Superiority of Treadmill Walking Exercise Versus Strength Training for Patients With Peripheral Arterial Disease

Implications for the Mechanism of the Training Response

William R. Hiatt, MD; Eugene E. Wolfel, MD; Robert H. Meier, MD; Judith G. Regensteiner, PhD

Background In patients with intermittent claudication, a supervised walking exercise program increases peak exercise performance and community-based functional status. Patients with peripheral arterial disease also have muscle weakness in the affected extremity that may contribute to the walking impairment. However, the potential benefits of training modalities other than walking exercise, such as strength training, have not been critically evaluated in this patient population. The present study tested the hypothesis that a strength training program would be as effective as treadmill walking exercise and that combinations of strengthening and walking exercise would be more effective than either alone in improving exercise performance.

Methods and Results Twenty-nine patients with disabling claudication were randomized to 12 weeks of supervised walking exercise on a treadmill (3 h/wk at a work intensity sufficient to produce claudication), strength training (3 h/wk of resistive training of five muscle groups of each leg), or a nonexercising control group. Graded treadmill testing was performed to maximally tolerated claudication pain to define changes in peak exercise performance. After 12 weeks, patients in the treadmill training program had a 74±58% increase in peak walking time as well as improvements in peak oxygen consumption (Vo2) and the onset of claudication pain. Patients in the strength-trained group had a 36±48% increase in peak walking time but no change in peak Vo2 or claudication onset time. Control subjects had no changes in any of these measures over the 12-week period. After the first 12 weeks, patients in the initial walking exercise group continued for 12 more weeks of supervised treadmill training. This resulted in an additional 49±53% increase in peak walking time (total of 128±99% increase over the 24 weeks). After the initial 12 weeks, patients in the strength-trained group began 12 weeks of supervised treadmill training and patients in the control group participated in a 12-week combined program of strengthening and treadmill walking exercise. The combined strength and treadmill training program and treadmill training after 12 weeks of strength training resulted in increases in peak exercise performance similar to those observed with 12 weeks of treadmill training alone.

Conclusions A supervised treadmill walking exercise program is an effective means to improve exercise performance in patients with intermittent claudication, with continued improvement over 24 weeks of training. In contrast, 12 weeks of strength training was less effective than 12 weeks of supervised treadmill walking exercise. Finally, strength training, whether sequential or concomitant, did not augment the response to a walking exercise program. (Circulation, 1994;90:1866-1874.)

Key Words • claudication • exercise • oxygen • clinical trials

Patients with peripheral arterial disease (PAD) develop atherosclerotic occlusions of the lower-extremity arterial circulation. Clinically, patients with this disease experience muscle aching or cramping during walking exercise secondary to ischemia in the calf, thigh, or buttocks.1,2 This exercise-induced ischemic pain (intermittent claudication) limits peak exercise performance and oxygen consumption during graded treadmill exercise testing.3,4 The reduced exercise performance is associated with a restricted range of ability to perform ambulatory activities at home, in the workplace, and during leisure time.

Walking exercise has been recommended as a nonsurgical treatment for claudication.5 Most training studies have been conducted in a supervised setting and used treadmill exercise as the primary training modality. In a supervised program, the patient typically walks on a treadmill at an exercise intensity sufficient to bring on claudication pain. The walking exercise is interrupted by rest periods to relieve the claudication pain, and then walking exercise is resumed for a total rest and exercise time of 1 hour.6 Supervised treadmill walking exercise is very effective in improving treadmill exercise performance and community-based walking ability.6,9 In addition to treadmill walking exercise, other activities have been incorporated into the training sessions of some programs. These activities have included isotonic exercise of specific muscle groups, bicycle exercise, gymnastic exercise, and stair climbing, often under the supervision of a physical therapist.10,11 However, the relative benefits of other training activities compared with walking exercise have not been studied. The observation that patients with PAD have muscle weakness12 provides a rationale for strength training muscle groups...
of the lower extremity to improve walking ability. The present study tested the hypothesis that a strength training program would be as effective as and that combinations of strengthening and walking exercises would be more effective than a walking exercise program in improving peak exercise performance. Twenty-nine patients with PAD were initially randomized to 12 weeks of treadmill walking exercise, a strength training program, or a nonexercising control group followed by an additional 12 weeks of a combination of these programs. The results demonstrate that treadmill walking exercise remains the most effective exercise training program for patients with intermittent claudication.

