

---

◎原 著

---

## Effect of partial cold-loading on peripheral circulation

Yasuhiro Hosaki, Fumihiro Mitsunobu, Takashi Mifune,  
Kouzou Ashida, Hirofumi Tsugeno, Makoto Okamoto,  
Shingo Takata, Tadashi Yokoi, Yoshiro Tanizaki,  
Koji Ochi<sup>1)</sup> and Takao Tsuji<sup>2)</sup>

Division of Medicine, Misasa Medical Branch,

<sup>1)</sup>Department of Clinical Laboratory,

<sup>2)</sup>First Department of Medicine, Okayama

University Medical School

**Abstract :** The purpose of this study is the effect of partial cold-loading on whole body peripheral circulation. The body surface peripheral circulation in 24 cases (25 years old to 86 years old, the average was 64.3 years) who were suffering coldness, numbness or pain in their feet was examined using Laser-Doppler blood flowmetry. The peripheral circulation at the base of the 2nd toe of the right foot was estimated after the foot was submerged and cooled for 5 min in a water bath at 20°C (i. e. cold-loading). At the same time, the distant body surface peripheral circulation was estimated at the base of the 2nd finger of the right hand. Simultaneous observations were made of blood flow, blood mass and blood velocity. The peripheral blood flow of the upper limbs at a room temperature of 20°C (pre-loading) was 5.00 ml/min 100 g tissue on average. The average blood mass was 287 and the average blood velocity was 0.516. On the other hand, the average peripheral blood flow of the lower limbs was 2.23, the average blood mass was 149 and the average blood velocity was 0.574. This result shows that the blood flow and blood mass of the upper limbs were more than in the lower limbs. The average blood flow at the upper limbs decreased to 3.69 from 5.00 (or at 26.2%) when the lower limbs were submerged and cooled for 5 min in a water bath at 20°C (i. e. cold-loading). On the other hand, blood flow of the lower limb was 1.51 ml under a condition of cold-loading, and decreased 32.3% from 2.23. Blood mass of the upper limb was 241 on average and decreased 16.0% from 287. Blood mass of the lower limb was 113 on average and decreased 24.2% from 149. There was no difference between blood velocity of the upper limb under the conditions of room temperature at 20°C (0.516) and cold-loading (0.501). However, blood velocity of the lower limb increased to 0.642 from 0.574. After the end of cold loading, there was some tendency for blood flow, blood mass and blood velocity to return to the amount at pre-loading. Twenty minutes after the end of cold-loading, blood flow increased to

5.74 (14.8%) compared with pre-loading (5.00). However, blood flow of the lower limb remained at only 83.9% (1.87) of the amount at pre-loading (2.23). These results show that partial cold-loading of the lower limb had a quantitative effect on the distant peripheral circulation. The speculated mechanism of this phenomenon is that it protects against losing body heat from the body surface under the conditions of local cold-loading. Our body has defense mechanisms to decrease whole body peripheral circulation to protect against losing body heat.

**Key word :** Laser-Doppler blood flowmetry, cold loading, peripheral circulation, blood flow, blood velocity

### Introduction

The number of patients with diabetes mellitus is increasing rapidly, as human lifestyles and food are changing. Patients with diabetes mellitus have many complications, such as retinopathy, nephropathy, neuropathy, and deep ulcerations and gangrene of the lower extremities<sup>1, 2)</sup>. We have observed peripheral circulation quantitatively by Laser-Doppler blood flowmetry<sup>3)</sup> and thermography<sup>4, 5)</sup> to prevent such deep ulcerations and gangrene of the lower extremities at the early stage. In a previous paper<sup>6, 7, 8)</sup>, We quantified the results of Laser-Doppler blood flowmetry and thermography so that it could be useful for studies on the peripheral circulation in patients with diabetes mellitus.

We have been unaware of the regulation mechanism of whole body peripheral circulation. Here, in a continuation of our previous studies, we observed the peripheral circulation, including blood flow, blood mass and blood velocity on the lower and upper extremities, under three different conditions : 1) placed at room temperature (20°C) for 15 min (pre-loading), 2) submerged and cooled for 5 min in a water bath at 20°C (i. e. cold-loading)<sup>6)</sup>, and 3) placed at room temperature (20°C) for 20 min after cold-loading (after-loading) in order to observe the response against the

cold-loading at distant points of peripheral circulation by Laser-Doppler blood flowmetry.

