INVESTIGATIVE REPORT

Freezing Fingers Syndrome, Primary and Secondary Raynaud's Phenomenon: Characteristic Features with Hand Thermography

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The aim of the present study was to establish a thermographic model of healthy subjects' hands and compare it with a model of the hands of patients with freezing fingers syndrome, a group usually regarded as a healthy population. A further aim was to establish the thermographic parameters that distinguish primary Raynaud's phenomenon (RP) from secondary RP. The study was conducted on a group of 74 subjects, divided into 3 groups: patients with freezing hands symptoms (G1), those with primary RP (G2), and those with limited scleroderma (G3). In addition, 69 healthy volunteers served as a control group (G4). The most distinctive features of healthy subjects' hands are the thermal symmetry between left to right measurements ($\Delta T < 0.5°C$) and between mean temperatures of the metacarpus and digits ($\Delta T < 0.5°C$ (1°C maximum)). A negative correlation was found between mean hands temperature and age of subjects in G4 ($p < 0.0001$). All the temperatures observed in G4 subjects were significantly higher than among patients in G1, G2 and G3 ($p < 0.001$). No significant differences were found between mean temperatures in G2 and G3. RP should be suspected when differences between mean temperatures of the metacarpus and digits are $\geq$ to 3°C. Moreover, we suggest that a cut-off point > 1°C is established for subjects with "freezing" symptoms. *Key words: thermography; Raynaud's phenomenon; scleroderma; freezing fingers; freezing hands.*

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The principle on which medical thermography is based (heat differentiation within the body as an indicator of disease) was first noted by Hippocrates in 480 BC. At that time it was a common practice among physicians to place mud or wet clay over a patient's body and observe where the clay dried first; these "hot" areas were considered to be the sites of underlying disease.

A thermogram is an image obtained by visualizing invisible infrared radiation. Thermography in medicine was popularized mainly by the Canadian researcher Ray Lawson, who observed temperature changes in neoplastic breast lesions (1, 2).

The literature reports the use of thermography in various fields of medicine has expanded since (3–7). Nevertheless, the evidence is limited because the studies have usually been conducted among numerically small groups. Another problem is the lack of a unanimous thermographic model of healthy subjects' hands. These 2 issues have often been emphasized by authors who work with thermographic cameras (8–12). Therefore, one aim of the present study was to establish a thermographic model of healthy subject's hands and to determine whether there are any statistically significant differences between particular age groups. Moreover, we also attempted to obtain a thermographic model of hands in patients with freezing fingers syndrome; a group usually regarded as a healthy population. To the best of our knowledge, there is no strict and clearly determined medical definition of freezing fingers syndrome. It is widely known that this problem is most commonly a concern for young women; however, there is lack of epidemiological studies addressing this issue. Furthermore, this study attempted to establish the thermographic parameters that can be used to distinguish between primary and secondary (due to systemic scleroderma (SSc)) Raynaud's phenomenon (RP), since the data regarding the problem are sometimes divergent (13). A further aim of the study was to determine whether there is any correlation between hand temperature in patients with limited scleroderma and the degree of disease activity, severity and duration.

MATERIALS AND METHODS

Subjects

The study was conducted within a group of 74 subjects (17 men, 57 women), age range 18–72 years (mean 43.1 ± 14.7 years). The studied population was divided into 3 groups: group 1 (G1): 29 patients with symptoms of freezing hands but without RP; group 2 (G2): 23 subjects with primary RP; group 3 (G3): 22 subjects with systemic scleroderma of acral type (limited scleroderma), diagnosed according to criteria proposed by the American Rheumatism Association (ARA). All of the patients with any other significant co-morbidities or abnormalities that could affect the results and jeopardize their reliable presentation in the study were excluded. Sixty-nine healthy volunteers (37 men, 32 women) aged 18–84 years (mean 47.9 ± 17.0 years) served as a control group; group 4 (G4). Detailed demographic characteristics of the study population are shown in Table I.

G1 comprised generally healthy people who had had freezing fingers syndrome for at least 2 years. They had no symptoms of RP/SSc (according to well-defined and established criteria: see below), chronic diseases, or drug/tobacco intake. The severity of freezing was measured on a 10-point visual analogue scale (VAS), where the higher the value, the more severe were the reports of freezing.

G2 consisted of individuals with RP classified according to criteria proposed by LeRoy & Medsger (14): bilateral, episodic, bi-or triphase vascular reaction of the fingers, toes, ears or nose, well-documented, for example, by cold stimulation or by other quantitative measures.

