◎原 著

Evaluation of Body Surface Temperature by Thermography 3. Correlation between the peripheral circulation estimated by Laser-Doppler blood flowmetry and thermography.

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Abstract: The body surface peripheral circulation in 12 cases, including 9 patients with diabetes mellitus who were suffering coldness, numbness or pain in their feet, and 3 healthy volunteers was examined using Laser-Doppler blood flowmetry. At the same time, the body surface temperature was estimated by thermography. Thermographic results were analyzed quantitatively by calculating a recovery ratio as : Recovery ratio = [Total counts of thermography (Pixels) over temperature (T) after cold loading] ÷ [Initial counts over T before cold loading] × 100(%). The recovery ratio and the blood flow were correlated, $r=0.68$, $p<0.01$.

The peripheral circulation of 16 patients with diabetes mellitus was observed at three different conditions including, 1)placed at room temperature at 20℃ for 15 min, 2) submerged and warmed for 5 min in a hot bath at 36℃ (i.e. hot loading), and 3) submerged and cooled for 5 min in a water bath at 20℃ (i.e. cold loading). Three different baseline temperatures, 26℃, 27℃ and 28℃, were used in processing the thermographic results into pictures. The highest correlation ($r=0.59$, $p=0.0002$) was obtained under the condition of cold loading using a baseline temperature limitation of 27℃.

The difference ratio (%) of blood flow was calculated as the blood flow at cold loading divided by the blood flow at hot loading in these 16 patients. The difference ratio of the blood flow and the recovery ratio of thermography were correlated, $r=0.46$, $p<0.0001$.

We found a strong correlation between the results of Laser-Doppler blood flowmetry and one of thermographic methods used to monitor peripheral circulation in patients with diabetes mellitus. Cold loading using a baseline temperature limitation of 27℃ were recommended for further examinations. Patients with low blood flow as well as with large differences in their peripheral circulation between cold loading and hot loading had severe coldness in their body surface temperature.

We showed the usefulness of the results of thermography, when quantified by picture processing using computer software, in relation with the results of Laser-Doppler blood flowmetry.

Key word:thermography, Laser-Doppler blood flowmetry, 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]. We observed body surface temperature by thermography for the purpose of estimating peripheral blood flow. Thermography[3] is useful method for body imaging, along with other systems like computed tomography (CT) and magnetic resonance imaging (MRI). In a previous paper[4], we quantified the results of thermography so that it can be useful for studies on body surface temperature in patients with diabetes mellitus. We also introduced a new pre-loading technique with hot water at 36℃ for 5 min (hot loading) for thermography to reduce the influence of weather so reliable observations could be made during different seasons[5].

Here, in a continuation of these studies, we first discussed the results of thermography was fasten in combination with another quantitative results for blood flow obtained by Laser-Doppler blood flowmetry[6]. Secondly, we observed the blood flow in lower limbs under three different conditions: 1) placed at room temperature at 20℃ for 15 min, 2) submerged and warmed for 5 min in a hot bath at 36℃ (i.e. hot loading), and 3) submerged and cooled for 5 min in a water bath at 20℃ (i.e. cold loading)[5] in order to find the optimum conditions for Laser-Doppler blood flowmetry and for thermography.

Finally, we showed that the difference of blood flow between post hot loading and post cold loading in patients with diabetes mellitus was important for coldness in their feet.

Subjects and Methods

The body surface peripheral circulation in 12 cases, including 9 patients with diabetes mellitus who were suffering coldness, numbness or pain in their feet, and 3 healthy volunteers was examined using Laser-Doppler blood flowmetry (Advance Co. ALF21D)[6]. The patients included two females and 10 males, with a mean age of 59.0 years (range from 28－80 years, average of HgbA1C was 10.1% in 9 patients with diabetes mellitus). The subjects were placed for 15min in a room controlled at a temperature of 20℃ and with relative humidity (60%－70%) as described in our previous paper[4]. Five points for each foot, a total 10 points, were observed by Laser-Doppler blood flowmetry. Detectors (ALC probe type C, Advance Co.) were placed using double- stick tape on the base of each toe; placed on the inside of the base of toe to avoid bones. The duration of the observation was 3 min for each point, and the lowest stable reading was used. The average blood flow obtained from 10 points was used for further analysis.

