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Evaluation of Body Surface Temperature by Thermography 2. Effect of Pre-loading with Hot Water

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Abstract: The body surface temperature of 41 patients suffering coldness, numbness or pain in their feet was examined using 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 (%). Three different baseline temperatures, 26℃, 27℃ and 28 ℃, were used in processing the thermographic results into pictures. The recovery ratio was susceptible to temperature, and we recommend a baseline temperature limitation of 27℃ for clinical study. A bi-modal distribution of recovery ratio was observed in 18 patients with diabetes mellitus. One group (6 subjects) had high recovery ratio between 80%-100%, and another group (10 subjects) had a low recovery ratio between 0%-19%. The results of thermography were also influenced by weather. To reduce the effect of outside temperature, we used pre-loading with hot water at 36 ℃ for 5 min (hot loading). A large difference in recovery ratio between presence and absence of hot loading was observed in 6 of the 30 subjects. The difference was over-estimated in more than 20% of recovery ratio without hot loading as compared with hot loading in these 6 subjects. The effect of drugs on peripheral circulation, such as beraprost sodium and sarpogrelate hydrochloride, was clear and quantified using thermography under these conditions of hot loading.

Key word: thermography, diabetes mellitus, peripheral circulation, cold loading, hot 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 an useful method for body imaging, along with other systems like computed tomography (CT) and magnetic resonance imaging (MRI). In the previous paper[4], we have quantified the results of thermography so that it can be useful for studies on body surface temperature in patients with diabetes mellitus.

In a continuation of the study, here we first discussed the results of varying the baseline temperature used in picture processing of thermographic results in order to find the optimum conditions for separating and grading patients with poor peripheral circulation. Secondly, we introduced a new pre-loading technique with hot water at 36℃ for 5 min (hot loading), so that we could compare results of thermography observed during different seasons. Finally, we used the new conditions for the study of peripheral circulation improved by drugs such as beraprost sodium[5] and sarpogrelate hydrochloride[6,7].

Subjects and Methods

Forty-one patients who had been suffering coldness, numbness or pain in their feet were examined by thermography; 18 with diabetes mellitus, eleven with osteoarthritis of the spine, five with arteriosclerosis obliterans (ASO), four with varicose vein, one with Buerger's disease and two with unclassified problems. They were 26 females and 15 males, with a mean age of 69.4 years (range of 32-87 years). The subjects were placed for 15min in a room controlled at temperature 20℃ and with relative humidity (60%-70%) as described in our previous paper[4]. 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 (26℃, 27℃ or 28℃) 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 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. 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. 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 (%). Three different baseline temperatures of 26℃, 27℃ and 28℃ were used in picture processing of the results. The effect of hot loading was compared with the effect without hot loading.

The effect of medication beraprost sodium or sarpogrelate hydrochloride was examined in two of these patients with ASO. One was a 66 year old male suffering from bilateral foot numbness. His peripheral

circulation was observed twice by thermography; before and 3 months after intake of 40 μg of beraprost sodium. The second case was a 77 year old female suffering from bilateral foot coldness and numbness. Beraprost sodium had been introduced for her therapy over 12 months prior to our experiment. However, because there was no effect, the therapy was abandoned, and sarpogrelate hydrochloride was used for her therapy. Her peripheral circulation was observed twice by thermography before and 3 months after the intake of 300 mg of sarpogrelate hydrochloride.

Results

We measured body surface temperature by thermography in 41 subjects who had no medication with drugs. The recovery ratios of these patients as measured by thermography are shown in Fig. 1. The recovery ratio was calculated at each temperature, T, by dividing the total counts of thermography (Pixels) over T after cold loading by the initial counts (Pixels) over T before cold loading. The ratio was expressed at different baseline temperatures of 26℃, 27℃ and 28℃. At 28℃, 24 subjects (58.5%) had low recovery ratios between 0%～19%, and only 6 had high recovery ratios between 80%～100%. At 27℃, 19 subjects (46.3%) had low recovery ratios between 0%～19%, and 9 had high recovery ratios between 80%～100%. At 26℃, 6 subjects (14.6%) had low recovery ratios between 0%～19%, and 14 had high recovery ratios between 80%～100%. These thermographic results show that the recovery ratio is susceptible to temperature.