In this paper, we show that there is a difference in the response of the lower and upper extremities against cold-loading, and that some mechanism exists for the regulation of whole body peripheral circulation.

### Subjects and Methods

The body surface peripheral circulation in 24 cases, including 5 patients with diabetes mellitus who were suffering coldness, numbness or pain in their feet, was examined using Laser-Doppler blood flowmetry (Advance Co. ALF21D)<sup>3)</sup>. The patients included 13 females and 11males, with a mean age of 64.3 years (range from 25–86 years). The subjects were placed for 15 min in a room controlled at a temperature of 20°C and with relative humidity (60%–70%) as described in our previous paper<sup>6)</sup>. Both lower limbs were submerged and warmed for 5 min in a hot bath containing 10 ℓ of water warmed to 36°C (i. e. hot loading)<sup>7)</sup> to reduce the effect of weather. Water was wiped off from both lower limbs. One point on the right foot and one point on the right hand were observed by Laser-Doppler blood flowmetry. Detectors (ALC probe type C, Advance Co., water resistant) were placed using double-stick tape on the base of each toe and finger ; placed between

the first and the second base of the toe and finger, respectively to avoid bones.

First, subjects were placed on a bed at a room temperature of 20°C for 15 min (pre-loading) and we observed peripheral circulation; blood flow, blood mass and blood velocity were observed in the lower and upper limbs. Second, both lower limbs were submerged and cooled for 5 min in a water bath at 20°C (i. e. cold-loading)<sup>6)</sup> and peripheral circulation was observed. Third, subjects were placed at a room temperature of 20°C for 20 min after cold-loading (after-loading), water was wiped off from both lower limbs and peripheral circulation was observed.

Observations were made continuously over an initial interval of 3 min, a second interval of 5 min, and a final 20 min interval for a total of 28 min (Fig. 1). Averages for blood flow, blood mass and blood velocity were obtained from results of the last 15 sec as results came to be stable. These averages were then used for further analysis.

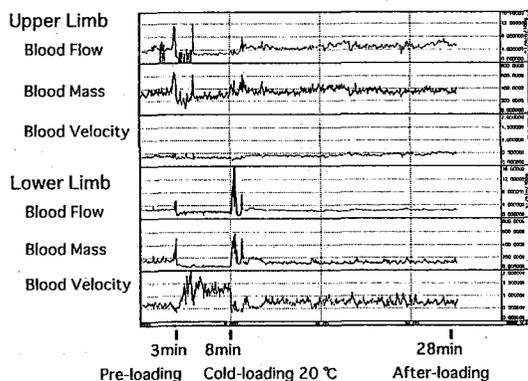


Fig. 1 Results of blood flow, blood mass and blood velocity of upper limbs and lower limbs under the condition with pre-loading, cold-loading and after-loading examined by Laser-Doppler blood flowmetry.

## Results

The body surface peripheral circulation in 24 cases was observed. The peripheral blood flow at the upper limbs under room temperature conditions at 20°C was  $5.00 \pm 3.14 \text{ ml/min}/100 \text{ g}$  tissue on average (Fig. 2). The average blood mass was  $287 \pm 87$  (Fig. 3), and the average blood velocity was  $0.516 \pm 0.186$  (Fig. 4). On the other hand, the average peripheral blood flow at the lower limbs was  $2.23 \pm 1.64$  (Fig. 2), the average blood mass was  $149 \pm 53$  (Fig. 3), and the average blood velocity was  $0.574 \pm 0.187$  (Fig. 4). This result shows that blood flow in the upper limbs was 2.24 times more than that in the lower limbs. Blood mass in the upper limbs was 1.93 times more than that in the lower limbs. There was no difference between blood velocity in the upper limbs relative to the lower limbs. However, we did not find any relation between the upper and lower limbs at these blood flow, blood mass or blood velocity in individual object, data was not shown.

