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Evaluation of Body Surface Temperature by Thermography

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Abstract : Body Surface Temperature was observed by thermography. The surface temperature of a healthy person's lower limbs, after being cooled in a water bath, increased in parallel with time. Patients with Diabetes Mellitus had different patterns in the rate of increase of the surface temperature. After cold loading, one patient had a 99% recovery ratio of surface temperature, the same level as healthy volunteers (83%, and 88%), as calculated by a picture processing program with the computerized thermotracer. However, the recovery ratio of other patients was poorer, ranging from 56% to under 6 % recovery. This measurement of elevation of body temperature is useful for the estimation of peripheral blood flow in patients with lower limb circulation failure.

Key word : Thermography, Diabetes Mellitus, Peripheral Circulation, Cold Loading

Introduction

Patients with Diabetes Mellitus have many complications, such as retinopathy, nephropathy, neuropathy, and deep ulcerations and gangrene of the lower extremities [1,2]. To prevent these lower extremity complications, we observed body surface temperature by thermography for the purpose of estimating peripheral blood flow. Thermography [3] is one useful method for body imaging, along with other systems like computed tomography (CT) and magnetic resonance imaging (MRI). In this paper, we have quantified the results of thermography so that it can be useful for further studies on the relations between body surface temperature and peripheral circulation in patients with Diabetes Mellitus, arteriosclerosis obliterans (ASO) and Buerger's disease, and for evaluation of the effect of medicines such as Prostagrandin E_1.

Procedure

The subjects were two healthy volunteers and 7 patients with Diabetes Mellitus (one female and 8 males, mean age 56.4 years, range 28−80 years). The subjects were placed for 15min in a room controlled at 20℃, and 60%−70% humidity. The upper side of bilateral lower limbs, 10cm from Malleolus lateralis, were covered with aluminum foil and cotton towels to limit the area for observation, and to reduce infrared radiation in the background. Both lower limbs were placed on a bed which was covered with aluminum foil and cotton towels in order to reduce infrared radiation. Thermographs were obtained using a high sensitivity infrared ray thermotracer 6T66 (NEC-Sanei Co.). The area of body surface which temperature was higher than 28℃ as initial area for observation was calculated with a computer software of picture processing (Temperature data transport and processing program Type 9610M for the thermotracer, NEC-Sanei Co.). Next, the covers were stripped off and both lower limbs were submerged and cooled for 5 min in a water bath containing 10 ℓ of water cooled at 20℃ (i.e. cold loading). Water was wiped off of both lower limbs, and both lower limbs were re-wrapped with aluminum foil and cotton towels. Thermographs were taken as described above, at 5 min, 10min, 20min, and 30min intervals after cold loading for a time study. The data obtained data were processed by the computer software mentioned above.

Results

First, we established a baseline by producing a thermografic image of the lower limbs of a healthy, 38 year old volunteer. Each thermographic image contained 74000 counts (pixels). Figure 1 is a histogram showing two peaks after calculation using a 1℃ step distribution. Peak A was infrared radiation from background; from the bed and the floor. Peak B was infrared rediation from the body surface of the healthy person's lower limbs. The total counts of peak B; the area between 28−33℃, were 26951 counts (36.4% of 74000 counts). The median temperature of the healthy person's lower limbs was 30℃. The count was correlated with square of each degree of body surface temperature in parallel. To reduce the effect of background, counts under 28℃ were omitted for further study.

Results of time course study of body surface temperature of the healthy volunteer after cold loading at 20℃ for 5 min are shown on Fig. 2. Temperature profiles are shown before cold loading (0 M), 5 min after cold loading (5 M), 10 min after cold loading (10M), 20 min after cold loading (20M), and 30 min after cold loading (30M). Total counts over 28℃ at each period are shown as shaded areas.

The recovery ratio was calculated as total counts over 28℃ at each period, divided by initial counts over 28℃ before cold loading (26951counts). Calculated recovery ratios were 12% at 5 M, 56% at 10M, 79% at 20M, and 83% at 30M. Between 20M and 30M, there was only a 4 % increase of initial counts and temperature reached a plateau. These results show that 30 min observation should be enough for the time study under the condition with temperature limitation being set at 28℃.

