J Neurosurg 62:716–720, 1985

Thermographic imaging of cutaneous sensory segment in patients with peripheral nerve injury

Skin-temperature stability between sides of the body

SUMIO UEMATSU, M.D.

Department of Neurosurgery, The Johns Hopkins University School of Medicine, Baltimore, Maryland

Sensory examination based on the patient's subjective assessment of symptoms may raise difficult questions about whether the individual's expressed complaint is based on organic nerve damage, psychogenic factors, or even malingering. A prototype computerized telethermograph has allowed clinical quantification of peripheral nerve injury. The system makes possible mapping and imaging of the damaged area, as well as skin temperature measurements. In normal persons, the skin temperature difference between sides of the body was only 0.24° ± 0.073°C. In contrast, in patients with peripheral nerve injury, the temperature of the skin innervated by the damaged nerve deviated an average of 1.55°C ($p < 0.001$). The new technique requires further refinement, but it appears that use of this method may be cost-effective in helping to resolve medicolegal conflicts concerning peripheral nerve injury.

KEY WORDS • **thermography** • **nerve injury** • **sensory examination** • **sympathetic nerve** • **skin temperature**

BECAUSE the patient's perception and expression of sensation can be influenced by many factors, interpretation of the results of a sensory examination may be difficult. In the past, several attempts have been made to document cutaneous sensory impairment objectively, including the skin resistance test and the starch-sweat test, but, since the methods are cumbersome and their results are not always reproducible,[2,5] they have not been widely used.

In recent years, a qualitative telethermographic technique has been used for evaluation of the vasomotor function of the skin, particularly in the patient with chronic pain,[8] but criticism of this technique arose because the results lacked quantification. It is known that skin temperature is altered in the field of an impaired peripheral nerve due to sympathetic vasomotor disturbance.[4,7,9] Therefore, we reasoned, the sensory segment in the area of an impaired peripheral nerve could be demonstrated as a thermographic image. Accordingly, the prototype equipment used in this study was designed to provide quantitative analysis of thermographic data.[1] We used a new technique that collects and computes the average temperatures in designated areas of the body surface, and provides temperature differences between two designated segments.

Thermography Technique

A color telethermograph with a built-in computer was used in this study. We mapped the skin surface areas to be measured by dividing the body's skin surface into 32 sensory "box" segments that approximate the areas of innervation of the major peripheral nerves (Fig. 1). This mapping is by no means complete: we arbitrarily excluded some areas of innervation because they are not large enough for precise sampling with our present equipment. In addition, we avoided hair-covered areas, such as eyebrows, and moist areas, such as lips and nostrils, because hair and moisture can cause unpredictable temperature changes.

Skin temperature on each sensory segment was measured in 32 healthy subjects, and in 30 patients with peripheral nerve impairment. These individuals ranged in age from 12 to 65 years. The average temperatures in the 32 sensory segments on the normal subjects were determined for both sides of the body. The degree of temperature difference between the sides of the body was determined for the 32 sensory segments in the control subjects (Table 1) and in the patients. The difference in skin temperature (absolute values) between nerve-damaged segments and the opposite cor-

