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Quantification of thermal asymmetry

Part 1: Normal values and reproducibility

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The use of thermography in evaluating nerve injury is based on the presence of temperature asymmetries between the involved area of innervation and the corresponding area on the opposite side of the body. However, interpretation of the thermographic image has been troubled by subjectivity. This paper describes a computer-calculated method of collecting data that eliminates subjective biases. Comprehensive normative data are presented on the degree of thermal asymmetry in the human body.

The degree of thermal asymmetry between opposite sides of the body (ΔT) is very small. For example, the value of ΔT for the forehead (mean ± standard deviation) was 0.18° ± 0.18°C, for the leg it was 0.27° ± 0.2°C, and for the foot it was 0.38° ± 0.31°C. These values were reproducible in both short- and long-term follow-up measurements over a period of 5 years. The ΔT's reported here were obtained from 40 matched regions of the body surface of 90 asymptomatic normal individuals. These values can be used as a standard in assessment of sympathetic nerve function, and the degree of asymmetry is a quantifiable indicator of dysfunction.

Key Words · thermography · thermometry · nerve injury

The skin, one of the largest organs of the body, is equipped with a network of vessels accompanied by dense nerve fibers. It serves as the body's thermoregulator, controlling blood flow within a few millimeters of the body surface.[6] The system is governed by autonomic nerve impulses generated from the hypothalamus and the brain as a whole. The system is both anatomically and physiologically symmetrical.[5] For this reason, localized, asymmetric temperature changes at the body surface have interested physicians as far back as Hippocrates.[8] The recent development of sophisticated thermographic measuring devices that can provide a map of the temperature of the body surface has increased this interest.[7] However, thermography has been criticized for its possible lack of objectivity, arising from interpretation of the colored thermogram. To minimize such subjectivity, it is proposed to use computer-calculated temperature differences (ΔT's) between homologous sections of the body as measures of the degree of thermal asymmetry.[7] This paper summarizes the ΔT's calculated for normal control subjects and discusses their use as a standard for evaluation of sympathetic nerve function in man.

Normal Subjects and Methods

Normal Subjects

The participants in this study were 90 healthy volunteers (38 men and 52 women) ranging in age from 19 to 59 years. All participants gave informed consent for the procedure. None of the participants reported ongoing acute or chronic pain, such as low-back pain, sciatica, recent or old body injury, or surgical procedures.

Study Procedure

All tests were conducted in the thermography laboratory, which is located in a central part of the hospital building, has no windows, and is free from drafts and interruptions. There is only one door in the testing room and conditions are monitored to ensure year-round ambient temperature stability at 23° to 26°C and humidity between 45% and 60%. Recognized thermographic guidelines are strictly followed.[4] Volunteers disrobe and remain in the laboratory for approximately 20 minutes in order to equilibrate their body-surface temperature to the room temperature.

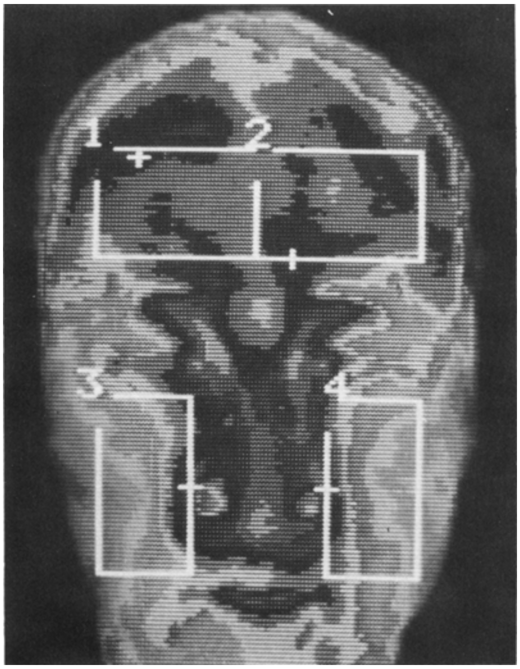

FIG. 1. Facial regions of interest. This close-up photograph reveals the individual picture elements (pixels) within a specified region of interest (ROI). The ROI on the right side of the forehead is labeled, that on the left side of the forehead, 2. The right and left cheeks are 3 and 4, respectively. The temperature of the right side of the forehead is 34.27°C, and that of the left side of the forehead is 34.32°C, so the ΔT for the forehead is 0.05°C. The ΔT for the cheeks is 0, since the cheek temperatures are equal (33.20°C on both sides).