Methods

Study Population

Subjects were evaluated for the study who had intermittent claudication, defined as pain in the calf, thigh, or buttocks that limited walking ability and that was relieved by rest within 10 minutes.13 Three patients reported that claudication was the limiting symptom during community-based activities as well as with treadmill exercise in the laboratory. The severity of claudication was stable over a 3-month period before enrollment (change, <1 block in walking distance by history). The claudication pain was also considered disabling, defined as severe enough to interfere with the ability of the patient to perform social, recreational, or vocational activities. PAD was confirmed by an ankle/arm systolic blood pressure ratio of <0.94 at rest that decreased to <0.73 after exercise.14 The study was approved by the University of Colorado School of Medicine Human Subjects Committee, and informed consent was obtained from all enrolled subjects.

Forty-four male patients with PAD were screened for the study, but 15 were excluded before randomization. Reasons for exclusion included leg pain at rest, ischemic ulceration, or gangrene. Patients were also excluded who were unable to walk on the treadmill at a speed of at least 2 mph or whose exercise capacity was limited by symptoms of angina, congestive heart failure, chronic obstructive pulmonary disease, or arthritis. Diabetics were excluded because the degree of glycemic control may affect the response to a conditioning program.15 Patients who had undergone vascular surgery or angioplasty within the previous year were also excluded from the study. Patients taking chronic medications were continued on their drugs, but the dosage was not changed during the study. Twenty-nine patients were subsequently enrolled and randomized into the study.

Design

All patients underwent an initial series of evaluation procedures and then were randomized to one of two treatment groups or a control group (Table 1). Control subjects were instructed to maintain their usual level of activity and not to exercise on a regular basis, and treated subjects were enrolled in a 12-week program of either supervised treadmill walking exercise or strength training. Two subjects in the control group refused to return for the 12-week evaluation; therefore, although they were included in the initial characterization of the patient groups, they were excluded from further analysis. After the first 12 weeks of the study, the relative benefits of the two training programs were compared with the responses in the control group (see below).

In the second phase of the study, patients in the treadmill group were continued for an additional 12 weeks of supervised walking exercise to determine whether a total of 24 weeks of training produced better results than 12 weeks alone. One subject refused to continue in the second phase, leaving nine subjects completing the full 24 weeks. Subjects randomized initially to strength training were crossed over to treadmill training in the second 12 weeks to determine whether an initial period of muscle strengthening would accentuate the training effects of supervised walking exercise. Three of these subjects refused to participate in the treadmill exercise program, leaving 6 subjects completing the full 24-week program. Finally, if strength training and walking exercise improve exercise performance by different mechanisms, combining these modalities in a 12-week program might be more effective than either method alone. Therefore, 6 of 8 subjects initially randomized to the control group (2 declined to participate) entered a combined program of strengthening and treadmill walking exercises in the second 12 weeks.

After randomization, 2 control subjects did not return for the 12-week evaluation, and 6 additional subjects did not complete the full 24 weeks of therapy (as described above). These subjects had ankle/arm ratios and peak treadmill walking times similar to those of the remaining subjects in the study.