G3 comprised patients with limited scleroderma. The disease was diagnosed on the basis of ARA criteria. Median disease duration was 4 years. The disease activity index was determined for each patient on the basis of physical examination and additional tests with compliance to the guidelines provided by the European Group for Research on Systemic Scleroderma (15). The score of the disease activity index ranges from 0 to 10 points (0: none, 10: maximum disease activity). The severity of the disease was measured according to the scale proposed by Medsger et al. (16) (range 0–36 points, where a higher score indicates higher severity).

G4 comprised healthy individuals according to the World Health Organization (WHO) definition; they denied smoking (ever) and reported no symptoms of freezing hands.

Thermography

All thermographic examinations were conducted with compliance to the recommendations proposed by the European Association of Thermology (EAT) with the use of a V-20 II VIGO System Camera (17). All thermograms were obtained in the same stable conditions (the distance between the camera and the skin of the dorsal surface of the hands was 60 cm). The images obtained were analysed by the means of the "Color 1 Continuous" palette (temperature range; 13–46ºC) with the following set of colours: black, violet, red, orange, yellow and white (the darker the colour, the lower the temperature). After delineating the skin areas of a given shape or size, the temperatures of the selected location were calculated by means of the software provided by the camera's manufacturer. For every thermographic image the minimal, maximal and mean temperature of the whole hand, digits and metacarpus were calculated, in addition to, $\Delta T1$ (the difference between whole left-hand and whole right-hand mean temperatures), $\Delta T2$ (the difference between mean temperatures of the metacarpus and digits of the right hand), $\Delta T3$ (the difference between mean temperatures of the metacarpus and digits of the left hand) and $\Delta T4$ (the difference between mean temperatures of the digits of the left-hand and right-hand) (Fig. 1).

The study was approved by the ethics committee of Wroclaw Medical University (protocol number- KB- 611/2007).

Statistical analysis

Statistical analysis was performed using the Student's *t*-test and the Pearson's correlation coefficient. We also calculated
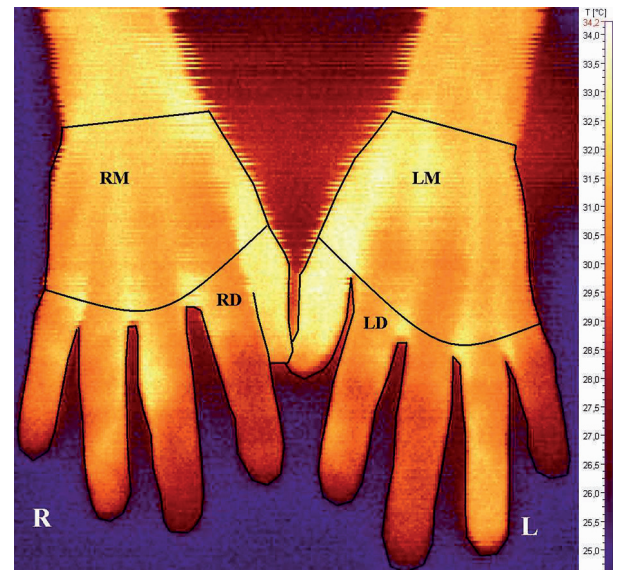

Fig. 1. Thermogram of the hands of a subject with scleroderma. Area exploited for calculation of mean temperature of the left metacarpus (LM), left digits (LD), right metacarpus (RM), and right digits (RD). $\Delta T1=|LM+LD–RM+RD|$; $\Delta T2=|RM–RD|$; $\Delta T3=|LM–LD|$; $\Delta T4=|LD–RD|$.

sensitivity (Sens), specificity (Spec), positive predictive value (PPV) and negative predictive value (NPV) for various cut-offs. $p < 0.05$ was considered statistically significant.

RESULTS

The mean temperatures of the left and right hands in healthy volunteers (G4) was 32.9 ± 3.9ºC and 32.5 ± 1.4ºC, respectively. The observed left-to-right differences were not statistically significant. Similar results were found in G1 patients (32.0 ± 3.9 and 32.5 ± 1.4, respectively). In G1 and G4 the thermal symmetry (according to EAT definition – both $\Delta T1 < 0.5$ºC and $\Delta T4 < 0.5$ºC) between the left and right hand was observed among most of the patients (91% and 83%, respectively), whereas no such symmetry was observed among G2 and G3 patients (mean $\Delta T1 = 0.6 \pm 0.6$ and $\Delta T1 = 0.7 \pm 0.5$, respectively). In these 2 groups the asymmetry was even more marked when the left to right mean temperature differences of the digits ($\Delta T4$) were taken into account (mean $\Delta T4 = 0.7 \pm 0.6$ and $\Delta T4 = 0.8 \pm 0.7$, respectively) (Table SI; available from http://www.medicaljournals.se/acta/content/?doi=10.2340/00015555-1508). In all