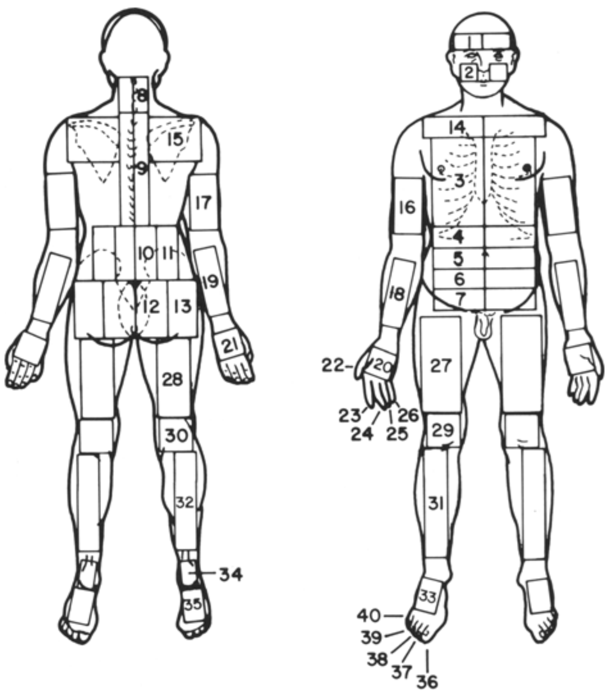

FIG. 2. Body segments assessed by computerized thermography. Each box represents a region of interest (ROI) identified on the computer for analysis. See also Table 1. Some areas, such as hair-covered areas (eyebrows) or moist areas (lips or nostrils), could provide misleading temperature data and are excluded from the ROI.

Equipment

From December, 1982, to December, 1983, the work was carried out using the JTG-500 M thermometry system (29 subjects) and thereafter an Infra-Eye-160 thermometry system was used (61 subjects).* Comparable systems are commercially available for clinical use. The equipment consisted of a computer-controlled infrared scanning system designed to scan the body surface (90,000 data points per scan, each point being 1 sq mm in size at a distance of 50 cm between detector and subject) and to provide the information necessary for the computer to construct a temperature map of the skin surface, which was then displayed on a color CRT monitor (Fig. 1). Typical thermographic systems are capable of discriminating differences as small as 0.03°C, and may be used to assess the absolute temperature of specific points on the body; alternatively, by employing one of the system's other features, it is possible to calculate the average temperature of specified regions of the body that are identified for the computer. These specific regions are referred to as regions of interest (ROI's).

Each scan lasts 3.7 seconds. Once a scanning image is obtained, the technician maps out the ROI on the image on the CRT screen, dividing the skin surface into one of the 80 sensory segments (Fig. 2) approximating the areas of innervation of the major peripheral nerves and spinal segments.[2] A built-in computer system compiles and analyzes the temperature data and displays the image on the CRT screen at the moment of completion of each 3.7-second scan. The technician notes 10 sequential temperature values for each ROI or point, and the ΔT's are calculated by subtracting the left side value from the right. These data are then used to derive the mean, standard deviation, and other statistical analyses. A well-trained technician can complete routine testing of the lower extremity in less than 1 hour.

In addition to the standard examination, six volunteers were asked to undergo a cold stress (one hand placed in cold water, temperature range 9° to 18°C) while the temperatures of their feet were monitored at 5-minute intervals for 60 minutes. Cold stressors have been shown to enhance sympathetic activation,[3] and thus seemed a reasonable method for assessing the symmetry of response to sympathetic challenge.

Results

The data in Table 1 represent the combined data from each ROI or point, across subjects, and are expressed as the mean ± the standard deviation of the

* JTG-500 M thermographic unit manufactured by Japan Electronic Optic Laboratory, Ltd., Tokyo, Japan; Infra-Eye-160 thermographic unit manufactured by Fujitsu, Ltd., Kawasaki, Japan.

