Thigh and Calf Blood Flows after Isometric Contraction in Untrained and Trained Subjects

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Abstract The present study was undertaken to examine whether or not there were any differences between untrained and trained subjects in the changes of blood flow in the ipsilateral and contralateral lower limbs after isometric exercise. Blood flow of the thigh and calf in both right and left legs were measured simultaneously before and after isometric contraction with mercury-in-silastic strain gauge venous occlusion plethysmography. In the present study, the main pattern of blood flow responses in the active and non-active limbs was strikingly similar in all subjects: a significant fall in blood flow immediately after isometric contraction at a force of about 50% of maximal muscle strength for 15 sec was observed in the non-active lower limbs. Peak blood flow of the exercised thigh in the trained group was significantly higher than that in the untrained ones. From these results, it was suggested that higher blood flow after isometric exercise in the trained subjects may be due to the improvement of degree of vasodilation in the lower limb as a result of physical training.

Key Words: blood flow, thigh and calf, isometric contraction, trained and untrained subjects.

Isometric exercise evokes a potent cardiovascular reflex involving significant increase in heart rate, arterial blood pressure, cardiac output, and pulmonary ventilation (MITCHELL and WILDENTHAL, 1974). These features of the efferent limb of the isometric exercise reflex have been well characterized in the human subject; the redistribution of blood flow which occurs during and after exercise involving an alteration of blood flow to non-active parts of the limbs has been studied by several investigators (BISHOP *et al.*, 1957; BLAIR *et al.*, 1961; LIND *et al.*, 1964; BEVEGÅRD and SHEPHERD, 1966; ZELIS *et al.*, 1969; DELIUS *et al.*, 1972; MARK

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北村潔和, 島岡みどり, 松井秀治, 宮村実晴

et al., 1973; EKLUND *et al.*, 1974). They compared the blood flow of the contralateral limbs such as right and left forearm, or upper limb and lower limb. Recently, however, the question has been raised as to the blood distribution in active and non-active parts of the ipsilateral limb. In the previous study (KITAMURA *et al.*, 1980), thigh and calf blood flows in both the right and left legs were measured simultaneously after isometric contraction of right thigh muscle at a force of about 50% of maximal muscle strength for 15 sec. It was found that in the untrained subjects the thigh blood flow of the right leg increased immediately after exercise in all subjects, while the calf blood flow of the right leg decreased conversely in spite of the exercised ipsilateral leg. The purpose of this study was two fold; first, to confirm whether or not similar blood flow changes, which were observed in the previous study, were recognized even in the trained subjects, and secondly, to examine whether or not there were any differences between untrained and trained subjects in the changes of blood flow in the ipsilateral and contralateral lower limbs after isometric exercise.

METHODS

Twenty six healthy male subjects ranging in age from 19 to 22 yr. took part in the study. Thirteen of them were untrained students and thirteen trained subjects who trained regularly 2–3 hr daily 4 to 5 times a week in soccer, volleyball, badminton, and track and field teams of Nagoya and Toyama Universities. None of the untrained subjects had ever engaged in formal physical conditioning and they were generally considered to be sedentary. The average values of physical characteristics of both groups are shown in Table 1. No significant differences could be detected between the values of age, height, and weight between the two groups. All subjects gave their consent after the nature of the experiments had been explained.

The subjects came to the laboratory on at least two separate days. On the first day, each subject was briefly informed of the experimental procedure, and familiarized with equipment and testing procedures. The actual testing was conducted on the second day at a constant room temperature of 20–22°C for the untrained group and 22–23°C for the trained group. All experiments were always performed in the afternoon about 2 hr after lunch, and in a supine position with the limbs at heart level; after the subjects put on an undershirt with half-length sleeves and jogging trunks, they lay on a firm couch with their feet suspended from the ceiling as mentioned previously (KITAMURA *et al.*, 1980).

The load cell using the strain gauge was utilized to measure muscle strength of the right and left thighs; the experimenter lifted the right or left knee of the subject up a little as his foot left the suspension from the ceiling, and then the subject performed maximal isometric contraction so that he exerted force downward against the rising knee. This maximal strength test of right or left thigh was carried out

Table 1. Physical characteristics and muscle strength in untrained and trained subjects.