Table I. *Demographic data of study population*

Group	M/F	Mean age (years)	Description
G1	5/24	40.7 ± 13.5	Study subjects were recruited from a group of healthy volunteers. From the group of 98 subjects, 29 (29.6%) had freezing hands symptoms. Those who denied the problem ($n=69$) constituted G4, which served as a control group. Left-/right-handedness: 2/27
G2	4/19	36.6 ± 14.2	Left-/right-handedness: 1/22
G3	8/14	51.7 ± 12.9	ANA titres: 1:1280 (12 subjects); 1:640 (4 subjects); 1:320 (6 subjects). Left-/right-handedness: 2/20
G4	32/37	47.9 ± 17.0	Left-/right-handedness: 6/63

G1: patients with complaints of freezing hands symptoms; G2: patients with primary Raynaud's phenomenon; G3: patients with limited scleroderma; G4: healthy volunteers; M: male; F: female; ANA: anti-nuclear antibodies.

of the analysed groups the left-/right-handedness was not of statistical relevance.

Moreover, a negative, significant, strong correlation was found between all mean temperatures (whole hands, metacarpus and digits) and age of the G4 subjects ($r=-0.59$, $p<0.001$ and $r=-0.63$, $p<0.001$ for left and right hand, respectively), whereas such a correlation was absent among G1, G2 and G3 patients. In G3, a negative correlation was found between the temperatures of the digits and the duration of the disease ($r=-0.5$, $p<0.05$ and $r=-0.47$, $p<0.05$ for left and right hand, respectively). All temperatures assessed in G4 subjects were significantly higher than among patients in G1, G2 and G3 ($p<0.001$).

In G1 patients, usually considered by other authors as a healthy population, the values of $\Delta T2$ and $\Delta T3$ were significantly higher compared with G4 ($p<0.001$) (Fig. 2). Moreover, both $\Delta T2$ and $\Delta T3$ were significantly higher among patients in G2 and G3 than among subjects in G1 ($p<0.001$ and $p=0.01$, respectively) and G4 ($p<0.001$ for all comparisons). No significant differences were found between all analysed mean temperatures in G2 and G3 subjects (Table SI). The mean VAS score for the severity of freezing fingers among G1 patients was 4.7 ± 2.3 points. In this group, statistically significant negative correlations between the mean temperatures of whole hands, digits, metacarpus and VAS were revealed ($r=-0.48$, $p<0.05$ and $r=-0.54$, $p<0.05$ for left and right hand, respectively).

The mean Medsger Disease Severity Score in G3 patients was 6.3 ± 2.1 points (range 4–12 points). The mean score of disease activity index for systemic sclerosis, assessed according to the criteria of the European Scleroderma Study Group, was 3.8 ± 1.7 points (range 2–8 points). No statistically significant correlations were found between the measured temperatures and disease severity score or disease activity index. Moreover, neither analysed hands' temperatures, nor disease severity score, nor disease activity index correlated significantly with anti-nuclear antibody (ANA) titres (data not shown).

DISCUSSION

All of the thermograms were performed on the dorsal surfaces of the hands. The same imaging technique has been used by most researchers in this field (8, 13, 18, 19), with the exception of Selenko-Gebauer et al. (20) who evaluated palmar surfaces in patients with RP. However, the change in the surface evaluated may cause the differences due to sweating exacerbated, for instance, by emotional stress accompanying an examination.

Therefore, we conclude that it is advisable to perform thermographic imaging on the dorsal surface of the hand.

The range of the mean temperature of whole hands among G4 volunteers was surprisingly broad (but almost identical for left and right hands). The temperatures differed by up to 7.3ºC (Table SI). The findings revealed that the mean hands' temperature is a non-specific and individual factor. The arithmetic average of the mean hands' temperatures was 32.9 ± 3.9ºC and 32.5 ± 1.4ºC for the left and right hand, respectively. The data on this issue are limited; thermography procedures were usually performed within small populations (approximately 12 subjects), but the findings generally corroborated the results of our study (10, 21–23). Lower temperatures were reported by Savastano et al. (24), who found the mean temperature to be 29.1ºC (11 subjects, all under 50 years of age). The divergence between the mean temperatures may be explained by the fact that, in our study, patients with symptoms of freezing hands were excluded from the control group (they constituted group G1).