The results of a study to determine the

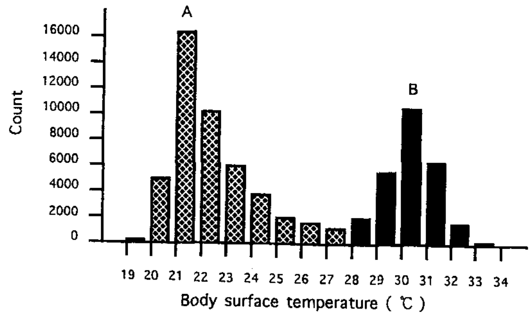

Fig. 1 Histogram of body surface temperature of the healthy volunteer.
Body surface temperature of the healthy person's lower limbs was observed by the thermography and calculated by a picture processeing program of the computerized thermotracer. Each picture of thermographic image had 74000 counts of dots (pixels) for each picture. The histogram showed two peaks after calculation on each 1 ℃ step distribution. Peak A was infrared radiation from the background; from the bed and the floor. Peak B was infrared radiation from the body surface of the healthy person's lower limbs. Total counts of peak B, area over 28℃, was 26951 counts (36.4% of 74000). The median temperature of the healthy person's lower limbs was 30℃.

temperature limitation for calculation of body surface temperature of a healthy person's lower limbs after cold loading at 20℃ for 5 min are shown in Fig. 3. The recovery ratio was calculated at three different temperatures, 27℃, 28℃ and 29℃. The recovery ratio was calculated as total counts over 27℃ at each period, divided by initial counts over 27℃ before cold loading (28253 counts). At other conditions, the recovery ratio was calculated as total counts over 28℃ at each period divided by initial counts over 28℃ before cold loading (26951 counts), or as total counts over 29℃ at each period divided by initial counts over 29℃ before cold loading (24787 counts). At 27℃, the recovery ratio increased quickly during the first 10min, and reached 89% at 20min, and 93% at 30 min. At 29℃, the recovery ratio increased slowly and was 63% at 20 min, but it was only 64% at 30 min. As described above (Fig. 2), at 28℃ the recovery ratio increased at a rate between those observed at 27℃ and 29℃, and reached 79% at 20min and 83% at 30min. From this study, setting the temperature limitation is best at 28℃ for the calculation of the recovery ratio. Otherwise, at 27℃ the recovery ratio might be influenced by background radiation, and at 29℃ the recovery ratio would be under estimated.

Under conditions described above, a total 9 persons were observed. The characteristics of the 9 cases, including age, sex, disease, Hb_{A1c} and the recovery ratio of body surface temperature are listed in Table. Two of 9 cases were healthy volunteers, at 28 and 38 years old. The other 7 cases were patients with Diabetes Mellitus, and were between 40 and 80 years old. Only one case was female. Past disease histories include one case of colon Ca., one case of gastric Ca., and one case of cerebral embolus. The highest result of Hb_{A1c} in the last 5 years in the clinical record are shown (%) in each case. Results were between 8.4% and 14.9%. Results of recovery ratio of body surface temperature of lower limbs at 30 min after cold loading at 20℃ for 5 min are shown (%). Results were between 99% and 0 % and most patients

