Changes in blood flow of common carotid artery due to physical exercise by means of ultrasonic measurement

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Abstract

The purpose of the present study was to shed some light on the blood flow of the head during exerise by observation of blood flow of common carotid artery, which should be related with the cerebral blood flow. The observation of changes in common carotid artery blood flow was made by an ultrasonic quantitative measurement system (QFM), and non-invasive measurements could be made on blood vessel diameter, blood flow velocity and blood flow rate, and a microcomputor was used in analyses of wave patterns and calculations. Moreover, continuous recording of ECG and pulse wave at the ear lobule were simultaneously made through the each experiment. The exercise was 10min running on a treadmill of 5.2% inclination and the speed of running was step-wise increase from 160m/min to 200m/min equally in each of 11 male subjects whose ranged from 18 to 24 years.

The observation evidenced a significant increase in blood flow of common carotid artery, which probably resulted in increase in blood flow of internal as well as external carotid artery. Then, it was presumed that the increase in blood flow of common carotid artery during exercise would result in an increase in blood flow of the skin and soft tissues of the head through internal as well as external artery and the increase as such would be a partial phenomenon of blood flow redistribution during exercise.

KEY WORDS : *Common carotid artery, Blood flow, Ultrasonic measurement, Exercise*

Introduction

Sufficient blood flow of active muscles is an important factor for endurance exercise to meet the need of sufficient supply of oxygen and nutrients as well as the transportaion of carbon dioxide and other metabolites, because the metabolism in the active muscles is accelerated by the exercise. However, the total blood volume in the body is almost constant. Therefore, there is needed not only an increase in cardiac output, but also somewhat restriction of blood flow to the inactive organs in order to attain the sufficient blood flow to the active muscles. Such a redistribution of peripheral blood during physical exercise is considered to be a reasonable compensatory response for physical activity, and physiological studies on this problem have been made heretofore by many scientists (Wade and Bishop, 1962 ; Rowell, 1974 ; Barnard et al., 1980). The present study was made for the purpose of shedding some light upon the above-mentioned compensatory redistribution of peripheral blood flow, especially the changes in blood flow during exercise through common carotid artery which might be related with the cerebral blood flow.

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Method

The apparatus adopted in the present study is called "Ultrasonic Quantitative Blood Flow Measurement System (QFM)", and the changes in the diameter, velocity of blood flow and blood flow rate of common carotid artery can be measured non-invasively and quantitatively with this apparatus. Determination is made by analysis of pulse waves and calculation with a microcomputer in the apparatus, and the results of calculation are given as printed records. The recordings of ECG and plethysmography of pulse wave at the ear lobule were made simultaneously with the measurements by QFM.

The exercise imposed upon the subjects was 10min running on a tradmill of 5.2% inclination and, regarding the speed of running, step-wise increasing method from 160m/min to 200m/min. The intensity of the exercise as such was regarded as near the upper limit of moderate work for the subjects from the view-point of their physiological responses such as heart rate. The measurements of blood flow rate were made just after the exercise and repeated in 15min thereafter in recumbent posture.

As the subjects served 11 healthy young men of 18-24 years of age (18.9 years on the average), and it was ascertained that they had no appreciable disorder by medical check, especially on the circulatory function.

Results

The heart rate was 197.6 beats/min on the average at the end of exercise and 170.6 beats/min just after the exercise. The heart rate as such seemed to suggest that the exercise beats was near the upper limit of moderate work for the subjects from the view-point of physiological load. The amplitude of pulse wave at the ear lobule showed significant increase due to exercise, although there was noted considerable individual differences. The level in 1-2 min after the exercise was 40-80% higher than that at rest.

