Controlled Trial of Aerobic Exercise in Hypertension

John E. Martin, PhD, Patricia M. Dubbert, PhD, and William C. Cushman, MD, FACP

To determine the antihypertensive efficacy of aerobic exercise training in mild essential hypertension, a prospective randomized controlled trial was conducted comparing an aerobic exercise regimen to a placebo exercise regimen, with a crossover replication of the aerobic regimen in the placebo exercise group. The study took place in an outpatient research clinic in a university-affiliated Veterans Administration Medical Center. Twenty-seven men with untreated diastolic blood pressure (DBP) of 90–104 mm Hg were randomized to the two exercise regimens. Ten patients completed the aerobic regimen. Nine patients completed the control regimen, seven of whom subsequently entered and completed the aerobic regimen. The aerobic regimen consisted of walking, jogging, stationary bicycling, or any combination of these activities for 30 minutes, four times a week, at 65–80% maximal heart rate. The control regimen consisted of slow calisthenics and stretching for the same duration and frequency but maintaining less than 60% maximal heart rate. DBP decreased 9.6±4.7 mm Hg in the aerobic exercise group but increased 0.8±6.2 mm Hg in the placebo control exercise group (p=0.02). Systolic blood pressure (SBP) decreased 6.4±9.1 mm Hg in the aerobic group and increased 0.9±9.7 mm Hg in the control group (p=0.11). Subsequently, seven of the nine controls entered a treatment crossover and completed the aerobic regimen with significant reductions in both DBP (−6.1±3.2 mm Hg, p<0.01) and SBP (−8.1±5.7 mm Hg, p<0.01). BP changes were not associated with any significant changes in weight, body fat, urinary electrolytes, or resting heart rate. This randomized controlled trial provides evidence for the independent BP lowering effect of aerobic exercise in unmedicated mildly hypertensive men. (Circulation 1990;81:1560–1567)

Levels of physical activity and fitness have often been found to be inversely related to the incidence and severity of hypertension in epidemiological surveys.1–4 In the past three decades, a number of studies have reported blood pressure (BP) reductions in hypertensives undergoing a regular program of aerobic exercise.5–31 Consequently, various reviews32–35 and the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure36 have concluded that exercise can be beneficial in the management of hypertension but that more studies are needed because there is still a paucity of adequately controlled randomized studies. Importantly, few of the studies conducted to date used a control group of hypertensives, and none used a credible attention control or placebo treatment control group of hypertensive subjects.34

The present study attempted to isolate the effects of aerobic exercise from nonspecific treatment and nontreatment factors in a controlled trial. The study examined the antihypertensive efficacy of an aerobic exercise treatment regimen as compared with an “exercise placebo” regimen in a randomized trial of mild hypertensive male subjects.

Methods

Sedentary men, aged 18–60 years, with diastolic blood pressure (DBP) of 90–104 mm Hg without antihypertensive medication were recruited for a 10-week exercise training program. Subjects were excluded who were greater than 60% overweight, had a history of cardiac, renal, or joint disease, diabetes, significant psychopathology, or showed an abnormal
resting or exercise electrocardiogram (ECG). Also excluded were any individuals who were adhering to a weight loss or a sodium-restricted diet or who were currently exercising. For subjects who were taking antihypertensive medications at the time they were screened, drug therapy was gradually tapered and discontinued for a minimum of 2 weeks before they entered the prerandomization period. They could be followed longer than 2 weeks, if necessary, for the DBP to rise into the 90–104 mm Hg range.

After signing consent forms approved by the Institutional Review Board, subjects were seen at weekly intervals for at least 1 month for baseline assessment. Cuff size was determined at the initial visit according to arm circumference. At the beginning of each visit, after 5 minutes of rest, two seated BP readings were taken with a Hawksley random-zero sphygmomanometer, and the mean systolic blood pressure (SBP) and DBP were recorded as the visit BP. BPs were assessed by a nurse specialist or one of two trained technicians. To be eligible for randomization, the average DBP of the last three pretreatment visits and the final pretreatment DBP had to be 90–104 mm Hg. Additionally, the final pretreatment DBP could not represent a clinically significant increasing or decreasing trend (e.g., 5 mm Hg or more) beyond the two previous measures.

