Baroreflex Buffering in Sedentary and Endurance Exercise–Trained Healthy Men

Demetra D. Christou, Pamela Parker Jones, Douglas R. Seals

Abstract—Baroreflex buffering plays an important role in arterial blood pressure control. Previous reports suggest that baroreflex sensitivity may be altered in endurance exercise–trained compared with untrained subjects. It is unknown, however, if in vivo baroreflex buffering is altered in the endurance exercise–trained state in humans. Baroreflex buffering was determined in 36 healthy normotensive men (18 endurance exercise–trained, 41 ± 5 [SEM] years; 18 untrained, 41 ± 4 years) by measuring the potentiation of the systolic blood pressure responses to a phenylephrine bolus and to incremental phenylephrine infusion during compared with before ganglionic blockade with trimethaphan. The exercise-trained men had a lower resting heart rate and higher maximal oxygen consumption and heart rate variability than the sedentary control subjects (all \( P = 0.01 \)). Mean levels and variability of blood pressure, cardiovagal baroreflex sensitivity (change in heart rate/change in systolic blood pressure), and basal muscle sympathetic nerve activity were not different in the two groups. The systolic blood pressure responses to phenylephrine were not different in the endurance-trained and untrained men before or during ganglionic blockade (\( P > 0.6 \)). Measures of baroreflex buffering with the use of a phenylephrine bolus (3.9 ± 0.8 versus 4.0 ± 0.7, trained versus untrained, \( P = 0.85 \)) and incremental infusion (2.8 ± 0.4 versus 2.5 ± 0.6, \( P = 0.67 \)) were similar in the two groups. Baroreflex buffering does not differ in endurance exercise–trained compared with untrained healthy men. These results support the concept that habitual vigorous endurance exercise does not modulate in vivo baroreflex buffering in healthy humans. (Hypertension. 2003; 41:194–200.)

Key Words: arterial pressure ■ autonomic nervous system ■ baroreflex ■ exercise ■ phenylephrine

The baroreflexes are an important mechanism by which the central nervous system controls arterial blood pressure (BP) through the autonomic nervous system. As part of this control, baroreflexes actively buffer the BP responses to pressor stimuli. Under such conditions, the increases in BP are determined by both the sensitivity of the vasculature to the stimulus (eg, adrenergic agonist) and the buffering capacity of the baroreflexes.1–5 Baroreflex buffering is reduced in patients with autonomic dysfunction and essential hypertension,6 and recently we demonstrated decreased baroreflex buffering with aging in healthy humans.7

Regular aerobic-endurance exercise is widely recommended as a lifestyle behavior for reducing the risk of cardiovascular and other chronic diseases.6,7 However, despite extensive investigation in both humans and experimental animals, the influence of habitual aerobic-endurance exercise on baroreflex function remains controversial. Efforts to date have focused either on certain characteristics of the reflex function or on measuring the sensitivity (responsiveness) of baroreflexes. The results of these studies are equivocal, with baroreceptor function variously reported as being augmented,8–13 not different12,14–19 or reduced,14,20–24 in healthy exercise-trained compared with untrained subjects.

Recently, Jordan and colleagues3,4 presented a novel experimental approach for determining baroreflex buffering in humans, which we have established in our laboratory.3 In this model, neurotransmission in the autonomic ganglia is interrupted pharmacologically with the use of trimethaphan, thus abolishing baroreflex modulation of cardiac output and vascular resistance in response to changes in BP evoked by an adrenergic receptor agonist. The magnitude of the increase in the BP response to phenylephrine during compared with before ganglionic blockade provides a measure of the in vivo buffering capacity of the baroreflexes. This approach may better characterize the in vivo physiological function of the baroreflexes rather than simply assessing heart period or sympathetic neural responsiveness to BP perturbations as in standard baroreflex testing. In the current study, we used this new method to determine if baroreflex buffering capacity differs in the aerobic-endurance exercise–trained compared with the untrained physiological states in healthy adult humans.