The blood flow rates of common carotid artery in each subject at rest before exercise, just after exercise and in the recovery stage are shown in Figure 1. The wave forms illustrated in the diagram show the changes in blood flow rate per one heart beat in each stage, calculated from the mean accumulative value of 5 heart beats. The figures in the diagram mean the heart rate in each stage. As seen in the diagram, the blood flow rate just after the exercise is highest, and the peak in systolic phase is markedly higher than the values at rest before exercise and in recovery stage.

Figure 2 shows the mean and standard deviation of blood flow rates of all the subjects calculated from wave forms in systolic phase, in the stage of mean blood pressure and in diastolic phase. The systolic value of blood flow rate of common carotid artery at rest was 23.37 ± 1.05ml/sec, the value in the stage of mean blood pressure was 7.53 ± 0.57 ml/sec and the diastolic value was 3.85 ± 0.52ml/sec.

The maximun flow rate at the systolic phase was 40.10 ± 4.34ml/sec, viz., 70% higher than that at rest, and the average flow rate in the stage of mean blood pressure was 14.22 ± 4.41ml/sec, viz., 85% higher than that at rest. The diastolic value just after the exercise was

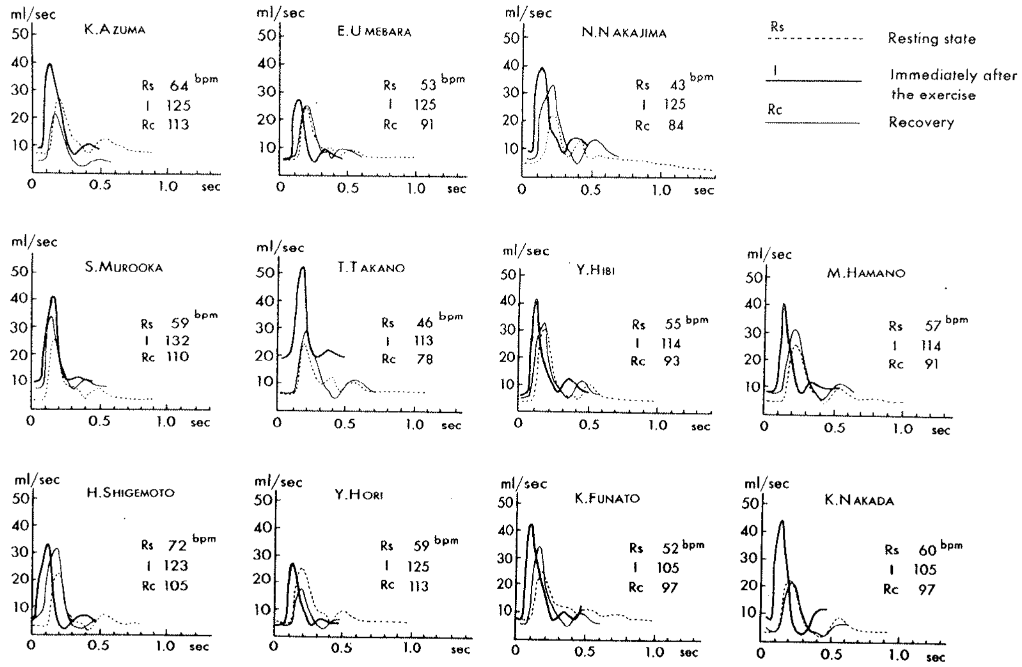

Fig.1. Changes in blood flow pattern of common carotid artery at rest, immediately after the treadmill exercise and in recovery stage.