Other baseline measures included body weight, height, resting heart rate (HR), percentage of body fat, 24-hour urine sodium, potassium, and creatinine excretion, resting ECG, and a maximal graded exercise test (GXT) using the Bruce protocol. With the exception of height, these measures were repeated at the end of treatment. Percentage of body fat was estimated from skinfold thickness obtained at four sites (triceps, biceps, subscapular, and suprailiac). Subjects were asked to refrain from changes in diet, alcohol intake, or exercise (except for the prescribed program) during the 10-week treatment period.

After completion of baseline assessment, subjects were randomly assigned to aerobic exercise training or the control exercise condition. The treatment programs for both groups consisted of four 30-minute sessions per week, with two of the four supervised by the project staff at the laboratory and the remaining two sessions performed by the subjects independently, outside the laboratory. The program for the aerobic exercise group consisted of fast walking, jogging, cycling, or any combination of these activities at an intensity to maintain HR at 65–80% of the maximum HR attained at the pretreatment GXT. The program for the control exercise group consisted of stretching and easy calisthenics at an intensity maintaining an HR not to exceed 60% of the maximum attained during the GXT. HR was monitored throughout each laboratory and home exercise session with a portable HR monitor (Exersentry model EX-3, Respironics, Inc., Monroeville, Pennsylvania), which had been preset to sound a tone if the HR exceeded or declined below the prescribed range. Subjects were asked to keep records of exercise sessions completed outside the laboratory, and these records were reviewed in detail each week by the therapists.

Resting BP was assessed before each exercise session; if the DBP exceeded 104 mm Hg on three consecutive visits, the subject was dropped from treatment and referred for alternate therapy. Otherwise, subjects were not told their level of BP during the study and they were instructed not to have their BP checked outside the laboratory until the study was completed.

Before randomization, subjects were told the purpose of the study was to test the effects of different kinds of exercise on BP and that they would be assigned to one of two levels of exercise, that is, “high intensity” or “low intensity.” Subjects in both groups received equivalent attention from therapists and were assessed at the same intervals. Two weeks after beginning the exercise program and then at 4-week intervals, subjects in both groups had a random-zero sphygmomanometer BP reading and were weighed. To enhance treatment credibility and compliance to the two respective regimens, at the same 4-week intervals participants were tested for improvements in fitness and flexibility. Aerobic exercise subjects were given submaximal GXT at these intervals, whereas control exercise subjects were given “flexibility” assessments, which consisted of measuring changes in the distance they could reach in several of the stretching exercises. For aerobic exercise subjects, improvements (decreases) in HR at the various stages of the submaximal GXT and, for control exercise subjects, improvements in stretching ability were pointed out as evidence of progress. To further ensure the comparability of treatments with respect to nonspecific expectation and belief-mediated effects on blood pressure and other measures, ratings of treatment credibility and satisfaction were obtained for all subjects after 1 month of treatment and after treatment cessation using five-point and nine-point qualitative ratings.

All subjects received a maximal GXT again after the 10-week treatment phase. Subsequently, subjects who completed the control exercise regimen, and who had not achieved a significant decline in their BP by the end of the initial treatment period, were offered the aerobic exercise regimen to serve as a replication of the aerobic training conducted with the original experimental group.

Group-by-time-of-assessment (2×4) repeated measures analysis of variance (ANOVA) was used to test for significance of differences in the primary dependent measure, DBP, as well as SBP, between the two treatment groups at pretreatment and after 2, 6, and 10 weeks of exercise. Thus, a repeated measures across time ANOVA was used, with treatment as a grouping factor. Specific multiple comparisons were then performed using Bonferroni inequalities with the overall alpha set at p=0.05. The interaction term in the repeated measures ANOVA estimates the treatment effect of differential change
between groups across time.\textsuperscript{38} Treatment effects are estimated from these interactions.

\textbf{Results}

DBP served both as the primary dependent measure, and as the criterion for inclusion in the study. A total of 96 men meeting initial criteria were screened for the study; of these men, 13 developed an average DBP above the criterion range, 33 sustained an average DBP below 90 mm Hg, nine were excluded because of abnormal pretreatment graded exercise tests (i.e., ST depression or arrhythmias), and five had miscellaneous medical reasons for exclusion. Nine additional subjects failed to complete baseline assessment and, therefore, were dropped prior to randomization.