		Untrained (n=13)	Trained (n=13)	<i>p</i>
Age	(yr.)	19.5±0.8	20.0±1.4	n.s.
Height	(cm)	169.9±3.5	170.3±4.9	n.s.
Weight	(kg)	60.0±5.7	60.7±5.5	n.s.
MMS	(kg) R	26.8±9.9	37.0±5.6	<0.01
	L	26.0±11.3	35.3±6.0	<0.02
MS	(kg) R	15.0± 6.0	19.2±4.3	n.s.
	L	14.9± 7.2	18.2±3.1	n.s.
% MMS	(%) R	56.6±10.6	51.9±6.5	n.s.
	L	56.1± 5.6	51.8±6.1	n.s.

Values are mean and $\pm$ S.D. *n*, number of subjects; MMS, maximal muscle strength; MS, muscle strength as contracted at about 50% of maximal muscle strength; % MMS, MS/MMS $\times$ 100; R, right thigh; L, left thigh.

for a duration of about 5 sec by each subject at the start of experiment. Absolute values of maximal muscle strength (MMS) ranged from 15.0 to 45.0 (mean 26.8) kg for the right thigh and from 15.3 to 50.0 (mean 26.0) kg for the left thigh in the untrained group. In the trained group, it was from 23.0 to 44.0 (mean 37.0) kg for the right thigh and from 27.0 to 45.0 (mean 35.3) kg for the left thigh. MMS of the right and left thigh was significantly ($p < 0.01-0.02$) higher in the trained group than that in the untrained group (Table 1). Thirty minutes were then allowed before contraction was performed with the right thigh at about 50% of maximal muscle strength: after the resting control period, the subject started to contract the thigh for 15 sec. The strength of the contraction was displayed on the pen-recorder, so that the subject could observe his own level of tension exertion. The subject was also required to remove or minimize any muscular contraction in his non-active leg during contraction on the right thigh. The same isometric exercise test was conducted with the left thigh after 30 min of the right thigh experiment.

Blood flow of the thigh and calf in both the right and left legs were measured simultaneously before and after isometric contraction with mercury-in-silastic strain gauge venous occlusion plethysmography (WHITNEY, 1953). Four strain gauges, under tension of 25 g were wound lightly around the maximal circumferences of the calf and thigh, respectively. In order to occlude venous blood flow in the leg, both right and left femoral vein were pressed simultaneously by 2-3 kg/cm² pressure on the anterior surface of the femoral triangle near the sulcus inguinalis as reported previously (MATSUI *et al.*, 1978b). The strain gauge was balanced at a tension of 25 g, and calibrated with a micrometer before and after experiments.

The blood flow in the resting condition was measured 4 times at 1 min intervals. Measurement of the postexercise blood flow was taken as quickly as possible after exercise (within 10 sec), and then in about 20 sec intervals until 1 min of recovery.

After 30 min, isometric exercise was performed with the left thigh at a force of about 50% of maximal muscle strength for 15 sec, and blood flow was measured using the same technique as described above.

The data were treated statistically by means of Student's *t*-test, and significance was established at a 0.05 level of confidence.

RESULTS

Mean values and standard deviations for the muscle strength (MS) of right and left thigh were 15.0 ± 6.0 and 14.9 ± 7.2 kg for the untrained group and 19.2 ± 4.3 and 18.2 ± 3.1 kg for the trained group when the subject contracted at about 50% of maximal muscle strength. These values corresponded to 56.6 ± 10.6 and $56.1 \pm 5.6\%$ for the untrained group, and 51.9 ± 6.5 and $51.8 \pm 6.1\%$ for the trained group as expressed in percentage of maximal muscle strength ($\% \text{ MMS} = \text{MS}/\text{MMS} \times 100$). There are no significant differences in the $\% \text{ MMS}$ between untrained and trained groups as shown in Table 1.

Figure 1 shows actual plethysmographic trace of the thigh and calf in both right and left legs during and after a period of isometric contraction. Figure 2 indicates the blood flow of the thigh and calf in the right and left legs before and after isometric exercise with right or left thigh exerting a force of about 50% of MMS for 15 sec, and it was expressed in percentage of its value at rest in Fig. 3. The values of mean and standard deviation for the resting blood flow of the thigh and calf in the untrained group were 4.38 ± 1.85 and 3.86 ± 1.75 ml/(100 ml·min) for the right leg, and 4.34 ± 1.61 and 3.49 ± 1.11 ml/(100 ml·min) for the left leg, respectively. The difference in the resting values for the two legs were not signif-

Fig. 1. Actual plethysmographic traces of the thigh and calf of both right and left legs after isometric contraction of the right thigh at the force of about 50% of maximal muscle strength in the case of subject K.Y. Arrows indicate the starting point of venous occlusion.