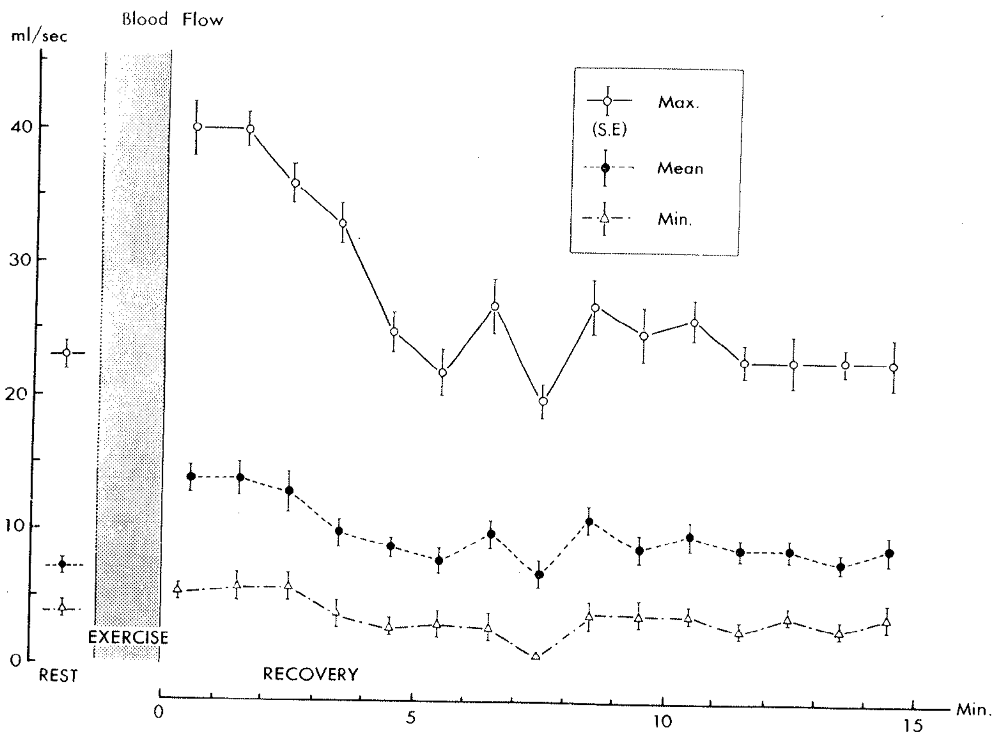

Fig.2. Changes in blood flow of common carotid artery due to the treadmill exercise.

5.51 ± 0.42ml/sec (higher by 43% than that at rest). However, these values decreased rapidly in 3 min after exercise, and the systolic value recovered the resting level in 11 min after exercise.

The maximum velocity of common carotid artery blood flow was 82.04 ± 4.89cm/sec just after the exercise, viz., 40% higher than 58.77 ± 1.91cm/sec at rest as seen in Figure 3. The average velocity in the stage of mean blood pressure was 32.91 ± 2.89cm/sec just after the exercise, viz., 63% higher than 20.16 ± 0.87cm/sec at rest.

The simultaneous observation at that time evidenced that the diameter of common carotid artery was 7.52 ± 0.31mm just after the exercise and 6.89 ± 0.18mm at rest. Namely, the increment due to exercise as seen in Figure 4 was about 9% of that at rest.

The blood flow rate, blood flow velocity and diameter of common carotid artery, respectively showed a significant positive correlation with the heart rate in the above-mentioned changes due to exercise. The correlation coefficient between average blood flow rate and heart rate as seen in Figure 5 was $r = 0.891$ ($P < 0.001$), that between average blood flow velocity and heart rate being $r = 0.674$ ($P < 0.01$) and that between average vessel diameter and heart rate being $r = 0.765$ ($P < 0.001$).

Figure 6 shows the relationship between the blood flow rate and the diameter of common carotid artery. In this diagram are plotted the values of all the subjects, and a significant