Though the data are limited, the negative correlation between all mean temperatures (whole hands, metacarpus and digits) and the age of the healthy subjects presented in this paper was also observed by Niu et al. (23). They reported a significant decrease in hands' temperature among subjects over 60 years of age.

In medical thermography, a value of 0.5ºC is ascertained as the cut-off point of clinical thermal symmetry between corresponding left/right-body localizations (6, 8, 10, 17, 25–27). The results of our research conducted among patients of G4 and G1 corroborate this conclusion. Moreover, our findings are concordant with those reported by Niu et al. (23). In contrast, the thermograms of G2 and G3 patients revealed thermal asymmetry ($\Delta T1>0.5$ºC) in most cases (Table SI). The results for asymmetry estimated by $\Delta T4$ were even more pronounced. Our results regarding primary and secondary RP in connection with thermal asymmetry were similar to those obtained by other researchers (11, 21). Therefore, the thermal symmetry ($\Delta T1$) between the left and right hand may serve as a helpful indicator for distinguishing RP among patients with symptoms of freezing hands. $\Delta T4$ seems to be an even more helpful and sensitive parameter for such distinction, while $\Delta T4>0.5$ºC was found for only 13% of controls and 7% of G1 individuals.

Amongst the healthy population, freezing hands syndrome affects approximately 30% of individuals, with a predominance in women (83%). It seems that it is a relatively frequent problem; however, epidemiological data on this subject are very limited. This can be explained by the lack of the objective measurement methods. In comparison with G4 subjects, the G1 subjects (generally considered to be a healthy population) had significantly lower mean temperatures of the whole hands, digits and metacarpus, while the values of $\Delta T2$ and $\Delta T3$ in those patients were significantly higher. The majority of G1 patients (89.7%) had $\Delta T2$ and $\Delta T3>1$ºC. Moreover, considering the revealed significant, strong negative correlations between the mean temperatures of whole hands, digits, metacarpus, and VAS evaluation
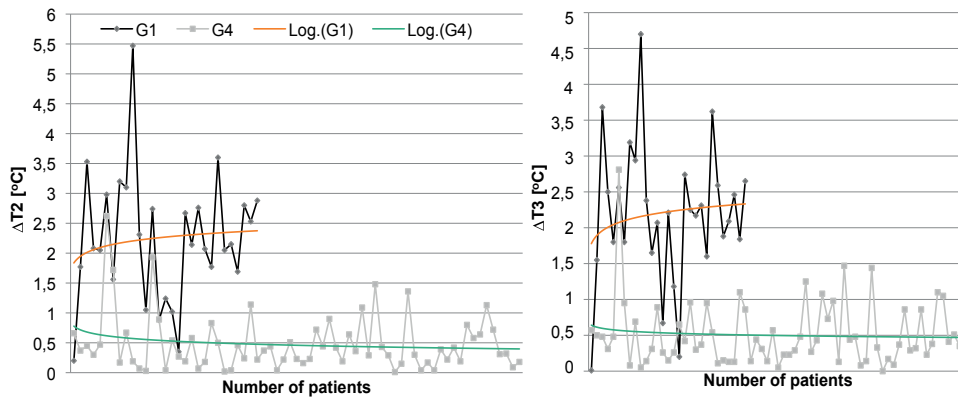
Fig. 2. (a) ΔT2 for G1 vs. G4, shown with logarithmic trend lines. (b) ΔT3 for G1 vs. G4, shown with logarithmic trend lines. G1: patients with freezing hands symptoms; G4: healthy volunteers.

of freezing symptoms, thermographic imaging may be a useful method for the objectification of the severity of symptoms of freezing hands. Concordant results (concerning RP) have been obtained by other researchers (15, 16).

Apart from the mean hand temperature, many authors emphasize the importance of ΔT2 and ΔT3 (8, 9, 13, 21). Ammer (8) defines RP thermographically as a situation in which ΔT2 and ΔT3 are >0.5ºC, whereas mean hand temperature is of no significance. In G2 patients the mean values of ΔT2 and ΔT3 were assessed as follows: 3.4 ± 1.6ºC and 3.3 ± 1.2ºC, respectively. None of the individuals in G2 had ΔT2 or ΔT3 < 0.5ºC. Therefore, Ammer's thesis was positively confirmed in our research. Also, up to 86% of G2 subjects had ΔT2 and ΔT3 ≥ 2ºC (≥ 3ºC up to 65%). Similar results were obtained in G3 (Fig. 3). Thus, it appears reasonable to lessen the strict criteria for diagnosis of primary and secondary RP (due to the SSc). In our opinion, RP should be suspected when ΔT2 or ΔT3 ≥ 3ºC. This claim is supported by the results obtained in G1, where the mean values of ΔT2 and ΔT3 were approximately 2ºC, and 93% of patients from this group had ΔT2 and ΔT3 > 0.5ºC. In addition, in the majority of G4 controls, ΔT2 and ΔT3 were < 0.5ºC and 1.0ºC (approximately 70% and 90%, respectively).