Fig. 2. Thigh (TBF) and calf blood flow (CBF) in both right and left legs after isometric contraction of the right (left panel) and left (right panel) thighs. Open and closed circles represent mean values ($\pm$ S.D.) of the untrained and trained groups, respectively. Significance level indicated by the asterisks for differences between trained and untrained groups. * $p < 0.05$, ** $p < 0.01$.

icant. It was also found that in the trained group average values for the resting blood flow of the thigh and calf were 3.54 ± 0.91 and 2.30 ± 0.58 ml/(100 ml $\cdot$ min) for the right leg, and 3.38 ± 0.54 and 2.43 ± 0.77 ml/(100 ml $\cdot$ min) for the left leg, and the differences in the resting blood flow for the legs were again not significant. Furthermore, there are no significant differences between untrained and trained groups in the resting blood flow of the thigh and calf.

When the subject performed isometric contraction with the right thigh, blood flow of the thigh and calf in the non-active parts of limb were decreased significantly ($p < 0.05-0.01$) immediately after exercise in all subjects: mean $\pm$ S.D. for the blood flow immediately after exercise in the left thigh and left calf were 2.21 ± 1.36 and 1.69 ± 1.17 ml/(100 ml $\cdot$ min) for the untrained, and 1.90 ± 1.09 and 1.77 ± 1.09 ml/(100 ml $\cdot$ min) for the trained group, respectively. These values corresponded to 48.1 ± 19.1 and $45.3 \pm 20.6\%$ for the untrained group, and 58.5 ± 31.5 and $68.3 \pm 22.2\%$ for the trained group as expressed in percentage of its value at rest. This was followed by a quick return toward the resting level in about 30 sec.

It was observed that immediately after exercise of right thigh the calf blood flow in the active (right) limb significantly ($p < 0.05-0.01$) decreased in all subjects

Fig. 3. Thigh and calf blood flow in both right and left legs after isometric contraction of the right (left panel) and left (right panel) thigh. Values are expressed as percentage of the value at rest, and all abbreviations are same as in Fig. 2.

in spite of having exercised the ipsilateral leg, while blood flow of the right thigh was increased significantly ($p < 0.01$) as compared with rest. Moreover, an interesting finding of the present study was that peak blood flow of the exercised thigh in the trained group was significantly ($p < 0.05$) higher than that in the untrained group, but not in the calf blood flow of the right leg. A similar pattern was observed in all subjects when the subject performed isometric contraction with the left thigh as shown in Figs. 2 and 3.

DISCUSSION

In the present study, blood flow of the thigh and calf both in the right and left legs were measured simultaneously with venous occlusion plethysmography.

In order to occlude venous blood in the leg and to obtain the most prominent volume change, the compression points were marked with black ink on the femoral triangle near the sulcus inguinalis and were compressed at a magnitude of 2–3 kg/cm² pressure each time with a pressing apparatus made of a block of stiff rubber including strain gauge. We have compared calf blood flow by two methods in order to confirm the reliability of our venous occlusion press method, because the flow of blood in the vena saphena parva could not be occluded when using the press method applied here: in one, venous occlusion was obtained by using a cuff as described by WHITNEY (1953), while in the other, venous occlusion was obtained by the method used in this experiment. The values obtained by the two methods were almost the same (MATSUI *et al.*, 1978a). These results seem to indicate that blood flow in the vena saphena may be so low as to be negligible. Furthermore, it was found in the previous study (MATSUI *et al.*, 1978b) that the values for blood flow in the thigh obtained after maximal treadmill and bicycle exercises agreed well with the data of previous authors (CLAUSEN and LASSEN, 1971; BONDE-PETERSEN *et al.*, 1975). However, the reliability of the measurement of thigh blood flow using our press method will require further investigation.