Eighteen of the 41 patients had diabetes mellitus, and the recovery ratios in these patients are shown in Fig. 2. At 28℃, 10 of 18 subjects (55.6%) had low recovery ratios between 0%～19%, and 4 had high recovery ratios between 80%～100%. The mean recovery ratio was 35.4%. At 27℃, 10 subjects (55.6%) had low recovery ratios between 0%～19%, and 6 had high recovery ratios between 80%～100%. The mean recovery ratio was 42.6%. At 26℃, 2 subjects (11.1%) had low recovery ratios between 0%

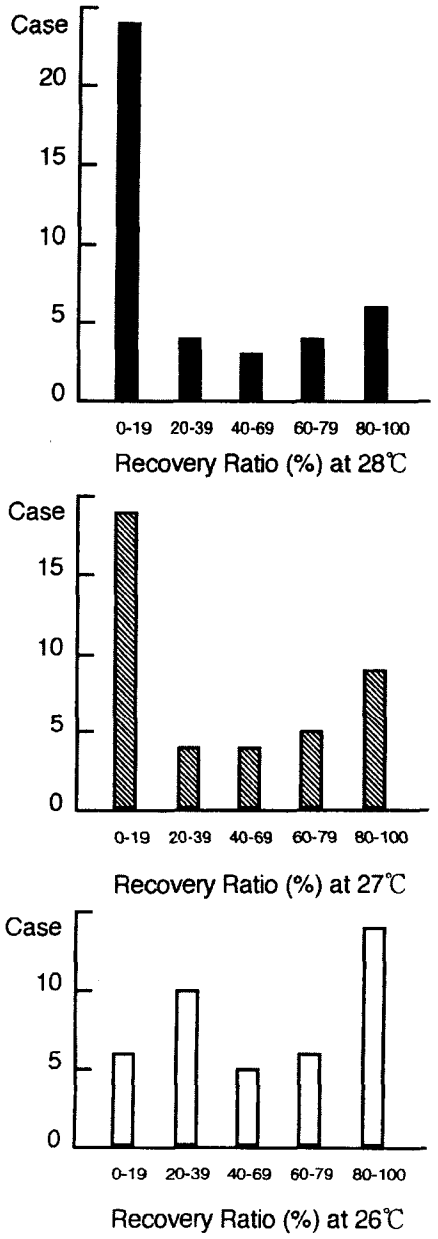

Fig. 1 Results of recovery ratio of 41 patients as measured by thermography. Recovery ratio was calculated at each temperature, T, by dividing total counts of thermography (Pixels) over T after cold loading, by initial counts (Pixels) over T before cold loading. The ratio was expressed at different baseline temperatures of 26℃, 27℃ and 28℃.

~19%, and 8 had high recovery ratios between 80% ~100%. The mean recovery ratio was 60.3%. As shown in Fig. 2, the mean recovery ratio increased as the baseline temperature decreased; the mean increased from 35.4% at 28 ℃ to 60.3% at 26 ℃. Recovery ratio was also susceptible to temperature in the same manner as described in Fig. 1. The ratio showed a bi-modal distribution, one group having a high recovery ratio and another a low recovery ratio.

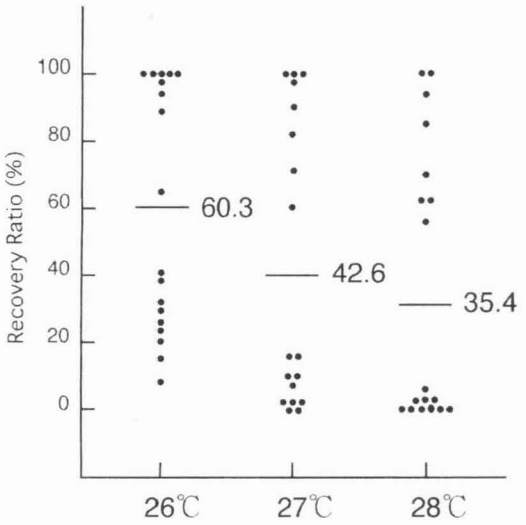

Fig. 2 Results of recovery ratio of 18 patients with diabetes mellitus. The recovery ratio was expressed at different baseline temperatures of 26 ℃, 27 ℃ and 28℃. The mean recovery ratio increased as the baseline temperature was lower.