Treadmill Testing Protocols

Subjects were tested on both a graded and constant-load treadmill protocol (conducted on separate days) on entry and after 12 and 24 weeks. Subjects had a familiarization graded treadmill test during the initial visit, with a second test on a subsequent day used for data analysis. The graded treadmill protocol has been described.4,16 Subjects walked on the treadmill at an initial workload of 2 mph, 0% grade for 3 minutes. Subsequent stages increased 3.5% in continuity every 3 minutes (with no change in speed) to maximal claudication pain. During exercise, heart rate (by 12-lead ECG) and brachial blood pressure were monitored every minute. Change in the severity of the claudication pain during the test was recorded on a scale of 1 to 5, with 1 indicating no pain; 2, onset of claudication; 3, mild; 4, moderate; and 5, severe pain. All subjects (at all evaluations) reached a maximal level of claudication pain that limited exercise during the graded treadmill test.

During all treadmill tests, an Ametek metabolic system (Ametek/Thermox Instruments) was used to measure rates of oxygen consumption (V\textsubscript{O\textsubscript{2}}) and carbon dioxide production (V\textsubscript{CO\textsubscript{2}}). The instrument was calibrated with known concentrations of O\textsubscript{2} and CO\textsubscript{2} before each test. Peak oxygen consumption was determined from the average of the final minute of data from the graded treadmill protocol. The respiratory exchange ratio (RER) was calculated as V\textsubscript{CO\textsubscript{2}}/V\textsubscript{O\textsubscript{2}}.

Subjects were also tested on a constant-load treadmill protocol to determine whether changes in steady-state V\textsubscript{O\textsubscript{2}} and other metabolic responses occurred as a result of the training programs. The workload for the constant-load protocol was individually set as the treadmill grade at which claudication pain first began on the graded protocol. The grade of the constant-load test ranged from 0% to 7%, with an

<table>
<thead>
<tr>
<th>Table 1. Study Design</th>
<th>Study Week</th>
<th>0</th>
<th>12</th>
<th>12</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM (10)</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S (9)</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C (10)</td>
<td></td>
<td>8</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Twenty-nine patients with peripheral arterial disease were randomized to either a treadmill training program (TM), strength training (S), or a nontreatment control group (C). After the initial 12 weeks, subjects in the treadmill training program continued with an additional 12 weeks of treadmill training. For the final 12 weeks, subjects in the strength training program crossed over to treadmill training, and subjects in the control group crossed over to the combined strength and treadmill training program (TM+S). Numbers in parentheses refer to the number of subjects at each time point.


Supervised strength training was conducted three times per week by a physical therapist (one therapist for two patients). Each 1-hour session began with 5 minutes of warm-up and ended with 5 minutes of cooldown activities. During the remaining 50 minutes, subjects performed resistive, isometric training of five specific muscle groups in each leg (see below). The training program consisted of applying a resistance to each muscle group with a cuff weight secured to the appropriate part of the leg. On entry, the weight that caused fatigue in the muscle group after six contractions (maximum-intensity repetitions, or 6 rep-max) was established. Every 2 weeks, the 6 rep-max was reassessed, and the weights were changed accordingly. Exercise training consisted of the subject’s performing six contractions of the five muscle groups on a given leg, followed by a rest period, and then repeating this circuit for a total of three sets per session. Training in the other leg was performed in an identical manner.

The gastrocnemius-soleus muscles were trained with one-leg heel-raises, initially against the subject’s body weight and then by additional weight applied in the form of a weight belt around the waist. The anterior tibial muscles were trained by dorsiflexion against a resistance applied to the forefoot. The quadriceps femoris muscles were trained with the subject in the seated position, applying full extension against a weight attached to the ankle. The hamstrings were trained with the subject in the prone position performing leg curls with a weight at the ankle. Conditioning of the gluteus maximus and gluteus medius muscles occurred with the patient in the prone or lateral position on an exercise table, contracting the muscles against an appropriate amount of weight applied to the ankle.

Patients in the combined strength and treadmill walking exercise program participated in three 90-minute sessions per week. Treadmill training was conducted for 60 minutes as described above, followed by 30 minutes of strength training of the gastrocnemius-soleus, the anterior tibial, and the gluteus maximus muscles of each leg. Subjects were also encouraged to continue the walking program at home twice a week.