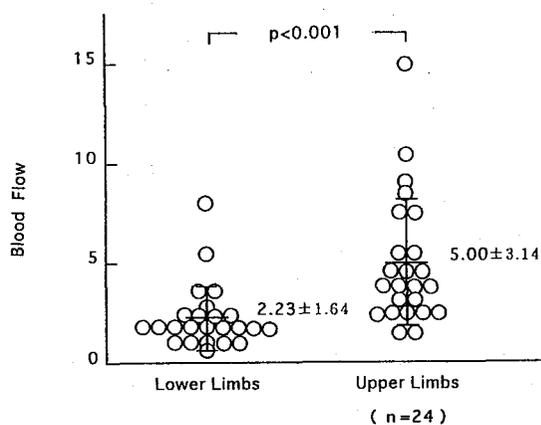


Fig. 2 Blood flow of upper limbs and lower limbs under the condition with pre-loading.

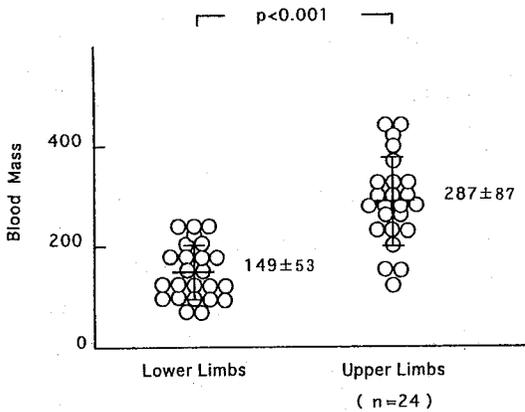


Fig. 3 Blood mass of upper limbs and lower limbs under the condition with pre-loading.

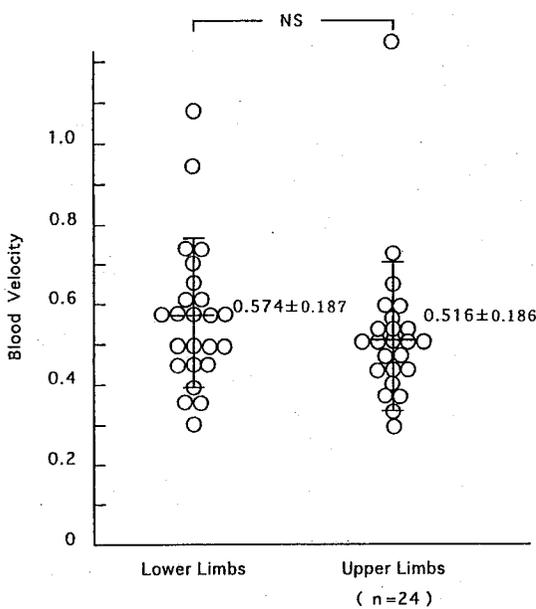


Fig. 4 Blood velocity of upper limbs and lower limbs under the condition with pre-loading.

The average blood flow in the upper limbs decreased to 3.69 from 5.00 (or 26.2%) when the lower limbs were submerged and cooled for 5 min in a water bath at 20°C (i. e. cold-loading) (Fig. 5). On the other hand, blood flow in the lower limb was 1.51 ml less than in the condition with cold-loading, and decreased 32.3% from 2.23. After cold-loading, the average blood flow in the upper limbs increased to 5.74 (after-loading) from 3.69 (cold-loading) or from 5.00 (pre-loading). The average blood flow at the lower limbs remained at 1.87 (after-loading) from 1.51 (cold-loading) or from 2.23 (pre-loading). In these experiments, there was a significant difference in the average blood flow in the upper limbs between the condition with pre-loading and cold-loading, and the condition with cold-loading and after-loading. The average blood flow in the upper limbs decreased significantly under the condition with cold-loading, and after cold-loading the average blood flow in the upper limbs increased more than the average at cold-loading. Also there was a tendency that the average blood flow in the upper limbs increasing more than the average at pre-loading, but it was not significant in these number of subjects. However, the average blood flow at the lower limbs decreased under the condition with cold-loading, and after cold-loading the average blood flow in the lower limbs increased more than the average at cold-loading, but stayed less than the average at pre-loading.

