Relationship between core temperature and skin blood flux in lower limbs during prolonged arm exercise in persons with spinal cord injury

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Abstract The purposes of the present study were to examine the response of the skin blood flux (SBF) in the paralyzed lower limbs of persons with spinal cord injury (PSCI) and to clarify the relationship between the SBF and core temperature during prolonged arm exercise. Eight male PSCI with lesions from T6 to L5 and six male control subjects (CS) participated in this study. The subjects rested for 60 min and then performed arm-cranking exercise at 20 W for 30 min at 25 °C. The tympanic membrane temperature ($T_{em}$) and SBF in the anterior thigh (SBFT) and in the posterior calf (SBFC) were continuously measured throughout the experiment. The SBFC did not change in either PSCI or CS during the experiment. The SBFT in four PSCI with high lesions (T6 to T12), remained unchanged during exercise. The SBFT in the other four PSCI with low lesions (T12 to L5, $ASBFT^+$) began to elevate markedly when the $T_{em}$ exceeded a threshold temperature of 36.69 °C. The pattern of increase of SBFT in $ASBFT^+$ was similar to that in CS, although onset of the increase in SBFT was delayed and the peak of SBFT during exercise was significantly lower in comparison with the CS. We consider that these differences between the $ASBFT^+$ and CS were largely attributable to the lower $Z_{em}$ in the former group, which took a prolonged time to reach the threshold of 36.69 °C.

Key words Prolonged arm exercise · Spinal cord injury · Tympanic membrane temperature · Skin blood flux · Paralyzed lower limbs

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Introduction

In our previous study (Muraki et al. 1995), we have investigated the response of skin blood flux (SBF) in the paralyzed lower limbs in persons with spinal cord injury (PSCI) during arm-cranking exercise for 6 min at various exercise intensities. That study has demonstrated that SBF at the thigh (SBFT) in PSCI with a lesion at L1 or below significantly increased with the increase in oxygen uptake ($\dot{V}O_2$) and heart rate (HR). In PSCI with a lesion at T12 or above, however, SBFT was unchanged, irrespective of the exercise intensity. Based on these results, we have speculated that the PSCI with supra-T12 lesions had lost the sympathetic vasodilatation response in the skin at the anterior thigh.

In able-bodied subjects, it has been confirmed that an elevation of core temperature ($T_c$) promotes SBF in inactive areas during exercise (Johnson and Rowell 1975; Wenger et al. 1975; Kenney and Johnson 1992). On the other hand, it is possible that SBFT in PSCI with high lesions (above T12) would not increase during arm exercise even when $T_c$ shows sufficient elevation, since in these PSCI the sympathetic vasodilatation of the lower limbs has been shown to be past (Normell 1974). To test this hypothesis, it is necessary to examine the relationship between $T_c$ and SBFT in PSCI with high lesions.

In addition, our previous study (Muraki et al. 1995) has also demonstrated that PSCI with lesions below L1 showed lower SBFT at a given $\dot{V}O_2$ and HR than able-bodied subjects at a constant ambient temperature ($T_a$) of 25 °C. It has been reported that in able-bodied subjects, the cutaneous vasodilatation begins to show a marked increase when the $T_c$ reaches a certain threshold (Hammel et al. 1963; Johnson and Rowell 1975; Johnson and Park 1981; Kellogg et al. 1991). In PSCI, however, it has been shown that $T_c$ is easily affected by a change in $T_a$ due to impairment of thermoregulation below the level of the lesion (Guttmann...
et al. 1958; Attia and Engel 1983; Petrofsky 1992). According to previous studies (Totel et al. 1971; Ishii et al. 1994, 1995), the $T_c$ in exposure to $T_a$ of 25°C in PSCI has been found to be lower than that in able-bodied subjects. Therefore, due to the lower $T_c$ in PSCI, a greater increase in $T_c$ may be required to reach the threshold eliciting cutaneous vasodilatation in comparison with able-bodied subjects, assuming that the threshold is the same for both PSCI and able-bodied subjects.

Therefore, the purposes of the present study were to examine the response of SBF in the paralyzed lower limbs of PSCI during prolonged arm exercise sufficient to produce an increase in $T_c$ and to clarify the relationship between the SBF and $T_c$.