Methods

Subjects

Thirty-six nonobese men were studied: 18 endurance exercise-trained (41 ± 5) and 18 untrained (41 ± 4 years). Subjects were
normotensive (BP <140/90 mm Hg) nonsmokers who were not taking any medications. All were healthy, based on medical history, physical examination, urinalysis, blood chemistries, and ECG and BP at rest and/or in response to maximal exercise. The endurance-trained men were performing running, cycling, or combined triathlon exercise training at least 40 minutes per day, ≥4 days per week, continuously for the last 2 years, and were top finishers in local racing events. The untrained men had not performed any regular exercise for at least 2 years. All procedures were approved by the Colorado Multiple Institutional Review Board and the Human Research Committee, and written informed consent was obtained from all subjects.

Experimental Procedures
All procedures were performed in the University of Colorado General Clinical Research Center or in the Human Cardiovascular Research Laboratory as described in detail previously.25 Maximal oxygen consumption was measured by on-line computer-assisted open circuit spirometry during incremental treadmill exercise as oxygen consumption was measured by on-line computer-assisted use of the microneurographic technique, as described previously.2,27 multiunit recordings of muscle sympathetic nerve activity (MSNA) of heart rate. On a separate morning under fasting conditions, (25, 50, and/or 100 μg) and (b) 6-minute steady-state incremental infusions of phenylephrine (0.02, 0.04, 0.08, and 0.16 μg/kg per minute) were determined before and during ganglionic blockade (intravenous trimethaphan). The latter was established by absence of a change in heart rate in response to bolus injection of phenylephrine (25, 50, and/or 100 μg).

Baroreflex buffering was measured (a) as the potentiation of the systolic and mean arterial BP responses to a standard 25-μg bolus dose of phenylephrine (BRBbolus) during compared with before ganglionic blockade and (b) as the change in the slope of the increase in systolic and mean BP in response to the incremental infusion of phenylephrine (BRBslope) from baseline to ganglionic blockade, as described recently.3

Statistical Analyses
Differences between endurance exercise–trained and untrained subjects for baseline characteristics and baroreflex buffering were made with the use of t tests for independent group comparisons. BP responses to phenylephrine before and during ganglionic blockade were analyzed by means of a 2-way ANOVA with repeated measures [group×condition (baseline versus ganglionic blockade)]. Statistical significance was based on differences of P<0.05 or greater. All data are reported as mean±SEM.

Results
The endurance exercise–trained and untrained men did not differ in body mass (76.7±1.6 versus 79.8±2.1 kg), body mass index (24.2±0.4 versus 25.3±0.7), urinal sodium excretion (127±3 versus 123±2 mmol/d), or in baseline BP, BP variability, cardiovascual baroreflex sensitivity, or MSNA (Table). However, resting heart rate was lower and HRV and maximal oxygen consumption were higher in the endurance exercise–trained men (Table). During ganglionic blockade, heart rate and mean blood pressure changed similarly in the two groups (+16±2 versus +16±2 beats/min and −26±2 versus −22±2 mm Hg, P>0.4, trained versus untrained), resulting in baseline values during ganglionic blockade of 68±2 versus 76±3 beats/min and 60±2 versus 61±2 mm Hg, respectively (P>0.2).

The increases in systolic BP in response to phenylephrine were not different in the exercise-trained and untrained men before or during ganglionic blockade (left panels, Figures 1 and 2). BRBbolus (3.9±0.8 versus 4.0±0.7, trained versus untrained, P=0.9) and BRBslope (2.8±0.4 versus 2.5±0.6, P=0.67) were similar in the 2 groups (right panels, Figures 1 and 2). BRB values also were similar in the 2 groups when the mean BP responses to phenylephrine were used.

Discussion
In this study, we used an innovative experimental approach that takes advantage of the fact that the BP response to vasoactive drugs is mediated by the net effect of vascular sensitivity to the drug (+) and the counterregulatory actions of the baroreflexes (–). The increase in the BP response to phenylephrine during compared with before ganglionic

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### Cardiovascular-Autonomic Function During Supine Rest