The average blood mass at the upper limbs decreased to 241 from 287 (or at 16.0%) under the condition with cold-loading (Fig. 6). On the other hand, blood mass in the lower limb was 113 less than in the condition with cold-loading, and decreasing at 24.2% from 149. After cold-loading, the average blood

mass in the upper limbs increased to 316 (after-loading) from 241 (cold-loading) or from 287 (pre-loading). The average blood mass in the lower limbs remained at 126 (after-loading), between 113 (cold-loading) and 149 (pre-loading). In these experiments, there was a significant difference in the average blood mass in the upper limbs between the conditions of cold-loading and after-loading. The average blood mass at the upper limbs decreased under the condition with cold-loading, and after cold-loading the average blood mass at the upper limbs increased to not only more than the average at cold-loading, but also to more than the average at pre-loading. However, the average blood mass at the lower limbs decreased under the condition with cold-loading, and after cold-loading the average blood mass at the lower limbs increased more than the average at cold-loading, but stayed less than the average at pre-loading.

The average blood velocity in the upper limbs changed little from 0.516 to 0.501 (or at 2.9%) under the condition with cold-loading (Fig. 7). On the other hand, blood velocity in the lower limb was 0.642 under the condition with cold-loading and increased 11.2% from 0.574. After cold-loading, the average blood velocity in the upper limbs changed little from 0.501 (cold-loading) or 0.516 (pre-loading) to 0.512. The average blood velocity in the lower limbs stayed at 0.618 (after-loading) from 0.642 (cold-loading) or from 0.574 (pre-loading). In these experiments, there was no significant change in the average blood velocity in the upper limbs under the condition with cold-loading. However, there was a significant change in the average blood velocity in the lower limbs between pre-loading and cold-loading.

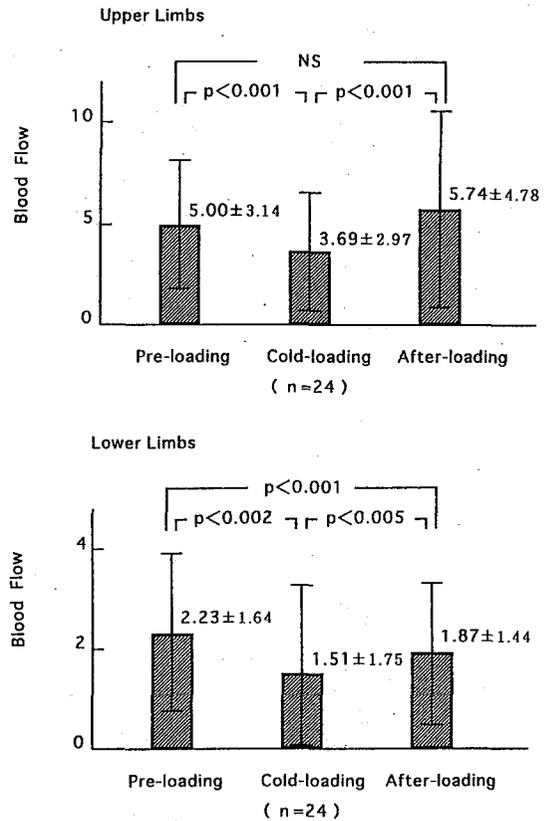


Fig. 5 Blood flow of upper limbs and lower limbs under the condition with pre-loading, cold-loading and after-loading.