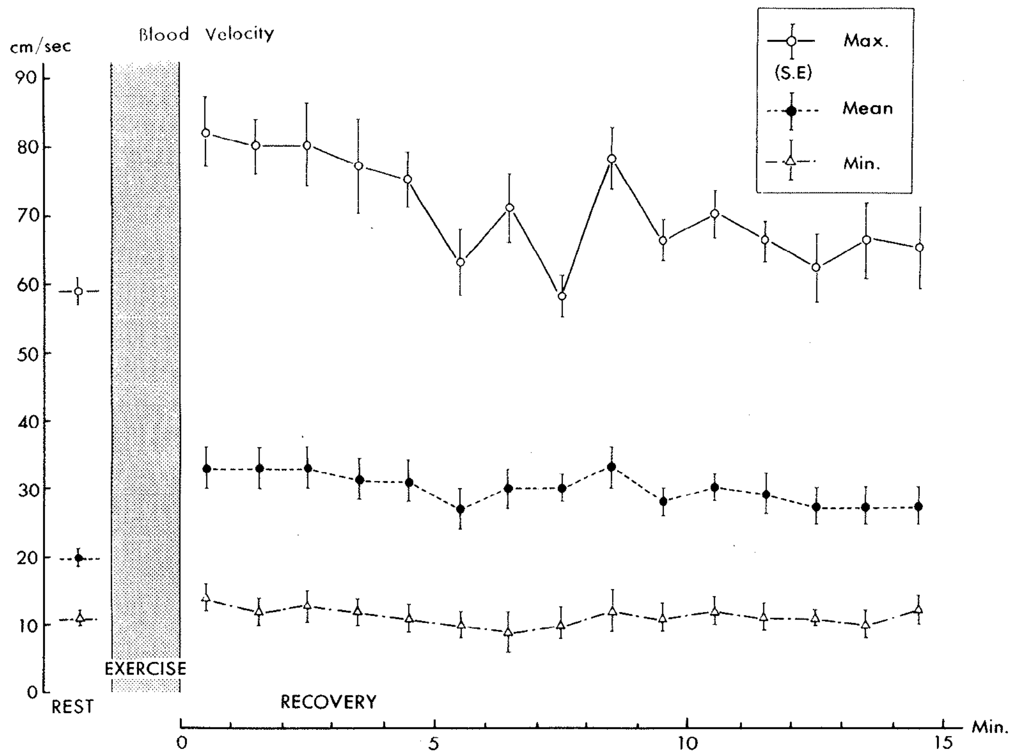

Fig.3. Changes in blood flow velocity of common carotid artery due to the treadmill exercise.

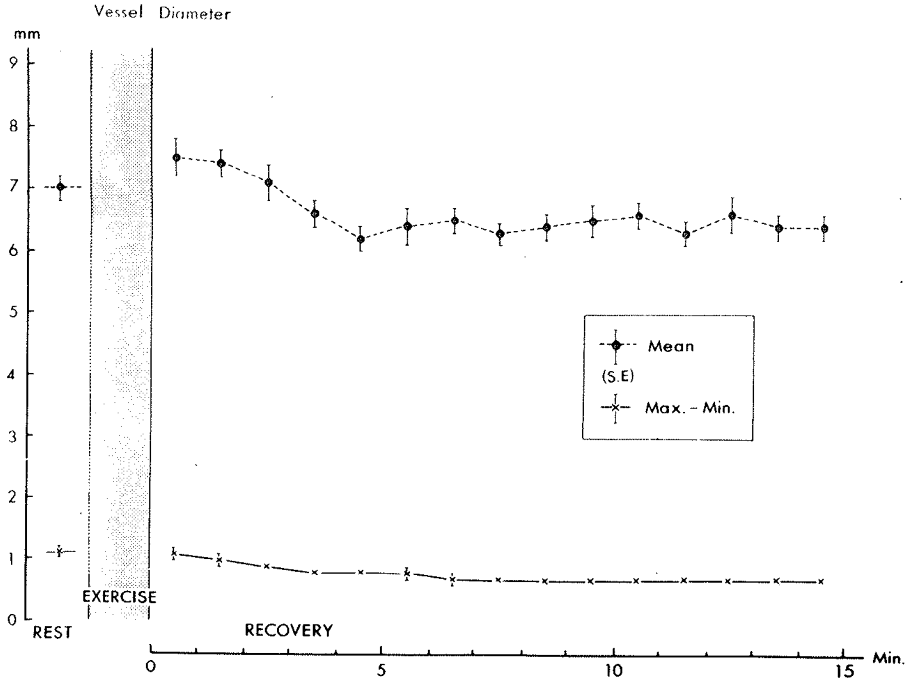

Fig.4. Changes in diameter of common carotid artery due to the treadmill exercise.