TABLE 1

Temperature asymmetries of normal control subjects

Region of Interest*	No. of Cases	Nerve (dermatome)	ΔT (°C)†
head			
1 forehead	32	trigeminal (first division)	0.18 ± 0.18
2 cheek	33	trigeminal (second division)	0.30 ± 0.17
trunk (anterior)			
3 chest	49	intercostal (T1–7)	0.20 ± 0.19
4 upper abdomen	43	intercostal (T8–9)	0.22 ± 0.15
5 abdomen I	90	intercostal (T-10)	0.21 ± 0.19
6 abdomen II	90	intercostal (T-11)	0.17 ± 0.14
7 abdomen III	89	intercostal (T-12)	0.20 ± 0.15
trunk (posterior)			
8 cervical	45	cervical (C3–5)	0.23 ± 0.16
9 thoracic	46	post. cutaneous (T2–12)	0.20 ± 0.17
10 lumbar (medial)	90	dorsal div. spinal (T-11, 12; L-1, 2, 3)	0.22 ± 0.19
11 lumbar (lateral)	88	dorsal div. spinal (T-11, 12; L-1, 2, 3)	0.34 ± 0.26
12 sacral (medial)	90	dorsal div. spinal (S-1, 2, 3)	0.28 ± 0.19
13 sacral (lateral)	90	dorsal div. spinal (S-1, 2, 3)	0.26 ± 0.22
extremities, upper			
14 shoulder (anterior)	54	supraclavicular (C-4, 5; T-1)	0.19 ± 0.12
15 shoulder (posterior)	44	dorsal div. spinal (T1–5)	0.31 ± 0.23
16 anterior arm	52	med. antebrachial (C-5, T-1)	0.27 ± 0.23
17 posterior arm	36	dorsal antebrachial axillary (C-7, 8)	0.39 ± 0.26
18 forearm volar	56	med./lat. antebrachial (C-5, T-1)	0.25 ± 0.21
19 forearm dorsum	56	med./lat./dorsal antebrachial (C-7, 8)	0.31 ± 0.22
20 hand	56	median, ulnar (C-7, 8)	0.24 ± 0.23
21 hand dorsum	57	median, ulnar, radial (C-7, 8)	0.31 ± 0.25
fingers			
22 thumb	48	median (C-6)	0.43 ± 0.43
23 index	48	median (C-7)	0.52 ± 0.46
24 middle	48	median (C-7)	0.35 ± 0.46
25 ring	48	ulnar (C-8, T-1)	0.43 ± 0.35
26 little	48	ulnar (C-8)	0.45 ± 0.39
mean fingers	48	med./ulnar (C-6, 7, 8)	0.43 ± 0.26
extremities, lower			
27 thigh (anterior)	71	ant. fem. cutaneous (L-2, 3)	0.24 ± 0.21
28 thigh (posterior)	70	post. cutaneous (S-1, 2)	0.23 ± 0.18
29 knee (anterior)	14	ant. fem. cutaneous (L-4)	0.23 ± 0.17
30 knee (posterior)	14	post. fem. cutaneous com. peroneal (S-1, 2)	0.12 ± 0.10
31 leg (anterior)	70	saphenous sup. peroneal (L-4, 5)	0.27 ± 0.20
32 leg (posterior)	70	sural, saphenous (S-1, 2)	0.29 ± 0.21
foot			
33 dorsum	70	sup. peroneal, sural (L-4, 5; S-1)	0.38 ± 0.31
34 heel	66	tibial (S-1, 2)	0.34 ± 0.21
35 plantar	29	tibial, med./lat. plantar (L-4, 5; S-1, 2)	0.35 ± 0.27
toes			
36 great	43	sup. peroneal (L-4, 5)	0.54 ± 0.44
37 second	43	sup. peroneal (L-5)	0.51 ± 0.48
38 third	43	sup. peroneal (L-5)	0.53 ± 0.48
39 fourth	43	sup. peroneal (L-5)	0.67 ± 0.41
40 fifth	43	sural (S-1)	0.67 ± 0.55
mean toes	36	sup. peroneal, sural (L-4, 5; S-1)	0.59 ± 0.27

* For regions of interest see Fig. 2.