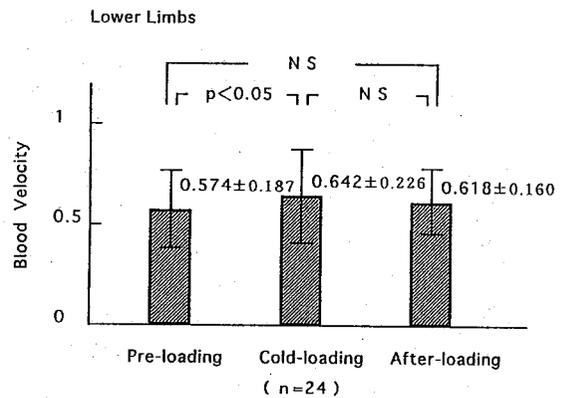
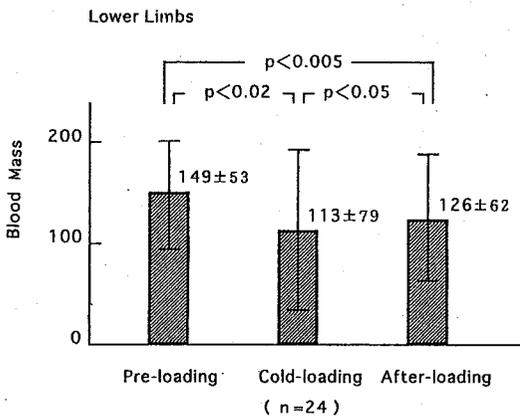
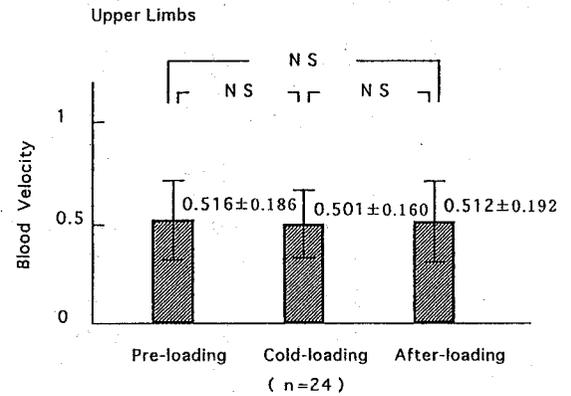
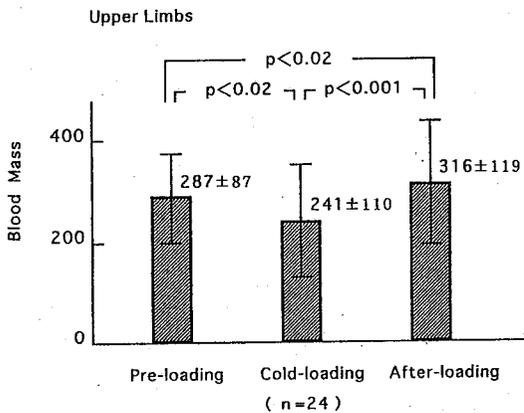


Fig. 6 Blood mass of upper limbs and lower limbs under the condition with pre-loading, cold-loading and after-loading.

Fig. 7 Blood velocity of upper limbs and lower limbs under the condition with pre-loading, cold-loading and after-loading.

### Discussion

We have attempted to show a regulation mechanism in whole body peripheral circulation. In this paper, the response against cold-loading was shown when bilateral lower limbs were submerged and cooled in a water bath. As a point of distant body peripheral circulation, the peripheral circulation in the upper limbs was examined under the same condition with cold-loading.

Before this experiment, we expected that

there might be two different results. One possible result was that the blood flow in the upper limbs would increase under the condition with cold-loading. Because the blood flow in the lower limbs would decrease, an excess in the available amount of blood would go to other portions of the body. Another possible result was that blood flow in the upper limbs would decrease under the condition with cold-loading. If the whole body peripheral circulation was controlled by the same mechanism as blood flow in the lower

limbs, then circulation would decrease under the condition with cold-loading in order for the body to minimize the loss of heat.

In these experiments, blood flow in the upper limbs decreased under the condition with cold-loading. In spite of the fact that blood flow in the lower limbs after cold-loading remained under the average at pre-loading, there was a tendency for blood flow in the upper limbs to increase to more than the average at pre-loading. Blood mass also showed the same behavior as blood flow. On the other hand, blood velocity was relatively constant in the upper limbs for pre-loading, cold-loading and after-loading.

From these results, it might be concluded that the most important homeostatic mechanism was keeping the same blood velocity under such conditions as cold-loading. A second homeostatic mechanism was keeping the constant body temperature against cold stress. A third homeostatic mechanism was keeping the total blood flow or whole peripheral circulation at a minimum. However, we did not observe the cardiac output at the same time in this experiment.

Blood velocity increased in the lower limbs only under the condition with cold-loading. This might mean cold-loading might be one of the most severe stresses on the body, and it could reveal one of the most important regulation mechanisms of peripheral circulation. The space of the vessel would be small by the contraction of the smooth muscle around of the artery by the regulation mechanism of peripheral circulation.

From these observations, we conclude that partial cold-loading had an effect on whole body peripheral circulation, and there were several regulation mechanisms of peripheral circulation to protect against losing body

heat.

In the future experiment, we would like to show how the regulation mechanism of peripheral circulation might be damaged by diabetes mellitus. Also, we would like to show the difference of damaged points in the cases of diabetes mellitus and lumbago.