Many researchers emphasize the impossibility of distinguishing primary and secondary RP by means of thermographic devices (10, 18). Nevertheless, some attempts are being made to address this issue. Anderson et al. (9) declare ΔT2 and ΔT3 to be quite sensitive indicators. They assume that the greater are ΔT2 and ΔT3, the greater the probability of secondary RP due to SSc. However, the results of our research (conducted in similar conditions) are in opposition to those reported by Anderson et al. (9). The mean values of ΔT2 and ΔT3 were even greater in G2 subjects than in G3 subjects (statistically not significant). This may be due to the fact that the recruitment criterion was the primary RP of long duration (more than 2 years).

ANA are specific for approximately 90–95% of people with SSc (28). However, the substantial majority of researchers state that neither ANA presence nor titre correlate with the activity/severity of the disease (28, 29). Our results are concordant with the above-mentioned statement. No correlation between ANA and hand temperatures was found, which is in opposition to findings by Watanabe et al. (13). They revealed the presence of a significant correlation between hand temperatures and ANA titre. However, there is a lack of data on this issue. Murray et al. (11) and Watanabe et al. (13) suggested that a decrease in hand temperatures is related to the increase in SSc severity. However, we were unable to observe such a correlation. This may be explained by the fact that our G3 patients, according to the Medsger scale (16), had only mild-to-moderate
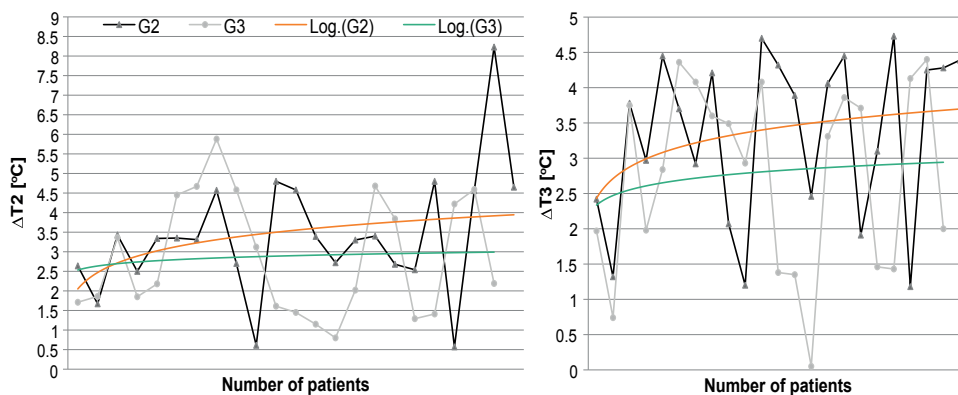

Fig. 3. (a) ΔT2 for G2 vs. G3, shown with logarithmic trend lines. (b) ΔT3 for G2 vs. G3, shown with logarithmic trend lines. G2: patients with primary Raynaud's phenomenon; G3: patients with limited scleroderma.

disease (SSc of acral type with almost no visceral involvement).

On the basis of our findings we were able to determine the most important features of the thermographic model of healthy subject's hands, which are: thermal symmetry between left to right measurements ($\Delta T1 < 0.5$ºC and $\Delta T4 < 0.5$ºC) and differences in $\Delta T2$ and $\Delta T3$ values of < 0.5ºC (with a maximum of 1ºC). It appears that the left-/right-handedness is not of relevance here.

Moreover, it was observed that the incidence of freezing hands was 30%, with a predominance among women. The thermographic camera may serve as the objective device for the evaluation of the grade of "freezing problem", as well as for distinguishing patients with RP from the whole group of patients with freezing hands. In our opinion, RP should be suspected when $\Delta T2$ or $\Delta T3$ are ≥ 3ºC (Sens = 0.65, Spec = 0.83, PPV = 0.75 and NPV = 0.75).

To the best of our knowledge, this is the first report distinguishing patients with "freezing hand problems" from the healthy population with regard to thermographic results. We conclude that a cut-off point of $\Delta T2$ and $\Delta T3$ of > 1ºC should be established for subjects with symptoms of freezing (Sens = 0.90, Spec = 0.88, PPV = 0.76 and NPV = 0.95).

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