† Mean ± standard deviation of the temperature difference between the left and right regions for subjects tested on the Infra-Eye-160 device.

difference between left and right regions. Longitudinal studies of four individuals were made over a 5-year period from 1982 to 1987. Sample data from these studies are provided in Table 2. Repetitive readings of every 3.7-second scan of major ROI's were also performed in order to investigate intrasession temperature reproducibility. An example of the data obtained is provided in Table 3. The mean and standard deviation of the repetitive readings were 30.8° ± 0.032° C, with a coefficient of variation of 0.1%.

Finally, the effect of the cold-water challenge on ΔT stability was also studied in six asymptomatic healthy individuals. The ΔT for the feet remained stable (within the control value listed in Table 1) throughout the 60-minute cold stress in all six normal volunteers. A typical temperature curve is shown in Fig. 3.

Discussion

Previous investigations have set the upper limit of normal ΔT at less than 1°C.[7] This 1°C norm was applied

TABLE 2

Reproducibility over time of temperature asymmetry for the dorsal foot of a healthy person

Study Date (month/day/year)	Temperature (°C)		Temperature Asymmetry (°C)
	Right	Left	
12/9/82	29.65	29.37	0.28
3/25/83	31.27	31.10	0.17
3/26/84	29.30	29.50	−0.2
12/2/84	31.60	31.60	0
7/2/87	34.50	34.90	−0.4
7/7/87	35.30	35.40	−0.1
7/29/87	31.90	31.40	0.5

TABLE 3

Intrasession measurement variation across 10 repetitive temperature readings

Reading No.	Right Foot Temperature (°C)
1	30.8
2	30.9
3	30.8
4	30.8
5	30.8
6	30.8
7	30.8
8	30.8
9	30.8
10	30.8

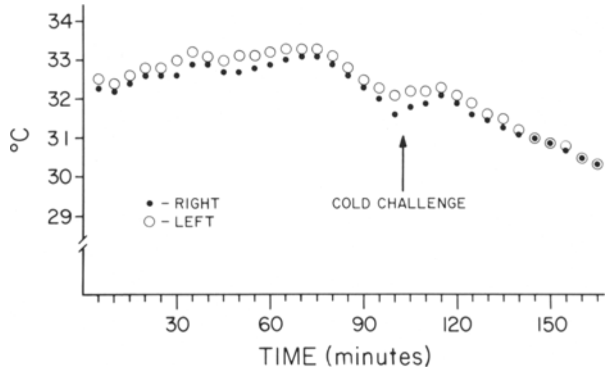

FIG. 3. Sequential temperature readings for the dorsum of the right and left foot for the first 100 minutes while the normal volunteer is sitting in a chair. When the right hand is placed in cold water for the cold challenge, the absolute temperature begins to drop, after an initial mild elevation. However, the ΔT for the feet remains smaller than 0.2°C during the entire 165-minute recording period. There was a similar ΔT stability during rest and a cold challenge in all six normal volunteers tested.

regardless of the body region examined. This value was established in a study of patients with chronic pain and, because a computerized system was not available at that time, the ΔT's were calculated from thermographic readings obtained from a less sophisticated thermographic unit than the one used in these studies.[1] The data reported here represent a more complete form of analysis of thermal asymmetry over the body surface than previously attempted.[8]

With use of the data, an abnormal thermal asymmetry can be defined, based on a statistical criterion, from the normal ΔT for a specific body area, rather than by using a single unit value (1°C) for all comparisons. Because the vasomotor responses may vary depending on underlying conditions, the degree of thermal asymmetry may vary in different underlying pathophysiological conditions. Therefore, in certain clinical cases, a ΔT value of less than 1°C may be significant.

It is noteworthy that our data, derived using different devices (the JTG-500 M system for 29 volunteers, reported earlier,[7] and the Infra-Eye-160 for 90 subjects, listed in Table 1), are similar. As may be expected, while the absolute temperature may vary with time, between nonhomologous regions, and between individuals, the ΔT's obtained from anatomically matched homologous regions are extremely stable and reproducible. It is our belief that the ΔT's we obtained for normal subjects may be used as a reference standard for comparison to ΔT's obtained in most clinical examinations. Deviations from the normal values will allow suspicion of neurological pathology to be quantitated and therefore can improve assessment and lead to proper clinical management.

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