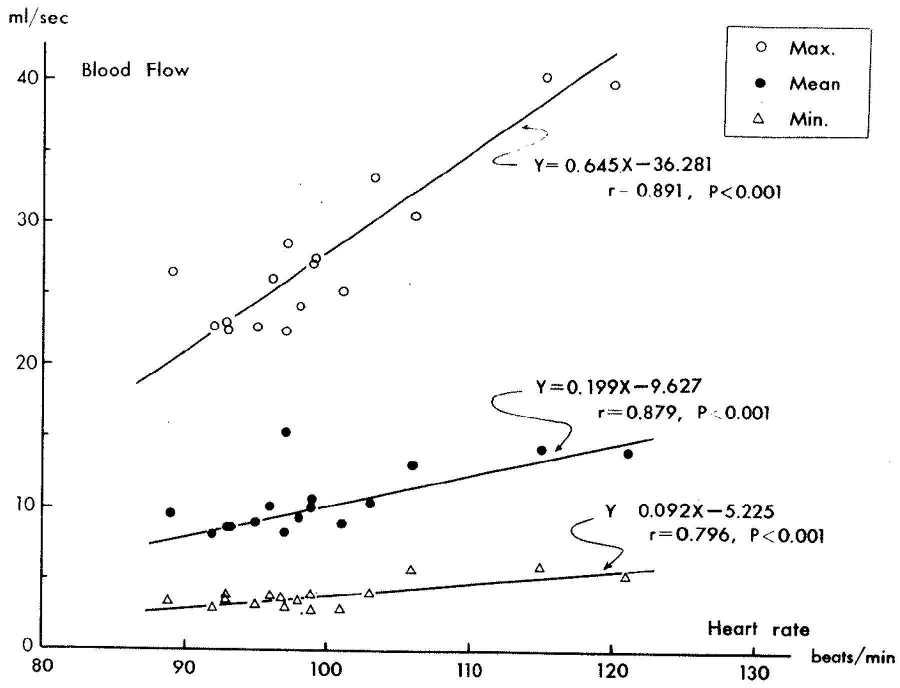

Fig.5. Relationship between blood flow of common carotid artery and heart rate after the treadmill exercise.