At the same time, the upper side of bilateral lower limbs, 10cm from Malleolus lateralis, was covered with aluminum foil and cotton towels to limit the area of 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. Japan). The body surface area at temperatures higher than the chosen baseline temperatures of 27℃ was calculated with computer software for picture processing (Temperature data

transport and processing program Type 9610M for the thermotracer, NEC-Sanei Co. Japan), and was used as an initial area (Pixels) for observation. Next, the covers were stripped off, and both lower limbs were submerged and cooled for 5min in a water bath containing 10 ℓ of water cooled at 20 ℃ (i.e. cold loading). Water was wiped off from both lower limbs, and both limbs were re-wrapped with aluminum foil and cotton towels. Thermographs were taken 30min after cold loading for calculation of the recovery ratio. The data obtained were processed using the computer software mentioned above. Recovery ratio was calculated as : Recovery ratio= [Total counts of thermography (Pixels) over temperature (T) after cold loading] ÷[Initial counts over T before cold loading] ×100 (%). A baseline temperature of 27℃ was used for picture processing in this study. Following this thermography, measurement of blood flow by Laser-Doppler blood flowmetry was done after this cold loading.

Second, 16 patients with diabetes mellitus who had been suffering coldness, numbness or pain in their feet were examined by Laser-Doppler blood flowmetry and thermography. There were 9 females and 5 males, with a mean age of 69.0 years (range from 51－82 years). The subjects were placed for 15min in the same room and thermographs were obtained as described in above. The body surface area at temperatures higher than the chosen baseline temperatures (26℃, 27℃ or 28℃) was calculated with computer software for picture processing, and results were used as an initial area (Pixels) for observation[5]. After thermography, 10 different points of bilateral foot were measured by Laser-Doppler blood flowmetry. Next, the covers were stripped off and both lower limbs were submerged and warmed for 5min in a hot bath containing 10 ℓ of water warmed to 36 ℃ (i.e. hot loading). Water was wiped off from both lower limbs, and both limbs were re-wrapped with aluminum foil and cotton towels. Thermographs were taken as described above 10min after hot loading in order to observe the initial area which was not influenced by outside weather, especially during the winter season. After the thermography, 10 different points of bilateral foot were measured using Laser-Doppler blood flowmetry.

Third, the covers were stripped off again and both lower limbs were submerged and cooled for 5min in a water bath containing 10 ℓ of water cooled at 20℃ (i.e. cold loading). Water was wiped off from both lower limbs, and both limbs were re-wrapped with aluminum foil and cotton towels. Thermographs were taken 30min after cold loading for calculation of the recovery ratio. The data obtained were processed by the computer software mentioned above. Three different baseline temperatures (T) of 26℃, 27℃ and 28℃ were used in picture processing of the results. After the thermography, 10 different points of bilateral foot were measured using Laser-Doppler blood flowmetry.

Results

The body surface peripheral circulation in 12 cases, including 9 patients with diabetes mellitus and 3 healthy volunteers was examined using Laser-Doppler blood flowmetry. Results of the blood flow in these 12 cases were 1.65－3.58ml／min／100g tissue and the average was 2.24ml／min／100g tissue. At the same time, recovery ratios were 114.9%－0%, and the average was 45.9% (Table 1). We found the recovery ratio and the blood flow

were correlated, $r=0.68$, $p<0.01$ (Fig. 1).

Table 1. The characters, age, sex, disease, hemoglobin A1C, and the recovery ratio (%) of thermography in patients with diabetes mellitus and healthy volunteer used in this study.