### Methods

#### Subjects

Eight male PSCI with complete lesions at levels ranging from T6 to L5 volunteered to participate in this study. Their characteristics are listed in Table 1. The six able-bodied men who served as control subjects (CS) ranged in age from 21 to 50 years (mean 30.3 years), in height from 160 to 181 cm (mean 168.8 cm), and in body mass from 60 to 75 kg (mean 65.6 kg). No subject had any cardiovascular, metabolic, or pulmonary disease. Before the experiment, informed consent was obtained from all subjects. The study was approved by the private Human Research Committee of our faculty at Hiroshima University.

#### Experimental procedures

The subjects fasted for at least 3 h before the test. The experiments were carried out in a climatic chamber at $T_a$ of 25°C and a relative humidity of 50%. After the subject, who wore only shorts, had been seated in his own wheelchair for 60 min, the data at rest were acquired for 10 min. The subject then performed arm-cranking exercise at 20 W at a frequency of 50 revolutions min$^{-1}$ using a mechanically braked arm-cranking ergometer (Monark Rehab Trainer model 881E) in the seated position. The periods of exercise lasted 30 min with a 10-min recovery.

#### Physiological measurements

The SBFT and SBF at the calf (SBFC) were continuously monitored with a laser-Doppler flowmeter (ALF 21, Advance Co., Tokyo, Japan) which has been described in detail in our previous paper (Muraki et al. 1995). Laser-Doppler flow provides a continuous measurement of the index of skin blood flux that has been shown not to be influenced by arterial blood to underlying muscle (Johnson et al. 1984; Saumet et al. 1988). The laser-Doppler probes were attached to the centre of the anterior thigh and posterior calf. The laser signals were recorded with a digital printer (ALF-P1, Advance Co., Tokyo, Japan) and an analogue pen recorder (Recti-Horiz 8k20, Sanei Sokki, Tokyo, Japan). This device has been developed by Masuda and Uchino (1978) for the measurement of $T_y$ during intense exercise. The thermistor was introduced into the auditory canal and was placed in direct contact with the tympanic membrane. The contact of the thermistor was confirmed by the subject's report of a dull pain. The $T_y$ data were recorded every 30 s into a data memory (K210, Technol Seven, Yokohama, Japan).

The $\dot{V}O_2$ was determined by measurement of the minute ventilation and the $O_2$ and $CO_2$ concentrations of expired air. The expired gas was collected in a Douglas bag for 5 min at rest and for the last 2 min of each 10-min interval throughout arm exercise. The $O_2$ and $CO_2$ concentrations of the samples of expired air were analysed using a polarographic type $O_2$ analyser and infrared $CO_2$ analyser (Respina 1H26, NEC-Sanei, Tokyo, Japan). The analyser was calibrated before and during the tests with room air and reference gases of known concentrations. The HR was recorded continuously using a heart rate monitor (PE-3000, Polar Electro, Finland).

#### Statistical analysis

Means and standard deviations were calculated for all variables in PSCI and CS. Unpaired Student's t-tests were used for comparison of $\dot{V}O_2$, HR, SBFT, SBFC and $T_y$ between PSCI and CS. Piecewise linear regression analysis was applied to examine the relationship of $T_y$ to the ratio of SBF during exercise to resting SBF. The analysis was undertaken to estimate the equations for the two regression functions and determined the cut-off point at which the slopes of the two segments of the regression line diverged. All $P$ values less than 0.05 were considered significant.

### Results

According to the response pattern of SBFT, PSCI were divided into two groups; $\Delta$SBFT– (subjects A–D with high lesions) and $\Delta$SBFT+ (subjects E–H with low lesions). The response patterns were basically dependent on the level of the lesion, although PSCI with a lesion at T12 showed one of two response patterns of SBFT. Figure 1 shows the course of change in SBFT, SBFC and $T_y$ in $\Delta$SBFT– (A), $\Delta$SBFT+ (B) and CS (C). The $\Delta$SBFT– showed no increase in SBFT. In contrast, the $\Delta$SBFT+ and CS showed a marked increase in SBFT during exercise. Figure 2 shows the peak values of SBFT during exercise in each group.