Original results of thermography are shown in Fig. 3. Thermograph A was taken under the condition without hot loading (room temperature). The total count of pixels over 27 ℃ was 14212. In this thermograph, the top of the toes was not observed when the temperature was under 25℃. Thermograph B was taken under the condition with hot loading. The total count of pixels over 27℃ was 20961. The initial square of body surface could be observed after all the toes were warmed over 27 ℃. Thermograph C was taken after cold loading. The total count of pixels over 27 ℃ was 10543. The top of the toes were not apparent as the temperature was under 25 ℃. The previous recovery ratio under the conditions without hot loading was calculated as 10543 / 14213 = 74.2 %. However, the corrected recovery ratio with hot loading was calculated as 10543 / 20961 = 50.3%. There was 23.9% over-estimation of the recovery ratio in the conditions without hot loading.

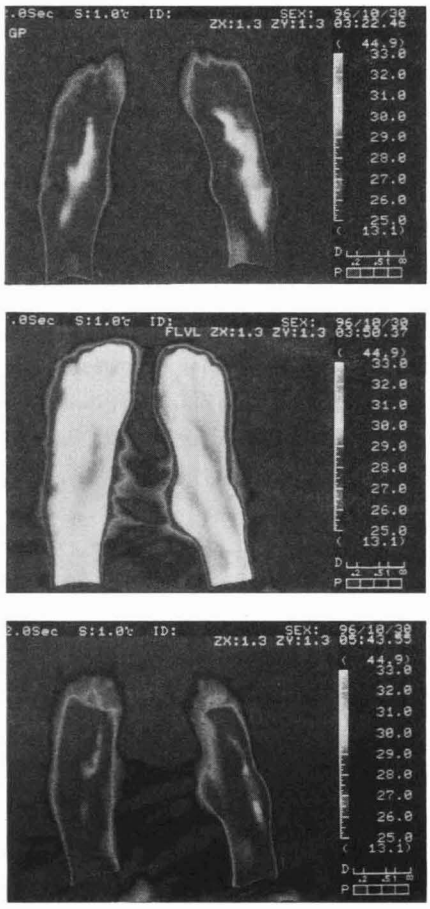

Fig. 3 Results of thermography under the condition without hot loading (room temperature, A), with hot loading (B), and after cold loading (C).

The recovery ratios in 30 patients with and without hot loading (room temperature) are shown in Fig. 4 . The recovery ratio changed over 20% in 6 of the 30 subjects (20%) at each condition of baseline tempera-

ture (28℃ , 27℃ and 26℃) . The remaining 24 subjects (80%) showed little change as a result of hot loading.

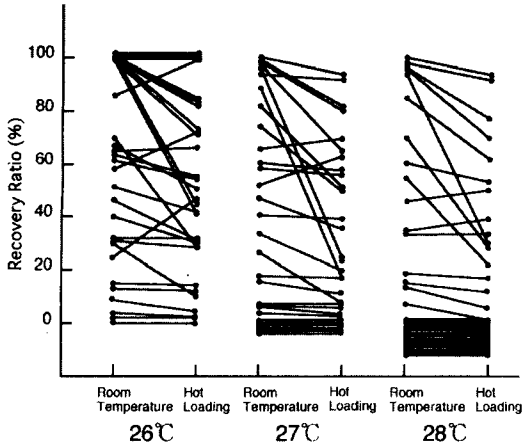

Fig. 4 Results of recovery ratio in 30 patients as measured by thermography. under the condition with hot loading and without hot loading (room temperature).

The effect of beraprost sodium on peripheral circulation in the patient with arteriosclerosis obliterans (ASO) is shown in Fig. 5. The recovery ratio with hot loading increased from 6.9% to 41.9% (6.1 times) at 27℃ , from 0% to 26.9% at 28℃ and from 29.2% to 56.9% (1.9 times) at 26℃, at 3 months after intake of 40μg of beraprost sodium.

The effect of sarpogrelate hydrochloride on peripheral circulation in the patient with ASO is shown in Fig. 6. The recovery ratio with hot loading increased from 1.9% to 17.3% (9.1 times) at 27 ℃, from 0% to 11.8% at 28℃ and from 10.8% to 30.6% (2.8 times) at 26℃, at 3 months after the intake of 300 mg of sarpogrelate hydrochloride.

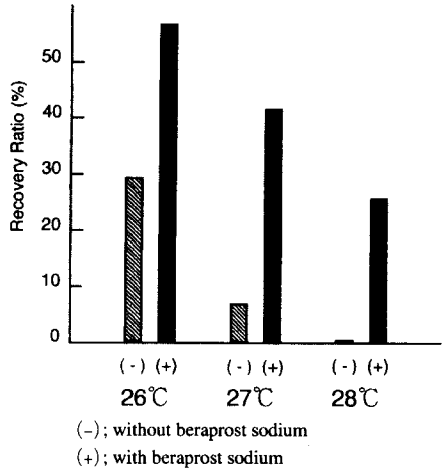

Fig. 5 Effect of beraprost sodium on peripheral circulation in the patient with arteriosclerosis obliterans (ASO). Results of recovery ratio as measured by thermography were shown under the condition with hot loading. Recovery ratio was shown without beraprost sodium (-) and with beraprost sodium (+). The recovery ratio increased at each temperature after the treatment with beraprost sodium.