Twenty-seven subjects (20 white and seven black men; mean age, 43.5 years; mean BP, 138/95 mm Hg; mean body weight, 126% of ideal) were randomly assigned to aerobic exercise training (n=13) or the control exercise condition (n=14). No differences between the groups were found in DBP; SBP; age; body weight; percentage of body fat; excretion of creatinine, sodium, and potassium; resting HR; or maximal work capacity (Table 1). Twelve of these subjects were previously treated with antihypertensive medications, which had been discontinued an average of 17.8 months (range, 1–96 months) before randomization. Five subjects did not complete the control exercise program; one subject was referred for medical treatment when his DBP exceeded the upper limit of 104 mm Hg, one subject developed diabetes, one subject asked to be started on antihypertensive medications immediately after his brother had a myocardial infarction, and two patients became nonadherent and were dropped. Three aerobic exercise subjects were dropped. In one subject, the DBP increased to greater than 104 mm Hg during the first treatment week; one subject moved out of state; and one subject became nonadherent to the regimen after a job-shift change. Therefore, after randomization, 77% of the aerobic exercise group and 65% of the control group completed the 10-week program.

Data from the credibility-and-satisfaction-with-treatment ratings were analyzed for between-group differences using t tests, and Pearson product-moment correlations. It was found that the two groups were comparable in terms of credibility and expectation for success, that is, all ratings were nonsignificantly different (t>0.05) and highly correlated (r=0.97) across the two groups. Thus, treatment credibility and satisfaction ratings indicated that subjects’ beliefs regarding the potential effectiveness of the treatments and their willingness to recommend the treatments to a friend with a similar problem did not differ.

\textbf{Resting Blood Pressure and Heart Rate}

After 10 weeks of exercise, average BP in the aerobic exercise subjects was reduced from 136.6/94.8 to 130.1/85.2 mm Hg, whereas in the control exercise subjects, mean BP increased slightly from 134.9/93.7 to 135.8/94.4 mm Hg (Table 2). SBP decreased 6.4±9.1 mm Hg in the aerobic group and increased 0.9±7.7 mm Hg in the control group; however, the difference between the groups failed to reach statistical significance (p=0.11). The DBP for the aerobic exercise group declined 9.6±4.7 mm Hg, as compared with a mean increase in DBP of 0.8±6.2 mm Hg in the control exercise group. This difference was statistically significant (p=0.02).

Average DBPs for the two groups became significantly different after 6 (p=0.03) and 10 (p=0.001) weeks of exercise. At week 6, the mean DBP for the aerobic group had decreased 6.1 mm below baseline, and by training week 10, the mean DBP was 9.6 mm Hg lower than baseline. By the 10th week of exercise, DBPs for nine of 10 of the hypertensive subjects randomized to the aerobic exercise were less than 90 mm Hg, whereas none of the control exercise subjects was below 90 mm Hg DBP (Figure 1).

Mean resting HR (Table 2) was reduced 8.3±9.7 beats/min in the group that received aerobic training, and 2.4±15.9 beats/min in the control exercise subjects. The differences in HR before and after aerobic training, or between the two groups, however, were not significant.