Case	Age (years)	Sex	Disease	HbA1C(%)	Recovery Ratio(%)
1	87	Female	DM	10.5	114.9
2	71	Male	DM	9.2	99.6
3	38	Male	Healthy Volunteer	-	93.3
4	28	Male	Healthy Volunteer	-	92.6
5	69	Male	DM+Gastric Ca	8.6	71.8
6	63	Male	DM+Buerger's disease	12.6	35.5
7	64	Male	DM	8.4	17.0
8	57	Male	DM	9.4	8.0
9	40	Male	DM	14.6	7.8
10	80	Male	DM+Cerebral Embolus	8.6	7.3
11	50	Male	Healthy Volunteer	-	3.5
12	61	Female	DM	8.5	0
Average	59			10.1	45.9

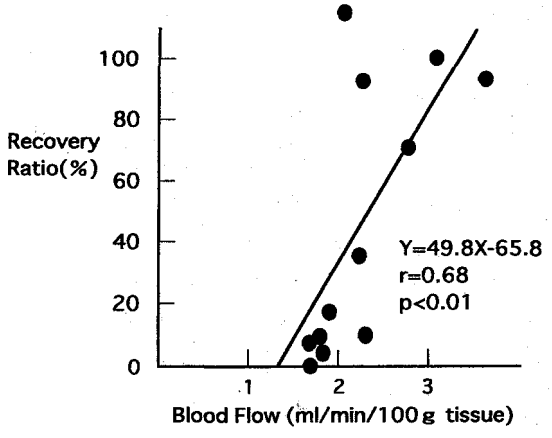

Fig. 1. The recovery ratio (%) of thermography and peripheral blood flow after cold loading in patients with diabetes mellitus and healthy volunteers.

Second, the peripheral circulation in 16 patients with diabetes mellitus was observed at three different conditions: 1) placed at room temperature at 20℃ for 15 min, 2) submerged and warmed for 5 min in a hot bath at 36℃ (i.e. hot loading), and 3) submerged and cooled for 5 min in a water bath at 20℃ (i.e. cold loading), to confirm previous results. Three different baseline temperatures, 26℃, 27℃ and 28℃, were used in processing the thermographic results into pictures. The results of the blood flow in these 16 cases were 1.22−4.62ml/min/100g tissue with an average of 2.62ml/min/100g tissue at room temperature, 0.91−6.24 with an average of 2.80 after hot loading at 36℃, and 1.11−5.36 with an average of 2.41 after cold loading at 20℃. The recovery ratio was 93.5% − 0% with an average of 44.1% (Table 2). Seven out of 16 cases were less than 50% in recovery ratio. There was a correlation between the recovery ratio at a baseline temperature limitation of 27℃ and the blood flow after cold loading, $r=0.59$, $p<0.0002$ (Fig. 2). Nine different conditions were compared in the relation between the blood flow and the recovery ratio (Table 3). The blood flow after cold loading showed the highest correlation, followed by room temperature and after hot loading. The baseline temperature limitation (T) of 27℃ was highest, followed by 26℃ and then 28℃. The difference ratio (%) of blood flow calculated as the blood flow after cold loading divided by the blood flow after hot loading in these 16 patients, and the recovery ratio of thermography were correlated, $r=0.46$, $p<0.0001$ (Fig. 3).

Discussion

We have quantified the results of thermography for the study of peripheral circulation, and found that there was good correlation between the result of Laser-Doppler blood flowmetry and one of therm-

Table 2. The characters, age, sex, hemoglobin A1C, and the recovery ratio (%) of thermography in patients with diabetes mellitus used in this study.

Case	Age (years)	Sex	HbA1C(%)	Recovery Ratio(%)
1	82	Male	8.7	93.5
2	60	Male	10.2	91.3
3	75	Female	12.6	82.3
4	66	Female	6.8	79.0
5	64	Female	8.4	64.6
6	78	Female	10.1	58.0
7	71	Female	7.6	51.8
8	75	Female	9.0	51.7
9	67	Male	8.6	50.5
10	59	Male	8.4	49.2
11	72	Female	11.7	19.9
12	75	Female	12.6	6.1
13	51	Male	12.5	6.1
14	81	Female	7.7	1.3
15	70	Male	7.3	0
16	58	Male	11.3	0
Average	69		9.6	44.1

Table 3. Correlation between the peripheral blood flow and the recovery ratio analyzed quantitatively by thermography.