#### References

1. Kahn CR, Weir GC, eds, *Joslin's Diabetes Mellitus*, 13th Edition, Philadelphia PV, Lea & Febiger, 1994
  2. Hirata Y, *Therapy for Diabetes Mellitus* 1993
  3. Kashima S, Oka S, Ishikawa J, Hiki Y : Measurement of tissue blood volume by Laser blood flowmetry. *Japanese Journal of Laser* 12 : 3 - 9, 1991
  4. Barnes RB, *Thermography*, *Ann N Y Acad Sci* 121 : 34-48, 1964
  5. Hitoi A, Matsuoka A : Patho-physiological analysis on peripheral circulation using thermography as an example of functional body imaging. *Japan J Clinical pathology* 38 : 1119-1125, 1990
  6. Hosaki Y, Nawa Y, Takeuchi K, Tsugeno H, Asida K, Yokota S, Mitsunobu F, Mifune T, Tanizaki Y, Ochi K, Harada H, Ikeda S, Taketa K : Evaluation of body surface temperature by thermography. *Annual Reports of Misasa Medical Branch, Okayama University Medical School* 67 : 63-70, 1996
  7. Hosaki Y, Takata S, Mitsunobu F, Mifune T, Ashida K, Tsugeno H, Okamoto M, Harada S, Tanizaki Y, Ochi K, Harada H and Tsuji T : Evaluation of body surface temperature by thermography.
2. Effect of pre-loading with hot water. *Annual Reports of Misasa Medical Branch, Okayama University Medical School* 69 :

68-75, 1998

8. Hosaki Y, Takata S, Mitsunobu F, Mifune T, Ashida K, Tsugeno H, Okamoto M, Harada S, Tanizaki Y, Ochi K, Tsuji T: Evaluation of body surface temperature by thermography.

3. Correlation between the peripheral circulation estimated by Laser-Doppler blood flowmetry and one by thermography. Annual Reports of Misasa Medical Branch, Okayama University Medical School 70: 36-42, 1999

#### 寒冷負荷の末梢循環に及ぼす影響

保崎泰弘, 光延文裕, 御船尚志, 芦田耕三, 柘野浩史, 岡本 誠, 高田真吾, 横井 正, 谷崎勝朗, 越智浩二<sup>1)</sup>, 辻 孝夫<sup>2)</sup>

岡山大学医学部附属病院三朝分院内科、

<sup>1)</sup>医学部臨床検査医学,

<sup>2)</sup>医学部第一内科

局所寒冷負荷の全身の末梢循環に及ぼす影響について検討する目的で、下肢の20℃冷水負荷時における上肢末梢循環の変化をレーザードプラー血流計を用いて数量的に測定し検討を行なった。症例は、下肢に冷え症、しびれ感を有した25歳から86歳までの24症例（平均年齢64.3歳）であった。下肢、上肢の末梢循環を20℃冷水負荷時に、末梢血流量、血液量、血流速度について観察した。上肢の末梢血流量は20℃室内安静時平均5.00ml/min/100g tissue、血液量は287、血流速度は0.516であった。下肢は血流量2.23、血液量は149、血流速度は0.574であった。上肢の血流量、血液量と

もに下肢より多いことが示された。しかし同一症例における上肢と下肢との間の血流量、血液量、血流速度に相関関係は認めなかった。下肢の20℃冷水負荷中の上肢の血流量は平均3.69で有意に低下(26.2%)した。下肢はその間1.51で有意に低下(32.3%)した。上肢の血液量は平均241で有意に低下(16.0%)した。下肢はその間113で有意に低下(24.2%)した。上肢の血流速度は平均0.501で不変であった。下肢はその間0.642で有意に増加(11.8%)した。冷水負荷直後よりそれぞれ負荷前に復帰する傾向を示した。負荷後20分では上肢の血流量は平均5.74で負荷前値に比べて増加(14.8%)傾向を示した。下肢は1.87で負荷前値に比べて低値(83.9%)に留まる傾向にあった。下肢の冷水負荷は上肢の末梢循環にも影響を及ぼすことが数量的に示された。局所の寒冷負荷による体温の低下を防ぐために反射的に全身の皮膚の末梢循環量を低下させていることが示された。

牽引用語：レーザードプラー血流計、冷水負荷、末梢循環、血流量、血流速度