\textbf{Body Composition and Urinary Excretions}

There were no significant changes across time in either treatment group for weight or percentage of ideal weight, that is, –0.4±1.9 kg for aerobic subjects and +0.4±1.4 kg for controls (Table 2). Furthermore, there were no significant changes in percentage of body fat for subjects in either group (–0.70% for aerobic subjects and –0.25% for controls). There were also no significant changes in urinary excretion of creatine, Na\textsuperscript{+}, and K\textsuperscript{+} during the study.
<table>
<thead>
<tr>
<th>TABLE 2. Mean Pretreatment, Posttreatment, and Changes in Values* for Aerobic and Control Groups</th>
<th>Aerobic exercise group (n=10)</th>
<th>Control exercise group (n=9)</th>
<th>Significance of time X group interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diastolic BP (mm Hg)</td>
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<td></td>
<td></td>
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<tr>
<td>Pre</td>
<td>94.8±4.6</td>
<td>93.7±3.6</td>
<td></td>
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<tr>
<td>Post</td>
<td>85.2±5.0</td>
<td>94.4±4.3</td>
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<tr>
<td>Change</td>
<td>−9.6±4.7</td>
<td>+0.8±6.2</td>
<td>0.02</td>
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<tr>
<td>Systolic BP (mm Hg)</td>
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</tr>
<tr>
<td>Pre</td>
<td>136.6±9.4</td>
<td>134.9±5.7</td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>130.2±10.2</td>
<td>135.8±7.9</td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td>−6.4±9.1</td>
<td>+0.9±9.7</td>
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<td>Resting heart (beats/min)</td>
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<td></td>
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<tr>
<td>Pre</td>
<td>80.7±8.5</td>
<td>78.8±9.8</td>
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<tr>
<td>Post</td>
<td>72.4±9.4</td>
<td>76.8±10.3</td>
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<tr>
<td>Change</td>
<td>−8.3±9.7</td>
<td>−2.4±15.9</td>
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<tr>
<td>Work capacity (METS)</td>
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<td></td>
<td></td>
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<tr>
<td>Pre†</td>
<td>11.2±2.3</td>
<td>9.7±1.7</td>
<td></td>
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<tr>
<td>Post†</td>
<td>13.2±1.8</td>
<td>11.2±1.4</td>
<td></td>
</tr>
<tr>
<td>Change‡</td>
<td>+2.0±2.2</td>
<td>+1.5±1.2</td>
<td>0.55</td>
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<tr>
<td>Body weight (kg)</td>
<td></td>
<td></td>
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<tr>
<td>Pre</td>
<td>90.3±18.0</td>
<td>92.0±15.8</td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>89.9±17.0</td>
<td>92.4±16.9</td>
<td></td>
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<tr>
<td>Change</td>
<td>−0.4±1.9</td>
<td>+0.4±1.4</td>
<td>0.32</td>
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<tr>
<td>Body fat (%)</td>
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<tr>
<td>Pre</td>
<td>29.8±5.8</td>
<td>34.2±4.6</td>
<td></td>
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<tr>
<td>Post</td>
<td>29.1±6.7</td>
<td>33.9±4.0</td>
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<tr>
<td>Change</td>
<td>−0.7±2.8</td>
<td>−0.2±1.6</td>
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<td>Sodium excretion (mEq/24 hr)</td>
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<tr>
<td>Pre</td>
<td>235.8±7.4</td>
<td>283.0±137.6</td>
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<tr>
<td>Post</td>
<td>202.5±36.3</td>
<td>258.4±101.5</td>
<td></td>
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<tr>
<td>Change</td>
<td>−33.4±91.3</td>
<td>−24.6±148.6</td>
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<td>Potassium excretion (mEq/24 hr)</td>
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<tr>
<td>Pre</td>
<td>81.6±33.7</td>
<td>76.3±41.0</td>
<td></td>
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<tr>
<td>Post</td>
<td>74.8±32.4</td>
<td>97.1±66.5</td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td>−6.8±25.0</td>
<td>+20.7±66.5</td>
<td>0.70</td>
</tr>
</tbody>
</table>

*Groups were not significantly different (p<0.05) at baseline except where indicated. Changes from pretreatment to posttreatment were not significantly different (p<0.05) except where indicated.
†Groups were significantly different (p=0.028) at pretreatment and posttreatment.
‡Both groups showed significant (p=0.001) improvements at posttreatment.

Pre, pretreatment; Post, posttreatment.

Adherence and Fitness Changes

Records of laboratory and home exercise sessions indicated that aerobic subjects complied with the exercise prescription (a total of four weekly sessions) 86.5% of the time, whereas the control group met this requirement 74.7% of the time. These differences were not statistically significant.

Although both groups were equivalent in fitness after randomization, when the dropouts were excluded, the aerobic subjects began treatment with greater work capacity. After the 10-week training period, work capacity as measured by the maximal GXT increased significantly in both groups, that is, 2.0±2.2 METS for the aerobic subjects and 1.5±1.2 METS for the control exercise group; however, those changes were not significantly different from one another (p=0.55).