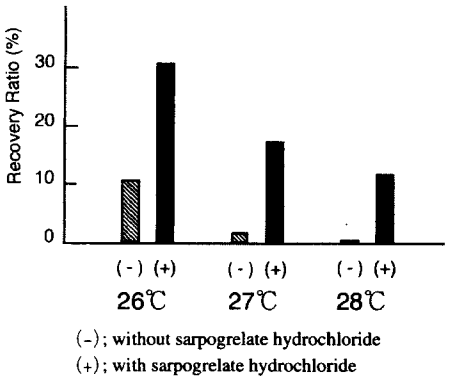

Fig. 6 Effect of sarpogrelate hydrochloride on peripheral circulation in the patient with ASO. Results of recovery ratio as measured by thermography were shown under the condition with hot loading. Recovery ratio was shown without sarpogrelate hydrochloride (-) and with sarpogrelate hydrochloride (+). The recovery ratio increased at each temperature after the treatment with sarpogrelate hydrochloride.

Discussion

We have quantified the results of thermography for the study of peripheral circulation, and found that they are susceptible to temperature. The reason is that, unlike healthy volunteer's whose body surface temperatures are typically over 28 ℃, patients with coldness, numbness or pain in their feet typically have body surface temperatures that are less than 28 ℃, occasionally under 25 ℃. To make a comparison between good and poor peripheral circulation, we previously recommended a baseline temperature limitation of 28 ℃[4] . However, this study for peripheral circulation, a baseline temperature of 28 ℃ was too high to compare results among the patients and between peripheral circulations before and after medication with prostaglandin (beraprost sodium) and sarpogrelate hydrochloride. In our previous paper[4], there is a possibility that the results of thermography were influenced by background radiation at 27℃ or a lower temperature. Therefore, in this study we examined three different baseline temperatures of 28℃, 27 ℃ and 26℃ in order to find the most suitable temperature. 58.5% of patients with diabetes mellitus, arteriosclerosis obliterans (ASO), varicose vein and osteoarthritis of the spine had low recovery ratios between 0%～19% at baseline temperatures of 28℃. This condition might be too critical to separate good and poor peripheral circulation. To test whether a baseline temperature of 28℃ was too high to separate the poor peripheral circulation, we examined 18 subjects with diabetes mellitus. From this study there were 2 groups; one group had a high recovery ratio and the other had a low recovery ratio. To separate the group of patients with low recovery ratios, baseline temperatures of 27 ℃ or 26℃ might be better. However, patients with low recovery ratios could be over estimated at baseline temperatures of 26℃. From these results, a difference of only 1 ℃ in picture processing of the result of thermography causes large differences in clinical evaluation of thermography.

In comparison of thermographic results, especially when comparing the effects of medication, the change of season becomes a problem if the weather changes 3 months after the intake of drugs with an effect on peripheral circulation. In some cases, patients were examined after a 20-30 min walk in the winter season at our hospital. Their lower feet had been cooled while walking in the snow. The body surface temperature did not rise in the room controlled at 20℃ within 15 min. Sometimes, their thermographic results before cold loading were under the results of cold loading at 20℃ for 5 min. In this case, the recovery ratio was over-estimated, as the initial square of body surface was under-estimated because a large potion of the body surface could not rise over 26℃ or 27 ℃ within 15 minutes in a room controlled at 20℃.

However, in the winter season, the need for examination with thermography increases. Patients complain of coldness, numbness or pain in their feet in the winter season. At the beginning of this study, we made examinations from May to October when the weather was warm. Examinations were done between 2p.m. and 4p.m., when the outside temperature was the highest in the day, typically higher than 20 ℃. To reduce the effect of seasonal temperature variations, we added the pre-loading in 36 ℃ water for 5min, called "hot loading". A comparison made at room temperature between patients with and without hot loading showed a large difference over 20% in recovery ratio in only 6 subjects (20%), whereas little difference in 24 subjects (80%). This means that the original method might be stable, but there is a possibility that the recovery ratio was influenced by weather. It also makes it more difficult to compare results taken during different seasons, especially winter and summer.

