<td>10/11 (91%)*</td>
</tr>
</tbody>
</table>

*HR indicates heart rate; BP, blood pressure; \(\dot{V}O_2\), oxygen consumption. Values are mean±SD.
†P<.05 vs baseline.
‡P<.05 vs 3 months' conditioning.

Changes in maximal oxygen uptake after conditioning programs in coronary patients have been attributed to both cardiac and peripheral adaptations.15 Changes in submaximal endurance capacity, however, appear to be primarily a result of increases in skeletal muscle oxidative capacity rather than changes in cardiac output or skeletal muscle blood flow,17,18 resulting in an increased capacity to process oxidative substrate, primarily free fatty acids. Preliminary data from our laboratory support this concept, because in a subset of our older population, we have demonstrated that after 3 months of aerobic conditioning, arteriovenous oxygen difference during exercise is increased and is associated with an increased activity of skeletal muscle oxidative enzyme activity (succinyl dehydrogenase), whereas maximal cardiac output and maximal calf blood flow were unchanged.19 Previous conditioning studies of younger and older healthy subjects demonstrate that lactate reduction during steady-state exercise at a similar relative work load is dissociated from increases in \(\dot{V}O_2\)max, suggesting that a mechanism other than that responsible for an increased maximal aerobic capacity is responsible.20,21 Lower lactate concentrations during exercise in trained individuals have generally been attributed to a lower lactate production by muscle, although lactate 

![Graph showing serum lactate levels during submaximal exercise before and after 3 months of conditioning. All patients with paired pre- and postconditioning data points are included. Postconditioning study was at the same absolute work load (ie, treadmill speed) as pre-conditioning.](http://circ.ahajournals.org/attachment/9162787)

![Graph showing perceived exertion during submaximal exercise before and after 3 months of conditioning (Borg scale 6 to 20). All patients with paired pre- and postconditioning data points are included.](http://circ.ahajournals.org/attachment/9162788)
clearance (by skeletal muscle and liver) may also increase with training. Nonetheless, it appears that at a given submaximal work load, after conditioning, there is a shift to a greater reliance on the aerobic oxidation of fat and sparing of carbohydrate, reflected by a lower RER and a lower blood lactate. From a clinical standpoint, lower lactate levels during exercise are associated with less CO₂ production (for buffering of lactate), a lessened ventilatory drive, and less dyspnea. Of interest, after conditioning, matched absolute intensities of submaximal exercise were performed at a lower oxygen consumption, suggesting an increased musculoskeletal or metabolic efficiency of work performed. Inefficiency of the ventilatory response during exercise in healthy older subjects has recently been shown, consisting of a greater minute ventilation and CO₂ production at a given work load compared with younger subjects. Our data document that, in older coronary patients, VO₂ per work load is lowered after conditioning, along with lowered ventilatory responses.

Although this report lacks a nonexercising control group, it has been clearly demonstrated in previous studies that improvements in functional capacity after cardiac events are significantly greater with a supervised exercise program versus spontaneous recovery alone. This study is furthermore limited by the fact that only 21% of patients >62 years old hospitalized at our institution with a diagnosis of myocardial infarction or coronary bypass graft surgery actually choose to enter our cardiac rehabilitation program, compared with 57% of younger patients. Nonentrants as a group, even within the older population, are older, more likely to smoke, and have more medical comorbidities than cardiac rehabilitation participants and may respond somewhat differently to a graded exercise program. It should be noted as well that the submaximal work load evaluated in this investigation (80% of pre-conditioning VO₂max) is somewhat higher than work loads encountered during daily household activities for most patients.

Favorable body composition changes were demonstrated during a 3-month period at conditioning intensities feasible for older coronary patients, despite no overall change in body weight. An association between low body fat and favorable lipid profiles has been demonstrated in young healthy subjects in our laboratory. However, the clinical significance of this finding remains to be elucidated. It will be of interest in future studies to examine changes in body composition and their relation to other cardiovascular risk factors, such as lipid profiles, body fat distribution, and blood pressure in coronary patients.

Performance during a submaximal exercise protocol reflects the capacity to sustain daily activities for extended periods of time and in this sense is a more important clinical indicator of training than changes in maximal performance. In this study of older coronary patients, a group at high risk of disability, remarkable improvements in submaximal endurance were demonstrated, with physiological confirmation of lower serum lactate levels and favorable alterations of substrate utilization (to using more fat) during steady-state exercise. Activities that were exhaustive before training became sustainable for extended periods after conditioning, and perceived exertion of work was lower. Almost all activities performed on a daily basis are performed at a submaximal level. These results strongly imply an increased functional independence after conditioning, since all activities are subsequently performed at a lower percentage of maximal capacity. Accordingly, exercise conditioning can be considered to have potent therapeutic benefits in older patients recovering from myocardial infarction and coronary bypass surgery.

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