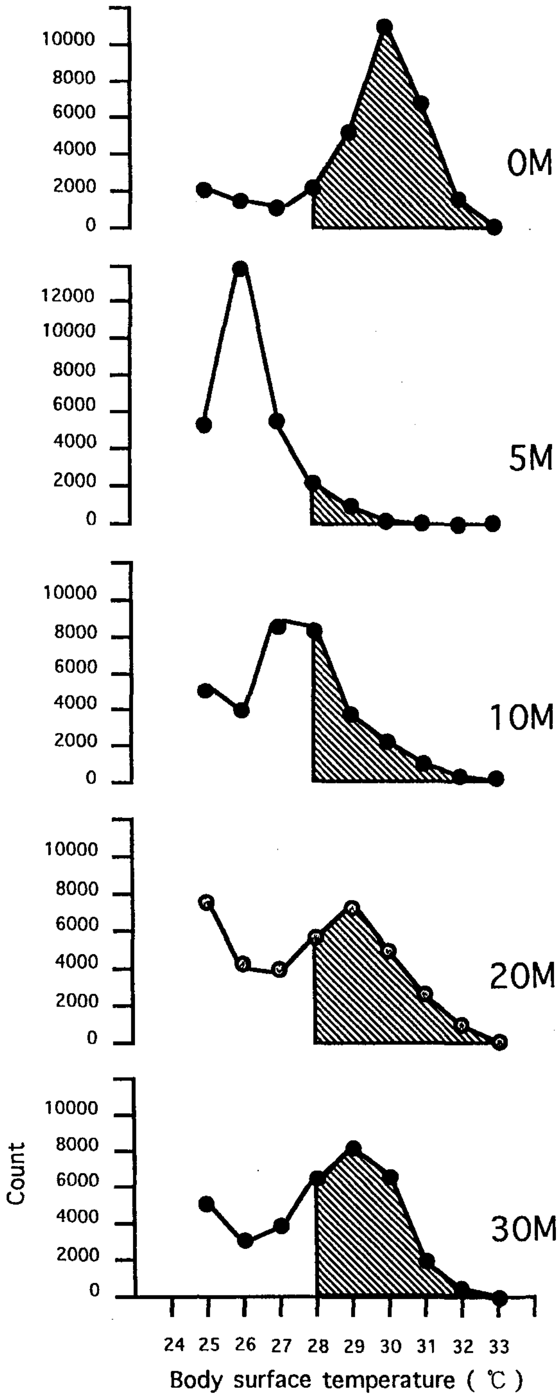

Fig. 2 Time course study of body surface temperature of the healthy volunteer after cold loading at 20 ℃ for 5 min. Body surface temperature of healthy person's lower limbs was observed by thermography. Time is shown before cold loading (0 M), 5 min after cold loading (5 M), 10min after cold loading (10M), 20min after cold loading (20M), 30min after cold loading (30M). Total counts over 28℃ at each period were shown as shaded area (▧). Total counts over 28℃ at each period were 26951 counts as initial counts (0 M), 3332 (5 M), 15011 (10M), 21326 (20M), 22381 (30M). The recovery ratio was calculated as the total counts over 28℃ at each period divided by the initial counts over 28 ℃ before cold loading (26951 counts). Calculated recovery ratio were 100% (0 M), 12% (5 M), 56% (10M), 79% (20M), 83% (30M). Between 20M and 30M, there was only a 4 % increase of initial counts and temperature reached a plateau. From this study, a 30min observation should be enough for the time study under the condition where the temperature limitation is set at 28℃.

with Diabetes Mellitus had a poor recovery ratio. A relationship between the recovery ratio and either results of Hb_{A1C} or age were not apparent in this study.

The time course of the recovery ratio of body surface temperature in the cases of the two healthy volunteers are shown in Fig. 4.

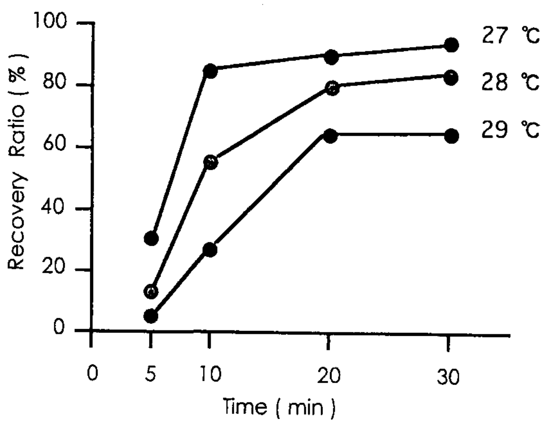

Fig. 3 Temperature study on the limitation for calculation of body surface temperature of the healthy volunteer after cold loading at 20℃ for 5 min. Body surface temperature of healthy person's lower limbs after cold loading was observed by thermography. The recovery ratio was calculated at different limited temperatures of 27℃, 28℃ and 29℃ for initial counts. The recovery ratio was calculated at each temperature, T, by dividing the total counts over T at each period by the initial counts over T before cold loading. Initial counts over T before cold loading was 28253 counts (over 27℃), 26951 (over28℃), and 24787 (over 29℃). At 27℃, the recovery ratio increased quickly during the first 10min, it reached 89% at 20min, and reached 93% at 30min. At 29℃, the recovery ratio increased slowly to 63% at 20min, and it was only 64% at 30min. As described earlier, at 28℃ the recovery ratio increased at rates between those observed at 27℃ and 29℃, reaching 79% at 20min, and 83% at 30min. From this study, setting for the temperature limitation at 28℃ is best for the calculation of recovery ratio.

Table The characters, including age, sex, disease, Hb_{A1c} and recovery ratio of body surface temperature for the 9 cases used in this study are listed.