Our method using hot loading could make it possible to get constant thermographic results, thereby minimizing the effect of weather. As described above, in comparing the recovery ratios in 30 subjects at different baseline temperatures, we found that at 28 ℃, 18 subjects (60%) had low recovery ratios

between 0～19%, and 2 (6.7%) had high recovery ratios between 80～100%. At 27 ℃, 14 subjects (46.7%) had low recovery ratios between 0～19%, and 4 (13.3%) had high recovery ratio between 80～100%. At 26 ℃, 7 subjects (23.3%) had low recovery ratios between 0～19%, and 7 (23.3%) had high recovery ratios between 80～100%. In the condition with hot loading, recovery ratio was still susceptible to temperature.

We examined the best conditions for thermography in patients with arteriosclerosis obliterans (ASO). Results of recovery ratio were compared before and after medication, with prostaglandin (beraprost sodium) and sarpogrelate hydrochloride. In the study of patients with beraprost sodium and sarpogrelate hydrochloride, the differences of peripheral circulation between the two patients were not clear at the baseline temperature of 28 ℃, as the recovery ratios were all 0% before medication. However, their recovery ratios did change at baseline temperatures of 27 ℃ and 26 ℃. Therefore, lower baseline temperatures of 27 ℃ and 26 ℃ were useful for separation of patients with poor peripheral circulation. In evaluation of the effects of these drugs on patients with poor peripheral circulation, the biggest difference of recovery ratio could be obtained at the baseline temperature of 27℃. Whereas at the baseline temperature of 28 ℃, it became difficult to compare the results of recovery ratio before and after medication, since the original recovery ratio was 0%.

From these observations, we conclude that preloading, or "hot loading", is essential for further examination of thermography, and we recommended the baseline temperature limitation of 27 ℃ for clinical study.

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サーモグラフィーによる体表面温度の測定
2. 温水負荷の効果

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下肢に冷感ならびにしびれ感または疼痛を訴える患者41症例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。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T℃以上の体表面温度のサーモグラフィーのPixelの総数］÷［温水負荷前の特定温度T℃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。サーモグラフィーで得られた結果と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T℃との関連について検討を行なった。その結果，回復率は特定温度T℃に影響を受けやすいことが明らかとなった。下肢の体表面温度の低い臨床症例においては27℃の条件が適当と考えられた。

前述の41症例中の18症例の糖尿病患者について検討を行なった。そのサーモグラフィーの結果は，比較的回復率の高い（80％～100％）群の6症例と比較的回復率の低い（0％～19％）群の10症例の2群に別れた。わずかに残り2症例が20％から79％の間であった。

下肢の症状が気温の低い時期に出現しやすいためにサーモグラフィーの検査を冬期に行なう必要性が高まった。しかし，天候の影響を受けやすいために冷水負荷前の測定領域の下肢が冷えすぎているために20℃の室温に15分間の安静時間では体表面温度が十分に暖まることが出来ず，27℃以上の領域として測定範囲全体を観察できない問題に直面した。この問題点を解決する手段として36℃の温水に5分間下肢を入れて暖める温水負荷を加えることにした。そこで，温水負荷を行なった症例30症例について，温水負荷を行なう前（室温）の回復率と温水負荷を行なった後の回復率について比較検討を行なったところ，20％にあたる6症例において温水負荷を行なわなかった場合に20％以上の回復率の過剰評価が認められた。

温水負荷を行なうことにより年間を通じて天候の影響を最小限にすることが可能となり，この結果，長期間の内服薬の末梢循環に及ぼす影響の測定を行なった場合に，季節の影響を最小限にしてサーモグラフィーにより回復率を用いて数値化された測定結果を検討することが可能となった。

具体的に末梢循環の改善に薬効が有ると言われている薬剤であるベラプロストおよびサルポグレラートを3ヵ月間内服した場合の前後のサーモグラフィーで得られた回復率について検討を行なった。その結果はベラプロストにおいては，6.9％から41.9％に上昇または回復率の6.1倍の上昇を認めた。サルポグレラートにおいては，1.9％から17.3％に上昇または回復率の9.1倍の上昇を認めた。以上より，温水負荷を加えたサーモグラフィーの測定結果の数値化は下肢に症状の有る患者の末梢循環の評価ならびに薬効の評価の比較に有用であることが表わされた。

索引用語：サーモグラフィー，冷水負荷，温水負荷，糖尿病，末梢循環