Treatment Crossover

Seven of the nine subjects who completed the placebo control treatment volunteered for and completed the aerobic exercise training regimen as a crossover replication. These subjects completed the placebo control exercise treatment with a mean SBP of 139.1 mm Hg and DBP of 96.0 mm Hg (Table 3). After 10 weeks of aerobic training, their mean SBP was 130.0 mm Hg, a reduction of 9.1±5.7 mm Hg (p=0.005), and their average DBP was 89.9 mm Hg, a mean reduction of 6.1±3.2 mm Hg (p=0.007).
FIGURE 1. Plotting of individual diastolic (●) and systolic (○) blood pressures in millimeters of mercury (mm Hg) before and after treatment.

Resting HR, body weight, and sodium and potassium excretion did not change for these subjects (Table 3). Work capacity, however, increased 1.2±1.3 METS between ending the control exercise treatment and completing the subsequent aerobic training regimen (p=0.025).

Discussion

In this study, subjects were randomly assigned to either aerobic training or a placebo control treatment consisting of stretching and easy calisthenics. Significant reductions in BP occurred only with aerobic exercise. Importantly, BP reduction was not accom-

panied by changes in weight, body fat, or 24-hour urine sodium or potassium excretion. We believe this study provides evidence for the independent antihypertensive effect of aerobic exercise in mild essential hypertension.

Although habitual practice of vigorous exercise has been shown in epidemiological surveys to be inversely related to hypertension risk, independent of other known risk factors for hypertension,¹⁻⁴ and although prospective clinical studies have suggested the BP lowering potential of exercise,⁵⁻⁻³¹ the evidence for the efficacy of exercise in the treatment of high BP has been inconsistent. In normotensive subjects, several studies have failed to show any BP lowering effect from exercise,³⁰⁻⁴² whereas others suggest a moderate BP lowering effect.⁷⁻⁻¹⁰,¹¹,¹³⁻⁻¹⁵,²³⁻⁻²⁵,⁴³ In hypertensive patients, of the 30 studies conducted to date on exercise treatment,⁵⁻⁻³¹,⁴⁴⁻⁻⁴⁶ seven,¹⁰,¹³,²³,²⁴,⁴⁴⁻⁻⁴⁶ or 23%, found no significant antihypertensive effect of exercise, and many failed to rule out the confounding effects of dietary sodium or potassium intake, body weight, or body fat changes as an alternative explanation for the BP changes. Additionally, of the 30 studies, only nine were randomized controlled studies using hypertensive controls.¹⁰,¹²,¹⁷,¹⁹,²¹,²²,²⁹⁻⁻³¹

None compared exercise to a credible alternative treatment or attention/placebo. Furthermore, in two of these controlled studies,¹²,¹⁷ the untreated hypertensive controls exhibited significant average reductions in BP (mainly DBP) similar to their exercised counterparts. This is consistent with the experience in the Australian National Blood Pressure Study in which 48% of the mild hypertensive subjects were normotensive on placebos after 3 years, with most of the BP change occurring within the first few months.⁴⁷

The present study was designed with these limitations in mind and, therefore, included a randomized control group of hypertensives who received an exercise placebo treatment for comparison with the aerobic exercise regimen. As such, this study represents an evaluation of the efficacy of aerobic exercise in
mild hypertensive subjects that isolates the effects of exercise from nonspecific treatment effects such as amount of therapist attention, patient expectation of treatment success, and repeated measurement of BP.

The relative size of the DBP reduction found in the present evaluation (9.6 mm Hg) is very similar to that of previous studies of exercise in hypertension. This effect was replicated by using a partial crossover to further evaluate its reliability. That is, when the aerobic training was offered and subsequently provided to the seven control exercise subjects who agreed to continue participation in the project, significant reductions occurred once again in DBP (6.1 mm Hg) and, this time also, in SBP (9.1 mm Hg). Furthermore, of the 17 subjects who received the 10 weeks of aerobic training (10 randomly assigned originally to aerobic exercise and seven who crossed over to aerobic training after completing the control exercise protocol), 14 (82%) achieved DBP levels less than or equal to 90 mm Hg.