Data Analysis

The sample size for this study was estimated from our previous experience with the treadmill training program. Differences between groups on entry were determined with a between-subjects ANOVA for continuous variables and the chi-squared statistic for categorical variables. Changes within groups over the three time points (entry, 12 weeks, and 24 weeks) were assessed with the nonparametric Quade test, since the data were not normally distributed. Percent change in treadmill walking time with each treatment was determined individually for each patient, and then the results were averaged. Comparisons of the percent change from entry to 12 weeks between treadmill and strength training were made with an unpaired t test. Values are reported as mean±SD and are considered significant when P<.05 with a two-tailed test.

Results

Subjects

On entry, the 29 subjects were well matched by age and weight (Table 2). A similar number of patients in each group had a history of coronary artery disease (previous myocardial infarction or coronary bypass surgery), cerebrovascular disease (previous stroke, transient ischemic attack, or carotid surgery), and chronic obstructive pulmonary disease, but none of these conditions were limiting during graded treadmill exercise. Seven patients had a history (>1 year before enrollment) of peripheral vascular bypass surgery or angio-plasty. All patients had a history of smoking, and the majority were current smokers, with a similar number of pack-years of smoking between groups. Finally, the
prevalence of hypertension, hyperlipidemia, and the use of cardiovascular medications was similar between groups.

Patients randomized to the strength training program reported fewer years of claudication than did patients in the other two groups (Table 2). However, the ankle/arm systolic blood pressure index at rest in the more diseased leg was similar between groups on entry and remained unchanged in all subjects over the 24 weeks of follow-up (data not shown). After exercise, the ankle/arm index was significantly decreased compared with resting values, and the postexercise values were also unaffected by the training programs during the follow-up period. Therefore, there was no evidence of arterial disease progression during the 6-month study period.

Peak Exercise Response to Training

Patients in the treadmill training program had a 74±58% increase in peak walking time. The change in peak walking time in the treadmill group tended to be greater than in the strength group (P=.07). However, strength-trained subjects had no changes in claudication onset time, peak VO$_2$, or the other measures of peak performance. Control subjects had no change in any measure of peak treadmill performance after 12 weeks.

After 12 additional weeks of treadmill training (24 weeks total) in the group originally randomized to treadmill training, there was an additional 49±53% increase in peak walking time and an increase in claudication onset time compared with values at 12 weeks (Table 3; Figure). Thus, the 24 weeks of treadmill training increased peak walking time a total of 128±99%. After 24 weeks of training, peak VO$_2$ was increased compared with baseline values, peak RER was increased over entry and 12-week values, and blood lactate concentration was increased over entry values. Thus, 24 weeks of treadmill training produced greater increases in peak exercise performance compared with only 12 weeks of training.

The addition of 12 weeks of treadmill training in patients who completed the strength program or in control subjects who participated in treadmill training in
combination with strength training resulted in significant increases in peak treadmill walking time for each group compared with the values after the first 12 weeks (Table 3; Figure). The change in peak walking time in these two groups was similar to the change in peak walking time after the first 12 weeks of training in the treadmill group. However, in contrast to 12 weeks of treadmill training alone, patients crossing over from the strength or control groups had no improvements in claudication onset time or peak \( V_O_2 \) with treadmill training.

### Constant-Load Treadmill Performance

Patients in the three groups were also evaluated with a constant-load treadmill protocol. Twelve weeks of treadmill training resulted in an increase in total walking time and claudication onset time on the constant-load treadmill protocol (Table 4). In contrast to the findings with graded treadmill testing, 12 weeks of strength training resulted in no change in total walking time or claudication onset time. Control subjects actually had a decrease in total walking time and no change in claudication onset time. After a total of 24 weeks of treadmill training, subjects in the treadmill group had a 332±283% improvement in total walking time. In the strength and control groups, the addition of treadmill training in the second 12 weeks of the study resulted in an increase in total walking time. This change in walking time was of a magnitude similar to that observed during the initial 12 weeks of treadmill training in the treadmill group.

