RELATIONSHIP BETWEEN VASCULAR FUNCTION AND VASOCONSTRICTIVE RESPONSE TO COLD

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INTRODUCTION

Artificial thermal conditions are maintained within comfortable range by air conditioning system. Outdoor temperatures in winter thus cause stress to the body, not only as feelings of discomfort, but also as elevated blood pressure and hypothermia, particularly in the elderly. In addition, the comfortable range of room temperatures in winter induces a decrease in basal metabolic rate (Maeda et al. 2005), causing a substantial increase in shivering thermogenesis (Maeda et al. 2007) on exposure to cold. Comfortable thermal conditions thus cause a reduction in cold tolerance. Maintenance and improvement of cold tolerance is thus needed in modern populations.

There were many studies that examined relationships between physical endurance training and whole-body cold tolerance, as evaluated by thermogenic ability and suppression of heat loss in the cold, but little agreement has been reached regarding mechanisms of improving cold tolerance. Previous studies have reported that cold-induced thremogenesis and heat loss were greater in individuals with high maximum oxygen uptake than in those with low maximum oxygen uptake (Bittel et al. 1988). Conversely, our previous study confirmed positive relationships between maximum oxygen consumption and peripheral vasoconstriction in cold, and negative relationships between basal metabolic rate and shivering thermogenesis in cold (Maeda et al. 2007), suggesting that physical training leads to improved suppression of heat loss and potentiality of thermogenesis.

With regard to mechanisms for improving the ability to suppress heat loss, vascular function might be affected by physical training. Many studies have examined the effects of exercise training on vascular endothelial function in patients with diabetes (Fuchsjager-Mayrl et al. 2002) and other diseases, revealing improvements in endothelial function with exercise training. However, no study has estimated relationships between whole-body cold tolerance and vascular function. The purposes of this study were to clarify relationships among vascular function, physical fitness and peripheral vasoconstriction during cold exposure, and to demonstrate the involvement of vascular function in improvement of cold tolerance by physical fitness.

METHODS

Subjects comprised 21healthy Japanese males volunteer who underwent whole-body cold exposure testing, and measurement of physical fitness and vascular function. The Ethics Committee of Fukushima Medical University approved the study protocols. Each subject received a complete explanation of the experimental test procedure prior to providing consent to participate in the study.

Cold exposure testing involved supine rest at 28°C for 60 min, decreasing temperature to 10°C for about 30-min, and remaining at 10°C for 60 min. Relative humidity was set at 50%. Rectal and skin temperatures of the forehead, abdomen, forearm, back of the hand, thigh, shin, and instep, skin blood flow on the index finger of left hand, and oxygen consumption were measured. Mean skin temperature ($\bar{T}_{ms}$) was calculated from these 7 points on the body using an equation by Hardy and DuBois (1938). Oxygen consumption ($\dot{V}O_2$) was used as an index of shivering thermogenesis, and rate of change of $\dot{V}O_2$ was calculated as the value at 90 min divided by the baseline value (0 min). Decrease in blood flow was used as an index of skin vasoconstriction. Subjects wore a short-sleeved cotton T-shirt and short cotton pants (about 0.3 clo).

Individual vascular function and aerobic physical fitness were measured the day after the cold exposure test. With regard to measurement of vascular function, blood flow at the left forearm was measured by strain gauge plethysmography before and after cuff inflation of 200 mmHg for 5 min. Endothelium-dependent vasodilation at reactive hyperemia was estimated using this methodology. Endothelium-dependent vasodilation is related to vascular endothelial function, but can co-instantaneously estimate flexibility of blood vessels. That is to say, the more flexible a blood vessel was, the greater the increase in blood flow. We used blood flow just after cuff release and mean value for 1 min after cuff release as an index of flexibility of blood vessels.

Maximum oxygen consumption ($\dot{V}O_{2max}$) was used as a directly index of aerobic physical fitness, and was measured during physical exercise on a bicycle ergometer with continuously incremental work load (+20 W/min). The test was terminated on self-determined exhaustion or when the subject could no longer maintain a 50 rpm cadence, despite encouragement by the investigator.