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sedentary</th>
<th>Trained</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBP, mm Hg</td>
<td>123±2</td>
<td>127±3</td>
</tr>
<tr>
<td>SBP variability, SD</td>
<td>4.0±0.3</td>
<td>4.7±0.4</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>63±1</td>
<td>66±2</td>
</tr>
<tr>
<td>DBP variability, SD</td>
<td>3.2±0.3</td>
<td>3.1±0.2</td>
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<tr>
<td>HR, beats/min</td>
<td>59±2</td>
<td>52±1</td>
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<tr>
<td>VO2max, mL/kg per minute</td>
<td>39.5±2.6</td>
<td>51.0±1.8</td>
</tr>
<tr>
<td>HR variability, SD</td>
<td>55±8</td>
<td>73±8</td>
</tr>
<tr>
<td>HR variability, high frequency power</td>
<td>758±126</td>
<td>1347±184</td>
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<tr>
<td>Baroreflex sensitivity, R-R/SBP</td>
<td>17.9±2.9</td>
<td>13.4±2.6</td>
</tr>
<tr>
<td>MSNA, bursts/min</td>
<td>30±3</td>
<td>29±3</td>
</tr>
</tbody>
</table>

SBP indicates systolic blood pressure; DBP, diastolic blood pressure; SD, standard deviation; HR, heart rate; VO2max, maximal oxygen consumption; phe, phenylephrine; R-R, R-R interval between ECG R-waves; and MSNA, muscle sympathetic nerve activity.
blockade provides a measure of the in vivo buffering capacity of the baroreflexes. Using this approach, we established that there is no difference in BRB in endurance-exercise–trained and untrained healthy men.

Conventional assessments of baroreflex function are helpful for determining how (a) selective characteristics of the baroreflex (eg, gain; response range; saturation) or (b) heart rate and sympathetic neural responsiveness to baroreflex perturbations may differ between subject populations or physiological states. However, these experimental approaches do not provide direct insight into the effectiveness of the actual BP-buffering capacity of baroreflexes under normal in vivo conditions. The results of the present investigation provide the first such insight into the possible effects of habitual exercise on this function. Our findings support the idea that aerobic-endurance exercise training does not modulate the BP buffering capacity of the baroreflexes in healthy humans.

Because BRB does not differ in healthy endurance exercise–trained and untrained adults, one might postulate that neither would the BP responses to standardized sympathovagal system adrenergic stimuli. Our related observations are consistent with this concept. For example, we have demonstrated previously that BP responsiveness to both physiological stimuli such as experimental hypovolemia, isometric exercise, and limb immersion in cold water28,29 and pharmacological stimulation of α-adrenergic receptors30 are similar in endurance-trained and untrained healthy men.

There are at least two limitations of the current study that should be mentioned. First, because of safety concerns for human subjects, we did not determine BRB in response to reductions in BP evoked by administration of a vasodilating drug such as sodium nitroprusside. Ganglionic blockade reduces baseline BP to very low levels in certain individuals, and the addition of a vasodilator might prove harmful under these conditions. However, Jordan and colleagues4 observed the same group differences in BP responses and baroreflex buffering by using phenylephrine and sodium nitroprusside. Second, our results are limited largely to endurance exercise–trained and untrained healthy white men. There is no evidence to suggest differences in endurance-trained compared with untrained women or healthy adults varying in ethnicity. However, the current findings should not be generalized to other types of habitual exercise (eg, resistance training) or to patients with chronic cardiovascular or metabolic diseases.

**Perspectives**

Regular aerobic-endurance exercise is associated with enhanced physical work capacity (fitness) as well as reduced risk of developing chronic cardiovascular and metabolic diseases. As such, for many years, moderate to vigorous habitual exercise has been recommended by a variety of organizations with interests in public health including the American Heart Association.7 However, to those of us familiar with the cardiovascular exercise physiology scientific literature, there has been a lingering concern as to whether regular aerobic-endurance exercise causes problems with BP control mediated, at least in part, by impairment of baroreflex function.21,23,31,32 Cogent arguments have been made supporting31 and refuting32 this idea. Regular exercise of the type performed by most adults for fitness and health purposes does not appear to produce obvious detrimental effects on BP control. The results of our study are consistent with this observation, suggesting that even frequent and strenuous endurance exercise–training is not associated with an impairment in the in vivo buffering capacity of the baroreflexes in healthy humans. Thus, although some characteristics of baroreflex function may differ in the sedentary and endurance-trained states,8–14,20,22–24,31 our findings suggest that there should be no concern that adverse effects on baroreflex-mediated BP control will occur as a result of vigorous regular aerobic exercise in healthy adults.

**Acknowledgments**

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**References**


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