On entry into the study, total walking time on the constant-load treadmill protocol was claudication-limited in all but one subject. After 12 weeks, 3 subjects in the treadmill group and 1 subject in the strength group were not claudication-limited. The inability to achieve a claudication-limited exercise end point was the result of a training-induced increase in exercise performance that was beyond the dynamic range of the constant-load protocol. After 24 weeks (when all subjects had been exposed to the walking exercise program), 9 of 21 subjects (43%) were not claudication-limited during constant-load treadmill exercise. These results emphasize the enhanced utility of the graded treadmill protocol to define maximal walking time in patients with claudication compared with the constant-load treadmill test.20

The constant-load treadmill exercise test was also used to evaluate changes in heart rate and metabolic responses to exercise under steady-state conditions before and after the training programs. All subjects had reached steady state with respect to the parameters of
ft-lb in the more-diseased legs, which was less than the value of 31.5±9.7 ft-lb in the less-diseased legs (P<.05 for the difference between legs). After the initial 12 weeks of strength training, muscle strength increased 4.8±4.7 ft-lb in the more-diseased legs and increased 3.9±3.1 ft-lb in the less-diseased legs (both P<.05 compared with baseline values). However, muscle strength remained unchanged in treadmill-trained and control subjects. After 24 weeks, subjects in the strength group who crossed over to treadmill training lost strength in both legs compared with values at 12 weeks, and subjects in the combined program did not increase gastrocnemius strength.

**Discussion**

This trial demonstrated that 12 weeks of supervised treadmill training improved peak walking time and peak VO2 as well as claudication onset time on a graded treadmill protocol. As suggested by previous studies, 24 weeks of treadmill training was more effective than 12 weeks in improving peak exercise performance.8,21 Although strength training enhanced gastrocnemius muscle strength, the muscle strengthening program was less effective than treadmill training in improving peak treadmill walking time. Finally, control subjects had no changes in exercise performance over a period of 12 weeks, confirming a lack of spontaneous improvement in functional status in patients not provided specific therapy.

Previous studies have demonstrated that patients with PAD have muscle weakness12,22 and that gastrocnemius muscle strength is positively correlated with exercise performance on the treadmill.12 Many rehabilitation programs for claudication combine isotonic exercises with walking exercise,5,23 but the relative benefits of strength training or combinations of training activities have not been directly compared with a walking exercise program. Therefore, a goal of the present study was to determine whether strength training before treadmill training or in combination with treadmill training would result in greater increases in exercise performance than treadmill training alone. The results demonstrate that when treadmill training followed strength training or when strength and treadmill training were combined there was an increase in peak walking time on the graded treadmill protocol. However, the magnitude of improvement in patients receiving simultaneous or serial strength and treadmill training was not greater than the response to treadmill training alone. The lack of improvement in peak VO2 or claudication onset time in these groups compared with treadmill training alone is further evidence that strength training was not additive to treadmill training in PAD patients. Thus, in patients with PAD, modifying the strength of muscles in the lower extremity that are important for walking is not a major determinant of the training response. The strength training program was resource intensive, requiring special equipment and one physical therapist to treat two subjects, whereas eight subjects could be trained by one therapist in the treadmill program. Since the strength training benefits were modest, this form of exercise therapy cannot be recommended as a cost-effective treatment for claudication.
TABLE 4. Changes in Constant-Load Treadmill Performance and Metabolism With Training