The fact that the reduction in SBP of \(-6.4 \pm 9.1\) mm Hg, although clinically meaningful, did not reach statistical significance can be attributed to the relatively higher variability in SBP as compared with DBP, and because a priori power analyses to determine minimum group sizes were only conducted on DBP, the primary dependent variable. Not surprisingly, a post-hoc power analysis indicated that much larger groups would have been required to detect SBP change differences of the magnitude of those found in this study. Despite this limitation, in the crossover replication, aerobic exercise was associated with a statistically as well as clinically significant reduction in SBP of \(-9.1\) mm Hg. Thus, SBP should be investigated as a primary dependent variable in future studies with larger sample sizes.

One limitation of the present study concerns the ability to generalize these findings for the treatment and early control of elevated BP in a large population. Given the well-documented problems in achieving adequate medication compliance in treated hypertensive subjects, it might be expected that there would be more significant problems with a more complex and time-consuming exercise regimen. Yet, 77% of the subjects who were randomized completed the 10-week program, and 100% of those who crossed over to aerobic training after the ineffective control protocol completed the second 10-week program. The recent popularity and increase in facilities and equipment for aerobic exercise should make this form of nonpharmacological treatment reasonably practical for the mildly hypertensive population. Additionally, in recent years behavioral strategies have been developed and validated for enhancing the acquisition and maintenance of the exercise habit.48-52

The subjects in this study were young-to-middle-aged untreated mildly hypertensive men who were, on average, 25–30% overweight. This study does not address the potential response of women, the elderly, nonvolunteers, thin hypertensive subjects, moderate-to-severe hypertensive subjects, or medicated hypertensive subjects at any level, nor is it necessarily representative of the response expected in less systematically conducted or supervised programs. Our study was not designed to examine the mechanisms by which exercise might decrease BP; however, the changes observed could not be explained by any changes in body weight, body fat, or urinary sodium or potassium excretion although this was a relatively obese population with high sodium intakes (consistent with that found in the southeastern U.S.). Larger-scale controlled studies might now be warranted to further establish the safety and effectiveness, as well as the reliability and ability to generalize the antihypertensive effects of exercise. Additional questions that need to be addressed in these studies include the necessary dose and duration of treatment and the mechanism or mechanisms of antihypertensive effect.

The present study provides evidence for the independent BP lowering effect of aerobic exercise in unmedicated mildly hypertensive men. A systematic program of vigorous exercise might be an acceptable alternative to drug treatment in select hypertensive subjects. The role of exercise as adjunctive therapy with drugs is an attractive alternative to adding new drugs or increasing doses of current medication; however, this has not been adequately investigated. Despite the potential difficulty of attempting to obtain long-term adherence to exercise regimens, the apparent beneficial effects of exercise on hypertension, as well as on other important cardiovascular risk factors

| Table 3. Before and After Aerobic Exercise Data for Crossover Replication Subjects |
|------------------------|------------------------|------------------------|------------------------|------------------------|
|                        | Baseline              | After aerobic training | Change                 | p                        |
| n                      | 7                     |                        |                        |                         |
| Race (% white)         | 71.4                  |                        |                        |                         |
| Systolic BP (mm Hg)    | 139.1±10.6            | 130.0±7.9              | \(-9.1\)±5.7           | 0.005                   |
| Diastolic BP (mm Hg)   | 96.0±3.7              | 89.6±3.2              | \(-6.1\)±3.2           | 0.007                   |
| Resting heart rate (beats/min) | 76.2±11.1         | 73.5±6.0              | \(-2.7\)±13.0          | 0.301                   |
| Work capacity (METS)   | 11.3±1.6              | 12.6±1.9             | \(+1.2\)±1.3           | 0.025                   |
| Body weight (kg)       | 86.6±9.5              | 86.1±8.4             | \(-0.5\)±1.8           | 0.246                   |
| Sodium excretion (meq/24 hr) | 266.9±109.7       | 279.6±118.1           | \(+12.7\)±116.3        | 0.391                   |
| Potassium excretion (meq/24 hr) | 83.6±80.2         | 104.2±68.3           | \(+20.1\)±64.5         | 0.222                   |

BP, blood pressure.
such as obesity, dyslipidemia, diabetes, and perhaps “Type A—coronary prone” behavior, should be considered. We believe that the present study demonstrates that moderate aerobic exercise lowers BP in some hypertensive subjects and might be an important modality in the control of hypertension.

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References


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