Case	Age (years)	M/F	Disease	HB_{A1C} (%)	Recovery Ratio (%)
1	38	M	Healthy Volunteer	-	83
2	28	M	Healthy Volunteer	-	88
3	71	M	D M+Colon Ca	9.2	99
4	69	M	D M+Gastric Ca	8.6	56
5	64	M	D M	8.4	6
6	80	M	D M+Cerebral Embolus	8.6	1
7	57	M	D M	9.4	0
8	40	M	D M	14.9	0
9	61	F	D M	8.5	0

The body surface temperature of a healthy persons' lower limbs after cold loading at 20℃ for 5 min was observed. The elevation of temperature is shown at intervals of 5, 10, 20, and 30 min. In Case 2, the recovery ratio at 20 and 30min were as same as in Case 1. However, at 5 and 10 min, the recovery ratio was lower in Case 2 than in Case 1. In these healthy persons, there were differences at the early stage of recovery of body surface temperature. From this result, a comparison of recovery ratio at 30 min is preferred rather than shorter periods.

The recovery ratio of body surface temperature of 7 cases of Diabetes Mellitus is shown in Fig. 5. Body surface temperature of patients' lower limbs after cold loading at 20℃ for 5 min was observed. The elevation of temperature is shown at 5, 10, 20, and 30min. In Case 3, the elevation curve is similar to those of the healthy volunteers (Case 1 and 2), and the recovery ratio reached to 99% at 30min. In Case 4, the recovery ratio was 56% at 30 min. On the other hand, in Cases 5, 6, 7, 8 and 9,

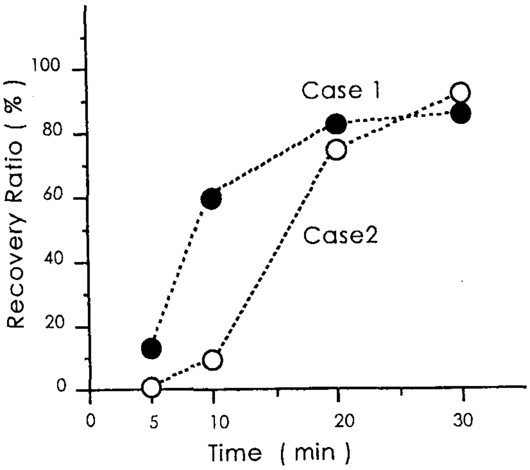

Fig. 4 Recovery ratio of body surface temperature for 2 cases using healthy volunteers. Body surface temperature of healthy persons' lower limbs after cold loading at 20℃ for 5 min was observed by the thermography. The elevation of temperature is shown at 5, 10, 20, and 30min. In Case 2, the recovery ratio at 20 and 30min were as same as in Case 1. However, at 5 and 10min, the recovery ratio was lower in Case 2 than in Case 1. In these healthy persons, there were differences at the early stage of recovery of body surface temperature. From this result, comparison of recovery ratio at 30min is preferred rather than shorter periods.

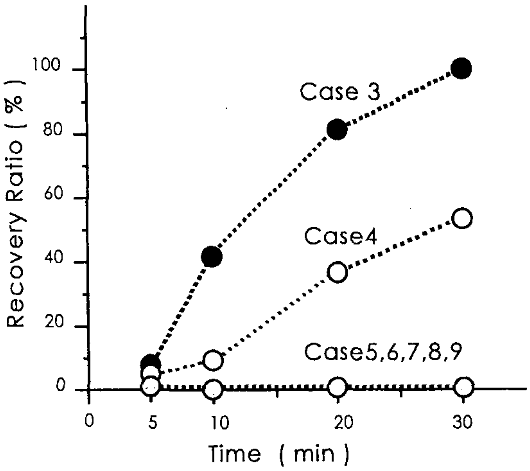

Fig. 5 Recovery ratio of body surface temperature of 7 cases of Diabetes Mellitus. Body surface temperature of patients' lower limbs after cold loading at 20℃ for 5 min was observed by thermography. The elevation of the temperature is shown at 5, 10, 20, and 30min. In Case 3, the elevation curve was similar to the healthy volunteers (Case 1 and 2) and the recovery ratio reached 99% of recovery at 30min. In Case 4, the recovery ratio was 56% at 30min. On the otherhand, in Case 5, 6, 7, 8 and 9, the recovery ratio was very poor after 30min. These results show that patients with Diabetes Mellitus had different recovery patterns of body surface temperature after cold loading.

the recovery ratio was very poor after 30 min. These results show that patients with Diabetes Mellitus had different recovery patterns of body surface temperature after cold loading.