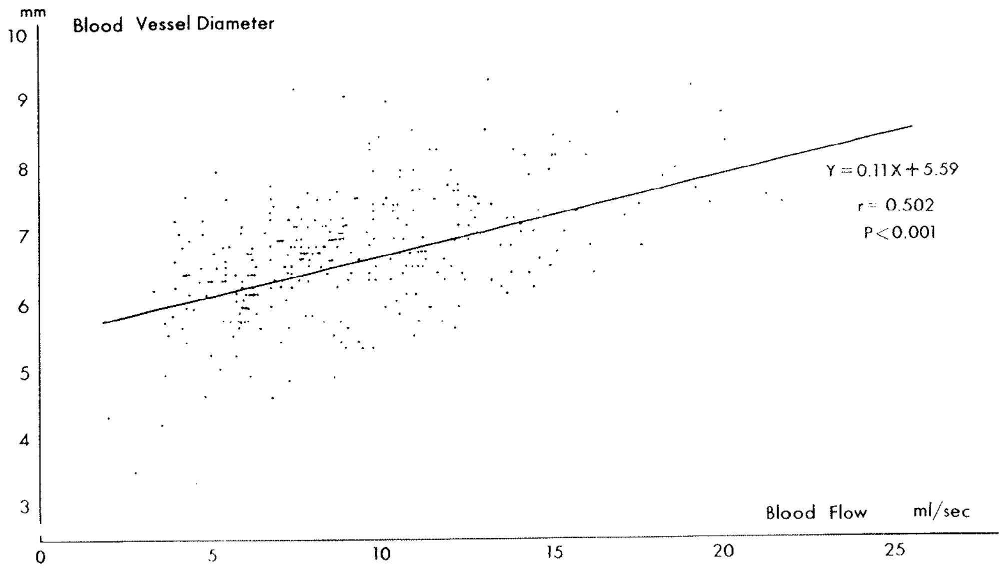

Fig.6. Relationship between blood flow and the diameter of common carotid artery after the treadmill exercise.

correlation was noted between them ($r = 0.502, p < 0.001$). There was also noted a significant correlation between the blood flow velocity and the blood flow rate ($r = 0.734$, $p < 0.001$). That is to say, when the blood flow rate, the blood flow velocity and the diameter of common carotid artery were measured with an intension to observe the acceleration of circulatory function due to physical exercise, there was noted a significant correlation between each two of them.

Regarding the amplitude of pulse wave, which was measured on the same side to the common carotid artery, presented also a significant correlation with the maximum blood flow rate ($r = 0.723$, $p < 0.001$), the average blood flow rate ($r = 0.613$, $p < 0.02$), and the minimum blood flow rate ($r = 0.559$, $p < 0.05$), respectively.

Discussion

The marked increase in blood flow rate of common carotid artery just after exercise in comparison with the resting value seems to suggest the increase in blood flow rate during exercise, and this fact also suggests the increase in blood flow rate of internal as well as external carotid artery. Samnegard et al. measured by electromagnetic method the blood flow rate of internal carotid artery during bicycle ergometer exercise in sitting and recumbent postures and noted increases of 10-15% due to exercise in the both postures and they reported that the heart rate at that time was in the range of 110-130 beats/min (Shephard and Vanhouette, 1979). Olesen also observed an increase in blood flow rate of internal carotid artery due to exercise of upper arm and he considered that the finding as such would be related with an increase in cerebral blood flow rate to meet the accelerated metabolism in the brain. (Rowell, 1974). However, Wade and Bishop (1962) reported that physical exercise caused no significant increase in cerebral blood flow and oxygen consumption of the brain. Scheinberg et al. (1954) also reported that the cerebral blood flow during treadmill walking showed marked individual differences among the subjects, namely, decrease in a half of them and increase in other half of them. Hedlund et al. (1962) observed an increase in cerebral blood flow rate by 18.5%, an increase in cardiac output by 77%, an increase in heart rate by 57% and an increase in arterial blood pressure by 21% in comparison with resting values, when they imposed on the subjects 5-10min bicycle ergometer exercise of 255-350 KPM in recumbent posture.

The cerebral blood flow is usually controled by the regulatory function of cerebral blood vessels to keep an adequate blood flow rate. However, their regulatory mechanism in case of intensive physical exercise, where the respiro-circulatory functions are markedly, accelerated, should be considered scrupulously as another point of discussion (Shephard and Vanhouette, 1979 ; Shibayama et al. 1983). Hedlund et al. (1962) emphasized in his discussion on the regulation of cerebral blood flow that the cerebral blood flow rate was not related with cardiac output and also with the rise in arterial blood pressure, and there might be an effective function of regulatory mechanism of cerebral blood flow during exercise. If it is assumed that the cerebral blood flow is kept constant even during exercise, the changes in blood flow of internal carotid artery, which would be influenced by the increase in blood flow of common carotid artery, might be another point of discussion.