In the present study the main pattern of blood flow responses in the active and non-active limbs was strikingly similar in all subjects, while there was some individual variation: a significant fall in blood flow immediately after isometric contraction at a tension of about 50% of maximal muscle strength for 15 sec was observed in the non-active lower limbs. As shown in Figs. 2 and 3, it was found that immediately after exercise the calf blood flow of the right or left leg decreased in both untrained and trained subjects in spite of having exercised the ipsilateral leg. It is well known that carbon dioxide pressure (P_{aCO_2}), hydrogen ion (H^+), lactate, and temperature in the arterial blood increase by exercise (DEJOURS, 1964). Since blood flow change in the non-active part is very fast, however, the reason for the decrease of blood flow in the non-active lower limbs after exercise seems to be a result of another nervous reflex rather than vasoconstriction *via* vasomotor center from peripheral chemoreceptors as consequence of increment of P_{aCO_2} , H^+ , and lactate in the blood. At present no definite explanation for the decreased blood flow in the non-active limb obtained here can be presented on definite physiological grounds.

RICHARDSON (1981) has determined calf muscle blood flow before, during and after static calf muscle contraction at 7.5, 15, and 30% of their maximum voluntary contractile strength for a period of 2 min, and demonstrated that at even small forces of contraction a sizable portion of the total flow response occurs in the postcontraction period. In these experiments, the blood flow in the exercised right thigh increased immediately after isometric exercise with the right thigh for 15 sec and the same tendency was observed in the left thigh when the subject performed the exercise with left thigh (Figs. 2 and 3). These results basically agree with data of HUMPHREY and LIND (1963), KONTOS *et al.* (1966), and RICHARDSON

(1981). We have no evidence to show whether or not the metabolites or hormones act directly upon intrinsic neurons as described by HONIG and FRIERSON (1976) and LIND and WILLIAMS (1979). Thus, it appears difficult to account for the reason why blood flow of the thigh increases immediately after isometric exercise despite a decrease of calf blood flow in the ipsilateral lower limb. This increment of thigh blood flow could be explained by a balance of two competitive factors: one is vasoconstriction, and the other is vasodilation; if vasoconstriction by the vasomotor center exists in the exercised right thigh, the increase of blood flow in the right thigh after exercise appears to be due to the vasodilation in the working muscle because of the rise of Pa_{CO_2} , H^+ , and temperature acting directly on the vessels as vasodilation. In other words, it is possible to assume that vasodilation tone in the exercised thigh may be higher than that of the vasoconstrictor. However, the possibility mentioned above needs further investigation.

On the other hand, the effects of training on the blood flow in the lower limbs during or after rhythmic exercise at a given work load has been studied mainly in young subjects. The lower blood flow during submaximal exercise or depressed post-exercise hyperemia was observed in the calf of trained subjects in comparison with untrained ones (ELSNER and CARLSON, 1962; VARNAUSKAS *et al.*, 1970; PHILIPPI *et al.*, 1973; SAITO *et al.*, 1980). These results suggest that training brings about a more effective utilization of the available leg blood flow for metabolic processes even at a lower flow. However, an interesting finding of the present study was that peak blood flow of the exercised thigh in the trained group was significantly ($p < 0.05$) higher than that in the untrained group as shown in Figs. 2 and 3. The reasons for the difference in the peak blood flow between two groups may be explained by a few possible factors: 1) decrease in the vascular resistance; 2) sensitivity of the arterial vasculature to blood occlusion; or 3) any combination of these factors (LAUGHLIN *et al.*, 1978). It has been reported by LIND *et al.* (1964) and DONALD *et al.* (1967) that during sustained hand-grip contractions, the amount of blood flowing through the forearm decreased as the tension increased, and the blood flow would be completely occluded when the tension was greater than 70% of maximal muscle strength. KROESE (1977) and ROMANOVSKA *et al.* (1981) found significantly higher postischemic blood flow and lower resistance in the calf, which was produced by 3 or 5 min blood occlusion, in the trained athlete compared with the untrained one. Although blood flow of the exercised thigh was considered to be occluded considerably, the amount of occluded blood in this experiment seems to be almost the same because there are no significant differences in the exercise time and % MMS between the two groups. From these results, it was suggested that peak blood flow immediately after isometric exercise in the trained may be due to the improvement of degree of vasodilation in the lower limb as a result of training.

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