Discussion

Thermography is one of useful methods for body imaging. Results of the thermography are susceptible to room temperature, humidity and wind. However the cold loading method is useful in reducing the influence of temperature or weather. Unfortunately, patients feel pain or numbness while cold loading in an iced water bath or cold water at 10℃, therefore, loading time can not be more than 1 min. Body temperature in such a short cold loading time may be influenced by variation in physical parameters such as body length and weight. We used a higher temperature bath (20℃) in order to elongate the loading time from 1 min to 5 min. Most of the volunteers and patients with Diabetes Mellitus had no complaint of pain of numbness while cold loading under this condition. The room temperature was set at 20℃ to reduce the exchange of heat between room air and the cooled body surface. A computer generated picture was used to calculate body surface temperatures for different areas. This picture processing made possible a quantitative description of the thermographic analysis. The peak background temperature was 2 1℃ (ranging from 20℃ to 27℃), and the peak body surface temperature of the lower limbs was 30℃ (ranging from 28℃ to 33℃). In order to eliminate infrared radiation from the bed, we used total counts over 28℃ as body surface area before cold loading in all calculations. Computer imaging revealed that the time course study resolved clearly the elevation of body surface temperature. A duration of 30 min for observation is preferred for clinical study. 28℃ was more useful than 27℃ and 29℃ under these condition, because the recovery ratio was under estimated at 29℃ and overestimated at 27℃. In 7 cases of Diabetes Mellitus, the recovery ratios were variable, ranging from 99% to 0%, and 5 of 7 were under 6%. This means that patients with Diabetes Mellitus have low blood flow in peripheral circulation of their lower limbs. This result agree very well with the results of previous studies by Matsuoka[4], et al. One of the most difficult complications of Diabetes Mellitus is diabetic gangrene. In general, patients with Diabetes Mellitus have peripheral circulation disorders caused by diabetic microangiopathy and diabetic neuropathy. The thermography with cold loading is useful for the diagnosis of peripheral circulation disorders in the early stage. The peripheral blood flow is controlled through artery venous shunt by the α- neuron of the sympathetic nerve. The control of peripheral blood flow in patients with Diabetes Mellitus is out of order as the activity of the α- neuron is decreased by diabetic neuropathy. In Diabetes Mellitus, macroangiopathy, like ASO, occurs frequently. Prostaglandin E_1 has the effect of extending peripheral blood vessels[5], and increasing the velocity of blood flow while reduce the viscosity of blood. This study might be useful for the diagnosis and estimation of microangiopaty in patients with Diabetes Mellitus in it's early stages, and evaluation of prevention using medicines such as Prostaglandin E_1.

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サーモグラフィーによる体表面温度の測定

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健常人並びに糖尿病患者を対象にして下肢の体表面温度を測定した。測定にはサーモグラフィーを用い，得られた画像の数値化にはコンピュータを用いた画像処理システムを利用した。健常人を用いた実験では，20℃の水を用いた冷水負荷を5分間行うことにより，冷水負荷後，下肢の体表面温度は時間とともに上昇して30分後に良好な回復を得ることができた。画像処理により28℃以上の体表面温度を呈した下肢の面積を負荷前と比較したところ，回復率は，2名の健常人についてみるとそれぞれ83%，88%であった。27℃で画像処理を行った場合には回復率は93%となり過大評価される可能性があった。また，29℃で画像処理を行ったところに，逆に，64%となり過少評価される可能性があり，28℃が最も良い条件であった。この様な条件下で，糖尿病患者7名について同様に測定を行ったところ，1名は健常人と同じく99%の良好な回復率を呈した。しかし，他の1名は56%であり，残りの，5名は6%以下であった。この様に，糖尿病患者では，下肢の体表面温度の冷水負荷後の回復率に顕著な差を認めた。この差は，糖尿病患者における，末梢循環障害の程度を反映しているものと考えられた。この様にコンピュータを用いた画像処理システムの応用によりサーモグラフィーの画像は数値化することが出来，測定結果はより客観的に据えることが可能となった。画像処理されたサーモグラフィーは下肢の循環障害を持つ患者の末梢血流量の評価に有用な測定方法であると考えられた。

索引用語：サーモグラフィー，冷水負荷，糖尿病，末梢循環