Blood Flow \ Recovery Ratio (%)	26℃	27℃	28℃
Room Temperature at 20℃	r=0.484 p<0.0001	r=0.483 p=0.0002	r=0.415 p=0.0012
After Hot Loading at 36℃	r=0.456 p<0.0001	r=0.481 p=0.0002	r=0.398 p=0.0013
After Cold Loading at 20℃	r=0.575 p<0.0001	r=0.590 p=0.0002	r=0.519 p=0.0011

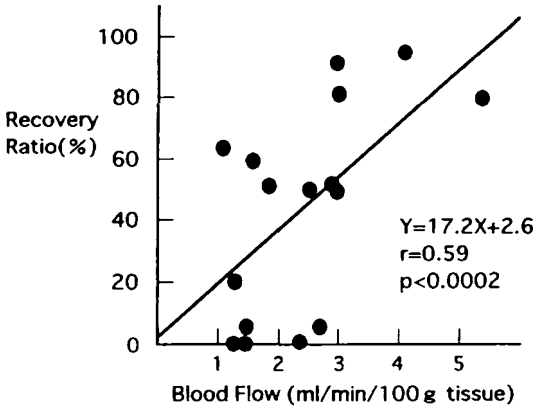

Fig. 2. The recovery ratio (%) of thermography and peripheral blood flow after cold loading in patients with diabetes mellitus.

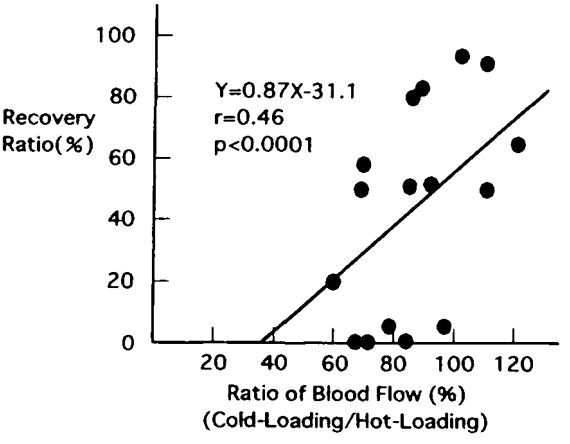

Fig. 3. The recovery ratio (%) of thermography and the ratio of peripheral blood flow (after cold loading/ after hot loading) in patients with diabetes mellitus.

ography in the peripheral circulation in patients with diabetes mellitus. Matsuoka mentioned the usefulness of the thermography for the analysis on peripheral circulation[7]. This is the first paper which shows a quantitative relation between thermography and Laser-Doppler flowmetry. We showed the results of a preliminary study with 12 cases, including 9 patients with diabetes mellitus and 3 healthy volunteers (Table 1, Fig 1). We found the recovery ratio and the blood flow were correlated, $r=0.68$, $p<0.01$. However, one of 3 healthy volunteers had low recovery ratio (3.5%) and low blood flow (1.7ml/

min/100g tissue). He was a heavy smoker, over 40 cigarettes per day. This result might indicated that smoking was a risk factor for low peripheral circulation such as arteriosclerosis obliterans (ASO). Next, we tried to find the optimal conditions for further studies, by changing the baseline temperature for computer processing and conditions such as room temperature, hot loading, and cold loading from the preliminary experiments. We increased the number of cases to 16 in the second study, and obtained the same high correlation between the result of the Laser-Doppler blood flowmetry and one of the thermography ($r=0.59$, $p<0.0002$) (Table 1, Fig. 2). The recovery ratio scattered from 93.5% to 0% when we used the baseline temperature at 27℃ for picture processing. At that condition, we got the highest correlation between the result of Laser-Doppler blood flowmetry and thermography, compared to thermography at 26℃ and 28℃ (Table 3). For blood flow measurements, cold loading is the best condition compared with room temperature and hot loading. The condition of cold loading reflected the patient's low peripheral circulation. From these results, we recommend cold loading and a baseline temperature limitation of 27℃ for further clinical examinations. From the second study, we found that the difference of the blood flow between post cold loading and post hot loading had a relationship with the recovery ratio. To show this, the difference ratio of blood flow was introduced (Fig. 3). There was correlation between the ratio of blood flow and the recovery ratio of thermography ($r=0.46$, $p<0.0001$). This means that the patients with good recovery after cold loading in their blood flow within 30 min had good recovery in their skin surface temperature. Some of them (3 out of 16) had difference ratios of more than 100%. The recovery ratio in thermography was over 50% in all 3 cases. This might mean that the cooled body surface was warmed with over circulation of blood flow to keep body temperature at 36℃ in the mean of homeostasis. However, other patient's mechanism might be damaged by diabetes mellitus. We would like to show the difference of damaged points in the cases of diabetes mellitus and lumbago in the future.