<table>
<thead>
<tr>
<th></th>
<th>Entry</th>
<th>Week 12</th>
<th>Week 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total walking time, min</td>
<td>TM 13.2±10.9</td>
<td>30.5±17.9*</td>
<td>TM 39.2±19.6†</td>
</tr>
<tr>
<td></td>
<td>S 10.4±7.5</td>
<td>12.7±11.7</td>
<td>TM 24.7±20.3†</td>
</tr>
<tr>
<td></td>
<td>C 8.9±4.9</td>
<td>7.5±5.4*</td>
<td>TM+S 22.3±14.5†</td>
</tr>
<tr>
<td>Claudication onset, min</td>
<td>TM 3.5±2.0</td>
<td>18.3±22.7*</td>
<td>TM 30.7±27.9*</td>
</tr>
<tr>
<td></td>
<td>S 2.5±1.3</td>
<td>2.8±1.5</td>
<td>TM 3.4±1.5*</td>
</tr>
<tr>
<td></td>
<td>C 3.0±0.9</td>
<td>2.5±1.1</td>
<td>TM+S 12.4±23.4</td>
</tr>
<tr>
<td>(\text{VO}_2), mL·kg(^{-1})·min(^{-1})</td>
<td>TM 11.9±1.7</td>
<td>10.1±1.9*</td>
<td>TM 9.9±1.3*</td>
</tr>
<tr>
<td></td>
<td>S 12.9±2.8</td>
<td>11.7±1.8</td>
<td>TM 10.3±1.5*</td>
</tr>
<tr>
<td></td>
<td>C 11.7±1.8</td>
<td>11.3±1.4</td>
<td>TM+S 11.1±3.4</td>
</tr>
<tr>
<td>Percent of peak (\text{VO}_2)</td>
<td>TM 80±11%</td>
<td>63±17%*</td>
<td>TM 58±17%*</td>
</tr>
<tr>
<td></td>
<td>S 88±11%</td>
<td>86±27%</td>
<td>TM 69±13%*</td>
</tr>
<tr>
<td></td>
<td>C 85±8%</td>
<td>83±17%</td>
<td>TM+S 76±23%</td>
</tr>
<tr>
<td>Heart rate, beats/min</td>
<td>TM 104±10</td>
<td>87±15*</td>
<td>TM 86±14*</td>
</tr>
<tr>
<td></td>
<td>S 103±20</td>
<td>99±16</td>
<td>TM 90±8</td>
</tr>
<tr>
<td></td>
<td>C 96±14</td>
<td>98±14</td>
<td>TM+S 93±16</td>
</tr>
<tr>
<td>Respiratory exchange ratio</td>
<td>TM 0.89±0.07</td>
<td>0.82±0.04*</td>
<td>TM 0.83±0.05*</td>
</tr>
<tr>
<td></td>
<td>S 0.89±0.07</td>
<td>0.86±0.05</td>
<td>TM 0.85±0.04</td>
</tr>
<tr>
<td></td>
<td>C 0.89±0.06</td>
<td>0.87±0.06</td>
<td>TM+S 0.85±0.03</td>
</tr>
<tr>
<td>Lactate concentration, mmol/L</td>
<td>TM 1.4±0.4</td>
<td>1.0±0.5*</td>
<td>TM 0.9±0.2*</td>
</tr>
<tr>
<td></td>
<td>S 1.4±0.4</td>
<td>1.4±0.9</td>
<td>TM 1.1±0.5</td>
</tr>
<tr>
<td></td>
<td>C 0.9±0.3</td>
<td>1.1±0.3</td>
<td>TM+S 1.5±0.8</td>
</tr>
</tbody>
</table>

Measurements of \(\text{VO}_2\), percent peak \(\text{VO}_2\), heart rate, respiratory exchange ratio, and blood lactate concentration are reported for 6 minutes of exercise. Abbreviations as in Table 1. *P<.05 compared with entry value; †P<.05 week 24 compared with week 12.

