Effect of Long-Term Exercise Training on Blood Viscosity During Endurance Exercise at an Anaerobic Threshold Intensity

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Blood viscosity ($\eta_B$) is low in athletes, but the effect of exercise training on $\eta_B$ during endurance exercise at an anaerobic threshold (AT) intensity in non-athletes is not well known, although it is known that exercise training sometimes induces the hyperviscosity syndrome. Fourteen subjects were recruited and divided into 2 groups: those who trained at an AT intensity for 30 min/day, 3 times weekly for 1 year (Group T, n=8), and sedentary subjects (Group C, n=6). The test protocol consisted of a single 30-min treadmill exercise at each individual's AT intensity, which was determined in advance. The $\eta_B$, plasma viscosity ($\eta_P$), and hematocrit were measured just before and at the end of the treadmill exercise. The subjects were not allowed to drink any water before exercise. In the Group C subjects, the hematocrit and $\eta_B$ increased significantly and the $\eta_B$ tended to increase. However, in the Group T subjects, the hematocrit and $\eta_B$ did not increase and the $\eta_B$ decreased significantly. These data indicate that long-term exercise training attenuates the increase in blood viscosity during exercise.

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Key Words: Anaerobic threshold; Blood viscosity; Exercise training; Non-athletes

Exercise training is widely recommended for heart disease patients because it improves many coronary risk factors, as well as cardiovascular and skeletal muscle function. However, during long-term exercise, blood viscosity increases because of hemocoagulation as a result of fluid transfer from the blood to the interstitial spaces. Increased blood viscosity activates the platelets and injures the endothelial cells, the 'hyperviscosity syndrome' and the consequences of this cascade can be thromboembolism\(^1\) and myocardial infarction\(^2\).

Blood dilution is reported to occur in endurance athletes\(^3\) and the hematocrit and hemoglobin concentration of these athletes are usually lower than those in sedentary subjects. These changes may be an effect of exercise training and decrease the blood viscosity during exercise, but it is not well known what effect exercise training in non-athletes has on the exercise-induced increase in viscosity. The present study investigated the effect of endurance exercise training on blood viscosity during exercise at an anaerobic threshold intensity in non-athletes.

Methods

Subjects

Fourteen consecutive subjects who underwent an exercise test during the same time period were recruited. Eight subjects who had performed regular exercise training were enrolled into Group T (mean age, 55.1±14.6 years; F/M, 3/5). The underlying diseases were ischemic heart disease (n=4), dilated cardiomyopathy (n=1) and hypertension (n=1), and 2 subjects were normal volunteers. They had performed home-based walking exercise training at an anaerobic threshold (AT) intensity for 30 min/day, 3 times weekly for 1 year. Six subjects who did not have regular exercise were enrolled into Group C (mean age, 42.8±18.5 years; F/M, 3/3; ischemic heart disease (n=1), dilated cardiomyopathy (n=2), normal volunteer (n=3)). The exercise capacities of the participants are shown in Table I.

Four subjects in Group T and 2 in Group C were taking aspirin and anticoagulant drugs. There was no significant difference in the use of these drugs between the 2 groups (p=0.532).

Exercise Test

A cardiopulmonary exercise test was performed to obtain the AT for each individual. A treadmill ergometer (MAT 2100, Fukuda Denshi, Tokyo) and a breath-by-breath gas sampling system with a MINATO AE 280S (Minato Ika-gaku, Osaka, Japan) were used.

Protocol 3 min rest, 3 min warm-up at 0 W, then ramp exercise (10 W/min) was performed until exhaustion.

The AT was determined using the V-slope method\(^4\). After the first cardiopulmonary exercise test, subjects in Group T continued their home-based exercise training.

One year later, the cardiopulmonary exercise test was performed again to determine the AT. One week later, at the AT intensity, a 30-min constant work rate exercise was performed on the treadmill ergometer. All exercise tests were conducted in the same room maintained at the same temperature and humidity. None of the subjects were allowed to drink any water for at least 30 min before the test. Blood samples were collected just before (pre-exercise sample) and at the end (post-exercise sample) of the exercise test and kept at 37°C. The plasma hematocrit and blood

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viscosity were measured within 10 min.

Measurement of Blood Viscosity
The whole blood viscosity and plasma viscosity were measured using the Taniguchi-Ogawa blood viscometer, which has a vacuum glass suction tube needle.

Statistics
All data are shown as mean±SD. The paired Student's t test was used to compare the pre- and post-exercise blood samples. The unpaired Student's t test and the chi-square test were used to compare intergroup differences as appropriate. A value p<0.05 was regarded as significant.

Results

Exercise Tolerance
The baseline ATs of the study were 15.5±7.7 ml·min⁻¹·kg⁻¹ for Group T and 16.8±6.0 ml·min⁻¹·kg⁻¹ for Group C (NS). The AT increased significantly (p<0.05) after the training period in Group T, but decreased significantly (p<0.05) in Group C.

Because the mean age of the subjects in Group T was higher than in Group C, the AT was not significantly different between the 2 groups (Table I). However, when the AT was adjusted for the patient's age and gender, the %AT in Group T was significantly higher than in Group C (p<0.05).