RESULTS

Figure 1 shows temporal changes in mean skin temperature, finger blood flow, and oxygen consumption. Mean skin temperature (Figure 1A) and finger blood flow decreased (Figure 1B), and oxygen consumption (Figure 1C) increased with decreasing temperature and exposure to 10 °C. Figure 2 shows the relationships between vasoconstriction during cold exposure and aerobic physical fitness, and vascular function. A positive relationship between vascular function and degree of peripheral vasoconstriction as estimated by differences in mean finger blood flow

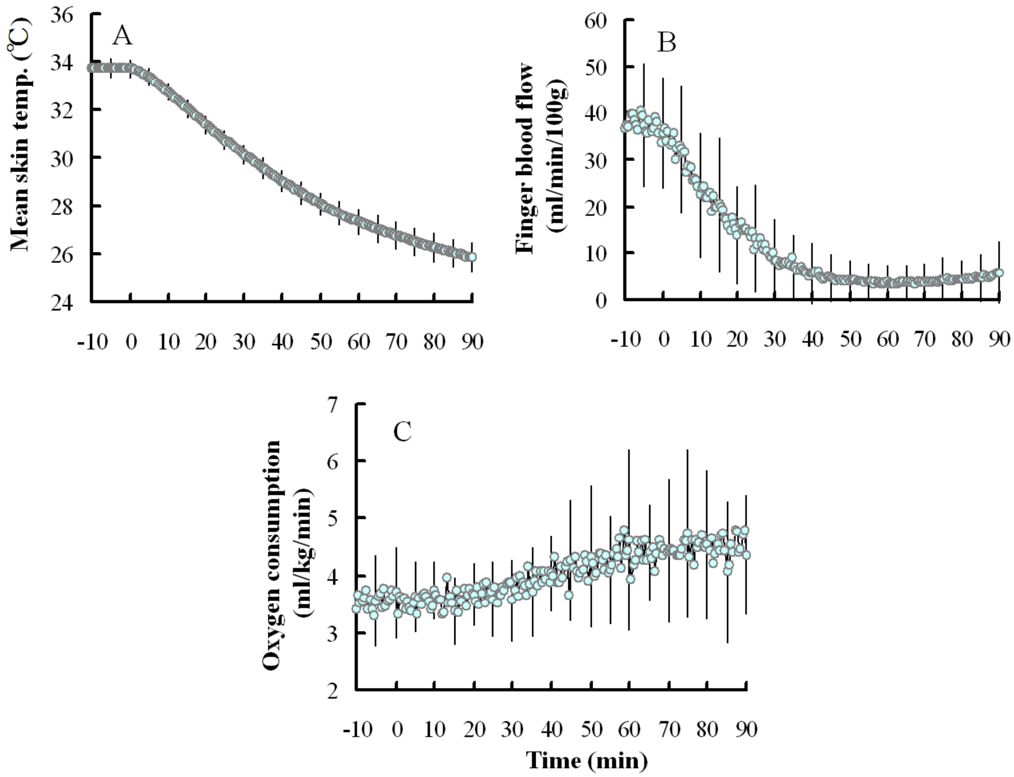

Figure 1 Temporal changes in mean skin temperature (panel A), finger blood flow (B), and oxygen consumption (C).

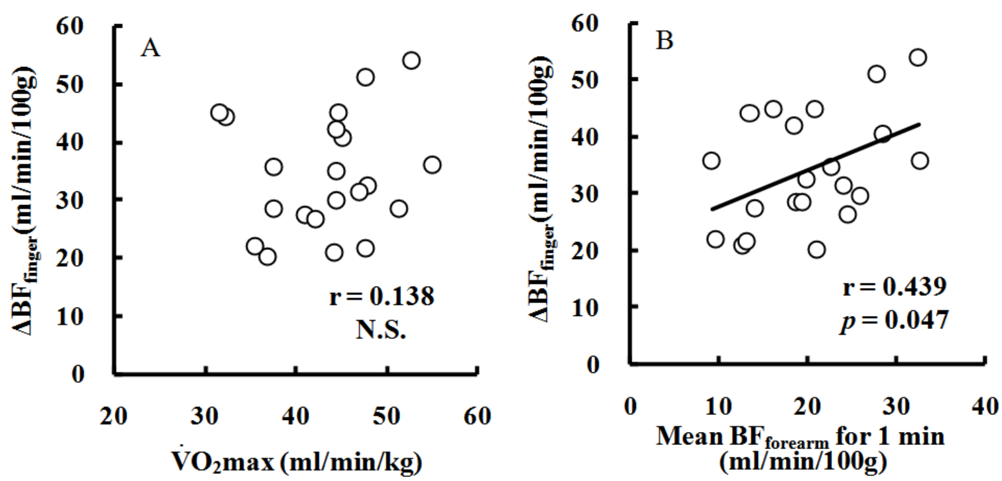

Figure 2 Relationships between finger blood flow in a cold and aerobic physical fitness(A), and vascular function (B).