Potential Mechanisms of the Exercise Training Response

In the present study, constant-load treadmill testing was used to evaluate the metabolic and heart rate responses to exercise training under steady-state exercise conditions. Previous studies of exercise training in patients with PAD have shown that at a given submaximal workload on a graded protocol, exercise training decreased heart rate and \(\text{VO}_2\) consumption. The present study confirmed these altered responses with treadmill exercise training under fixed load testing conditions (Table 4). If the onset of claudication is due to an oxygen demand-delivery mismatch, the lower \(\text{VO}_2\) at a given workload might contribute to the ability to sustain walking exercise for longer distances before claudication pain limits the activity. Although exercise training in normal elderly subjects does not alter the \(\text{VO}_2\)-workload relation, conditioning in older cardiac patients has been shown to decrease \(\text{VO}_2\) during constant-load treadmill exercise. The lower steady-state \(\text{VO}_2\) observed with training in PAD patients may be the result of a modification in gait or the biomechanics of walking that allows for less energy expenditure to support a given level of exercise. Therefore, in patients with cardiovascular disease, a decrease in the oxygen cost of walking exercise may allow the activity to be sustained for longer periods of time. This concept was supported by the observation that the patients with the greatest improvement in constant-load walking time also had the greatest decrease in steady-state \(\text{VO}_2\). However, since there was no further decrease in steady-state \(\text{VO}_2\) after 24 weeks versus 12 weeks of treadmill training, the continued increase in peak exercise performance at 24 weeks may involve factors other than changes in walking efficiency.

Further evidence that treadmill training modified the systemic responses to a constant exercise workload was the 17-beat per minute reduction in heart rate, the
reduction in RER (greater reliance on fatty acid oxidation), and the decrease in blood lactate concentration. Similar training responses in heart rate, RER, and blood lactate concentration have been observed with exercise conditioning both in normal subjects and in patients with coronary artery disease.25,26 These changes may be interpreted as a training-induced reduction in the relative intensity of a fixed workload due to an increase in either maximal VO₂ or the lactate threshold. In other populations, when an exercise workload is performed at a lower percentage of maximal VO₂, there is an associated decrease in lactate production, enhanced fatty acid oxidation, and improved exercise endurance.27,28 The steady-state heart rate, RER, and blood lactate concentration responses to constant-load exercise were unchanged in the strength and control groups after 12 weeks. Thus, the heart rate and metabolic adaptations to exercise training in the treadmill group were not simply due to increased familiarity with the testing procedures but rather were analogous to the physiological responses to classic aerobic training.29

Evaluation of the Treadmill Testing Protocols

Constant-load exercise testing has been commonly used to assess the effects of therapy for claudication. The traditional treadmill protocol for persons with PAD has generally been conducted at a slow speed of 1.5 to 2 mph, with the grade typically fixed at a level of 8% to 12%.30,31 However, a single workload may not be appropriate for a heterogeneous population of patients with different walking abilities. Therefore, the workload selected for patients in the present study was individualized as the specific grade on the graded protocol that was associated with the onset of claudication. On entry to the study, this individualized but constant workload was sufficient to bring all but one patient to a claudication-limited end point. Despite the initial optimization of the workload, after training, many of the patients experienced large improvements in performance and never reached a maximal level of claudication pain during the constant-load test. Therefore, in many patients the degree of improvement in total walking time after training was underestimated with the constant-load test. This finding has also been observed in patients with coronary artery disease when training-induced changes in endurance exercise performance were assessed with constant-load protocols.26 In contrast to the limitations of the constant-load protocol, the graded treadmill test demonstrated a large dynamic range that allowed all patients to be evaluated at a quantifiable maximal claudication end point.

Conclusions

Patients with PAD have a chronic disease that produces a moderate to severe degree of walking impairment without spontaneous recovery. Treadmill exercise training results in clinically important improvements in peak exercise performance and claudication pain severity, allowing patients to perform a greater range of activities.32 The treadmill training program is also associated with a decreased metabolic cost of walking exercise that allows patients to increase their walking distance. In contrast, strength training the muscles of the lower extremity has limited utility as a treatment for claudication. A supervised treadmill training program 24 weeks in duration should be considered an important treatment option for patients disabled by PAD.

Acknowledgments

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