The work rate at the AT increased significantly (p<0.05) after training in Group T (from 50.5±15.9 to 54.4±14.5 W). In Group C, it remained unchanged (from 49.2±17.9 to 43.2±16.9 W).

Hematocrit
The initial plasma hematocrit in Group T was not lower than in Group C. The plasma hematocrit increased significantly in Group C after the exercise test (p<0.01), compared with the pre-exercise samples, but was unaffected by exercise in the Group T subjects. The ratio of the plasma hematocrit before and after the exercise test was significantly different (p<0.05) between the 2 groups.

Whole Blood Viscosity
The whole blood viscosity tended to increase after exercise in Group C subjects compared with the viscosity before the exercise testing (p=0.076). In contrast, it decreased significantly (p<0.01) after exercise in Group T subjects. The ratio of the whole blood viscosity before and after exercise testing in Group T was significantly (p<0.01) lower than in Group C.

Plasma Viscosity
The plasma viscosity of the post-exercise testing samples in the Group C subjects was significantly (p<0.05) higher than that of the pre-exercise testing samples. In the Group

Discussion
This study demonstrates that endurance exercise training restrains the increase in whole blood viscosity and hemo-

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Table 1 Patients' Characteristics and Exercise Capacity

<table>
<thead>
<tr>
<th>Group</th>
<th>BH (cm)</th>
<th>BW (kg)</th>
<th>AT 1st (ml·min⁻¹·kg⁻¹)</th>
<th>AT 1st (%)</th>
<th>AT 2nd (ml·min⁻¹·kg⁻¹)</th>
<th>AT 2nd (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group T</td>
<td>167.0 (6.7)</td>
<td>59.4 (8.7)</td>
<td>15.5 (5.7)</td>
<td>100.8 (26.2)</td>
<td>16.9 (4.8)*</td>
<td>109.1 (19.9)*</td>
</tr>
<tr>
<td>Group C</td>
<td>164.0 (8.6)</td>
<td>52.8 (8.2)</td>
<td>16.8 (6.0)</td>
<td>90.0 (11.7)</td>
<td>16.5 (6.0)*</td>
<td>88.7 (13.7)*</td>
</tr>
</tbody>
</table>

p value: NS (0.239) NS (0.090) NS (0.373) NS (0.189) NS (0.443) 0.026

Mean (SD). *p<0.05 vs AT 1st: BH, body height; BW, body weight; AT, anaerobic threshold; AT 1st, AT obtained before the training period; AT 2nd, AT obtained after the training period.
concentration that normally occurs following 30 min of exercise at an AT intensity, which is the usual recommendation for heart disease patients. Exercise training at a higher intensity leads to sympathetic activation and excessive lactate production, which are undesirable consequences in cardiac patients. A 30-min exercise period is necessary to initiate fat metabolism, so we chose a 30-min exercise period at an AT intensity.

Two mechanisms explain the increase in the plasma hematocrit after exercise in Group C. One is exercise-induced hemococoncentration as a result of fluid transfer from the blood to the interstitial spaces. The other is the redistribution of red blood cells during exercise from the spleen to the circulatory system, which is regulated by the sympathetic nervous system. Because exercise training stabilizes sympathetic nervous activity, it is thought to decrease red blood cell release from the spleen and other organs. This effect of exercise might also be the explanation for the lack of any increase in the plasma hematocrit during exercise in Group T.

Whole blood viscosity is a function of the plasma hematocrit, plasma viscosity, and erythrocyte deformability. In Group C, the increase in whole blood viscosity during exercise might be ascribed to the rise in the plasma hematocrit. In contrast to Group C, the whole blood viscosity in Group T decreased during exercise, although neither the plasma hematocrit nor the plasma viscosity decreased significantly. The decrease in the whole blood viscosity might be related to improved erythrocyte deformability, which has been reported to be increased in well-trained athletes. The mechanisms responsible for the decrease in the blood viscosity in Group T are not clear and must be studied further.

The blood viscosity, plasma viscosity, and plasma hematocrit before the treadmill exercise in Group T were not significantly lower than those in Group C. It has been reported that the whole blood viscosity, plasma viscosity, and plasma hematocrit in top athletes are lower than those in sedentary people and the differences are assumed to be due to the intensity of the exercise training. The present subjects trained at an AT intensity and the duration of each training session was 30 min, whereas top athletes exercise much longer and more vigorously.

The work rate at the AT increased in Group T, so the training intensity would be lower than that of their actual AT just before the end of this study. However, we performed a second test and used the newly obtained AT for the collection of blood samples. Thus, the hematocrit, blood viscosity and plasma viscosity data relate exactly to the intensity of the AT.

Although there was no statistical difference in the patients' age, Group T subjects were older than those in Group C. Because blood viscosity tends to be high in aged subjects, the age difference must be considered if it affects the results. The viscosity of Group T subjects had been higher than that of Group C, we might consider that there had been some effect on our results, but since the Group T subjects were older we do not consider that age interfered with our results.

We have found that endurance exercise training of 30 min of treadmill exercise at an AT intensity can restrain the increase in the plasma hematocrit, blood viscosity, and plasma viscosity. This information may help in the development of exercise training programs for cardiac patients that have a lower risk of thromboembolic events than current programs.

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