VO_2max means maximum oxygen uptake. $BF_{forearm}$ means blood flow on forearm at reactive hyperemia. ΔBF_{finger} means differences in finger blood flow at 28 °C and 10 °C, which is an index of vasoconstriction during cold exposure.

at 28 °C and minimum value at 10 °C (ΔBF_{finger}) was found (Figuer 2B), although no relationship was identified between $\dot{V}O_{2max}$ and ΔBF_{finger} (Figuer 2A). Figure 3 shows a relationship between aerobic physical fitness and vascular function. A positive correlation existed between $\dot{V}O_{2max}$ and vascular function (Figure 3).

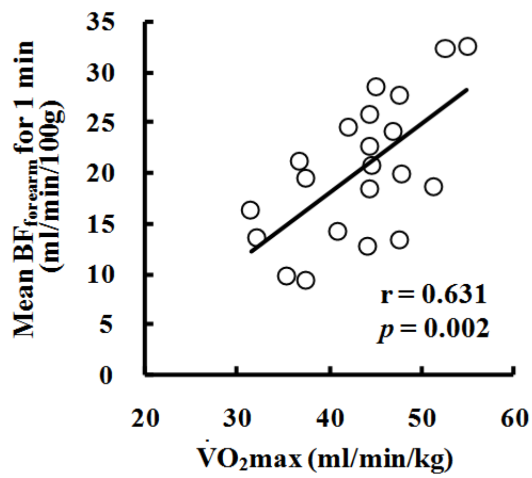

Figure 3 Relationship between aerobic physical fitness and vascular function.

CONCLUSIONS

It is well known that peripheral vasoconstriction is important for thermoregulation, especially for suppressing heat loss, in a cold environment and high ability of peripheral vasoconstriction enables regulation of body temperature without increasing metabolic thermogenesis which is the second stage of the thermoregulation after the vasoconstriction. The present study indicated the relationship between vascular function and peripheral vasoconstriction during cold exposure, suggesting that flexible blood vessels displayed strong contractility during cold exposure. Given the result of a correlation between $\dot{V}O_{2max}$ and vascular endothelial function, flexibility of blood vessels was improved by aerobic physical training, supporting the results of previous studies (Fuchsjager-Mayrl et al. 2002).

In conclusion, this study showed that exercise training leads to improved flexibility and responsiveness of blood vessels, thus improving vasoconstrictive capacity and cold tolerance.

ACKNOWLEDGEMENTS

This study was supported by the Grant-in-Aid for Young Scientists (A) (16687010) and Grant-in-Aid for Scientific Research (B) (19370103) from the Japanese Ministry of Education, Culture, Sports, Science, and Technology.

REFERENCES

Bittel JH, Nonotte-Varly C, Livecchi-Gonnot GH, Savourey GL, Hanniquet AM (1988) Physical fitness and thermoregulatory reactions in a cold environment in men. J Appl Physiol 65: 1984-1989

Fuchsjager-Mayrl G, Pleiner J, Wiesinger GF, Sieder AE, Quittan M, Nuhr MJ, Francesconi C, Seit HP, Francesconi M, Schmetterer L, Wolzt M (2002) Exercise training improves vascular endothelial function in patients with type 1 diabetes. Diabetes Care 25: 1795-1801

Maeda T, Fukushima T, Ishibashi K, Higuchi S (2007) Involvement of basal metabolic rate in determination of type of cold tolerance. J Physiol Anthropol 26: 415-418

Maeda T, Sugawara A, Fukushima T, Higuchi S, Ishibashi K (2005) Effects of lifestyle, body composition, and physical fitness on cold tolerance in humans. J Physiol Anthropol Appl Human Sci 24: 439-443