The ophthalmic arteries, which are branches of internal carotid artery, is related with the blood flow of the forehead, especially the blood flow of the forehead skin, because there are only meager muscles. Rowell (1974) and Ebashi and Shibayama (1977 and 1981) observed that the skin temperature at the forehead, which is closely related with the blood flow of the skin, would rise appreciably after exercise in order to dissipate the body heat produced by exercise. In this respect, it is presumed that the increase in blood flow rate of internal carotid artery, which is related with the blood flow of ophthalmic artery, seems to be reasonable, even if the increase in cerebral blood flow rate is not needed.

Of course, it is difficult to presume the changes in cerebral blood flow rate only on the basis of changes in blood flow rate of common carotid artery, but the latter might give little influence upon the cerebral blood flow rate, and it is generally accepted that the cerebral blood flow rate is kept fairly constant by the regulatory function of cerebral blood vessels and also by regulatory function of carotid sinus reflex to keep constant perfusion pressure of the brain. On the other hand, the increase in blood flow rate of common carotid artery must cause the increase in the blood flow rate of external carotid artery, too. The blood flow of the face, the cranial wall and the ear lobule is supplied by external carotid artery. The increase in amplitude of pulse wave at the ear lobule during and after exercise in comparison with the resting value was closely related with the increase in blood flow rate of common carotid artery (Ebashi et al. 1986). This fact seems to suggest the blood flow rate of the ear lobule, which would result from the blood flow rate of external carotid artery. Reneman (1974) observed with ultrasonic blood flow measurement system an increase in blood flow rate of common carotid artery, imposing treadmill exercise on a dog. However, his observation was made on the blood flow rate of internal and external carotid arteries separately, and he presumed that the increase in blood flow rate of common carotid artery was mostly related with the blood flow of external carotid artery, and, accordingly, with the increase in blood flow of soft tissues of the head.

As above-mentioned, the observation evidenced a significant increase in blood flow of common carotid artery which might result in increase in blood flow of internal as well as external carotid artery. However, no reliable finding could be obtained concerning the cerebral blood flow, which seems to depend on the blood flow of internal carotid artery, and considerations on the basis of conventional knowledge of regulation mechanism of cerebral blood circulation led the present authors to the presumption that the cerebral blood circulation would not be markedly augmented by physical exercise. Accordingly, it was presumed that the increase in blood flow of common carotid artery during exercise would result in an increase in blood flow of the skin and soft tissues of the head through internal as well as external artery and the increase as such would be a partial phenomenon of blood flow redistribution during exercise.

総頚動脈血流量の身体運動にともなう変動

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活動筋への血流を補償する運動時の血流再分布の機序を明らかにする研究の一環として，末梢血流，とくに脳血流を含む経頚動脈血流量を観察し，身体運動にともなう頭部の血流動態を明らかにしようとした。総頚動脈の血流変化は，超音波を用いたＱＦＭ法により，血流量，血流速度および血管径を無侵襲的，かつ定量的に測定した。総頚動脈血流の観察と同時に心電図および耳朶脈波を全経過にわたって連続的に記録した。運動負荷は，5.2％傾斜の10分間の treadmill 走とし，走行速度は負荷漸増法とした。被検者は18～24才の健康な青年男子11名である。

運動時心拍数は平均197.6拍／分に達し，運動終了直後でも平均170.6拍／分という高い生体負担を示した。運動終了直後に観察した総頚動脈血流量は収縮期に，安静時の23.37±1.05mℓ/sec にたいして70％の増加率を示した。最大血流速度も運動により，安静時の40％増加となり，また総頚動脈血管径は安静時に比し９％の増加率であった。身体運動にともなう総頚動脈血流量，血流速度，血管径の各変化と心拍数増加あるいは脈波振幅増高との間にはいずれも有意の正相関が認められ，運動時には総頚動脈血流量の有意の増加が推察された。このことは内頚動脈，外頚動脈血流量とも増加したことを示唆しており，脳循環調節機構の生理的特性を考慮に入れてもなお，運動時における血流再配分は，頭部末梢血流量の著明な増加をもたらすものと推定された。

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