From these observation, we concluded that there was a correlation between the result of Laser-Doppler blood flowmetry and thermography in peripheral circulation in patients with diabetes mellitus, and we recommended cold loading and a baseline temperature limitation of 27℃ for further examinations.

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. Barnes RB, Thermography, Ann N Y Acad Sci 121 : 34−48, 1964.
4. Hosaki Y, Nawa Y, Takeuchi K, Tsugeno H, Ashida 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.
5. 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.
6. Kashima S, Oka S, Ishikawa J, Hiki Y : Measurement of tissue blood volume by Laser blood flowmetry. Japanese Journal of Laser12 : 3−9, 1991.
7. 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.

サーモグラフィーによる体表面温度の測定
3. 体表面温度の回復率と末消血流量との相関

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末梢神経障害を有する糖尿病患者の末梢循環障害の程度を数量的に検討する目的で、下肢に冷感ならびにしびれ感または疼痛を訴える糖尿病患者9症例と健常ボランティア3例の計12例（平均年齢59歳）についてサーモグラフィーを用いて体表面温度を測定した。更に，サーモグラフィーで得られた結果と末梢皮膚血流量をレーザードプラー血流計を用いて測定して得られた結果と比較した。

サーモグラフィーによる測定で得られた結果は回復率として数量化して表示された。回復率の算出方法は回復率＝［冷水負荷後の特定温度27℃以上の体表面温度のサーモグラフィーのPixelの総数］÷［冷水負荷前の特定温度27℃以上の体表面温度のサーモグラフィーのPixelの総数］×100%で求めた。

レーザードプラー血流計を用いて測定して得られた末梢血流量は左右それぞれ5カ所，計10カ所の測定値の平均で表示した。その結果，末梢皮膚温度の回復率と末梢皮膚の血流量との間には正の相関関係（$r=0.68$, $p<0.01$）が認められた。

次に，末梢皮膚血流量について，室温20℃安静15分後，温水36℃浸水負荷10分後，冷水20℃浸水負荷30分後の異なる3条件について、またサーモグラフィーで得られた結果を，画像処理の過程で用いられた，26℃，27℃，28℃の3つの異なる特定温度との関連について検討を行なった。対象は，下肢に冷感ならびにしびれ感または疼痛を訴える糖尿病患者16症例（平均年齢69歳，平均HbA1C 9.6%）について測定した。その結果，末梢皮膚血流量は冷水20℃浸水負荷30分後に測定して得られた結果と，回復率は特定温度27℃で画像処理して得られた結果とが最も相関が高い（$r=0.59$, $p=0.0002$）ことが示された。次に，相関が高い条件は，室温20℃安静15分後に血流量を測定した場合（$r=0.483$, $p=0.0002$）であった。そして温水36℃浸水負荷10分後に測定して得られた結果とが最も相関関係が低い結果となった。

更に，冷水20℃浸水負荷30分後に測定して得られた結果を温水36℃浸水負荷10分後に測定して得られた結果で割った比を%で表示したところ回復率とこの比との間には正の相関関係（$r=0.46$, $p<0.0001$）が認められた。このことから，温水36℃負荷時と，冷水20℃負荷時との差が大きい患者において末梢皮膚温度の低下が著しいことが示された。

これまで悲観血的に測定されてきたサーモグラフィーによる末梢循環の数量的評価の試みは，レーザー血流計による結果と組み合わせることで，両者の間に正の相関関係が示されたことにより，今後，数量化された客観的評価を可能にした。

索引用語：サーモグラフィー，レーザードプラー血流計，冷水負荷，糖尿病，末梢循環