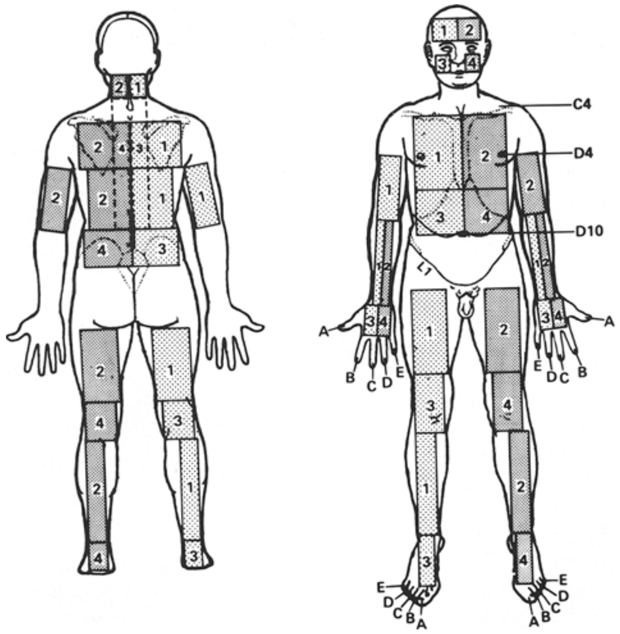

FIG. 1. Diagram showing the box segments used in the study for the front and back parts of the body. A total of 64 segments were studied (32 per side). Each box segment covers the distribution of a clinically important nerve section of the body.

responding intact segments on patients were contrasted with the differences between anatomically matched segments among the controls, using the t-test for correlated means.

Thermographic imaging of the sensory segment was carried out in three stages. Routine scout thermograms were recorded before sensory examination. At the examination, the border between the numb area and normal skin sensation was determined by pinprick test, and marked by a skin pen. After approximately 15 minutes to allow the pinprick effect to wear off, a droplet of cold glue was placed on each skin-pen mark so as to appear as a blue dot on the thermograms. The thermograms were then taken (Fig. 2).

Results

Normal Skin Temperatures

Skin temperature measurements were carried out in 32 healthy persons. The highest average skin temperature was 34.5° ± 0.73°C (on the forehead) and the lowest average skin temperature was 27.1° ± 4.03°C (at the toes). The fingers and toes averaged 2.8° ± 2.72°C and 4.4° ± 1.74°C colder than the forehead, respectively. The temperature of the fingers and toes was not as stable as that of other parts of the body; it also fluctuated between individuals and in any one individual from day to day.

Skin temperature differences from one side of the body compared to the other are not only extremely small but also very stable throughout the body (Table 1). For example, the difference between sides was only 0.12°C at the forehead and 0.25°C at the lumbar region of the back. The temperature differences between the sides of the body were not altered by the patient's age. The correlation coefficient between age and temperature difference was −0.52. This is additional evidence for the stability of skin temperature differences between sides of the body.

TABLE 1

Average skin-temperature differences between sides of the body for segments measured

Sensory Segment	No. of Cases	Temperature Difference (°C)	Standard Deviation (± °C)
head			
forehead	29	0.12	0.093
cheek	29	0.18	0.186
trunk			
chest	11	0.14	0.151
abdomen	11	0.18	0.131
cervical paraspinal	11	0.15	0.191
area		0.15	
thoracic paraspinal	11		0.092
area		0.25	
lumbar area	10		0.201
trunk, average		0.17	0.042
extremities			
shoulder	10	0.13	0.108
biceps	10	0.13	0.119
triceps	10	0.22	0.155
forearm			
lateral	19	0.32	0.158
medial	19	0.23	0.198
palm			
lateral	21	0.25	0.166
medial	21	0.23	0.197
thigh			
anterior	14	0.11	0.085
posterior	11	0.15	0.116
knee	14	0.23	0.174
popliteal area	14	0.12	0.101
leg			
anterior	16	0.31	0.277
calf	15	0.13	0.108
foot (top)	15	0.30	0.201
heel	15	0.20	0.220
extremities, average		0.20	0.073
fingers, average*		0.38	0.064
toes, average*		0.50	0.143

* Five segments were measured, but only the average is given here.

Skin Temperature of Impaired Nerve Distribution

Thirty-two peripheral nerves were studied in 30 patients. Some patients had more than one area of peripheral nerve impairment. In 23 consecutive cases of impaired peripheral nerve, skin temperature was altered an average of 1.55°C at the impaired nerve segment, a difference six times higher than the temperature difference seen in the control group. The correlated means t-test between 23 normal control subjects and the 23 patients on consecutive anatomically matched samples

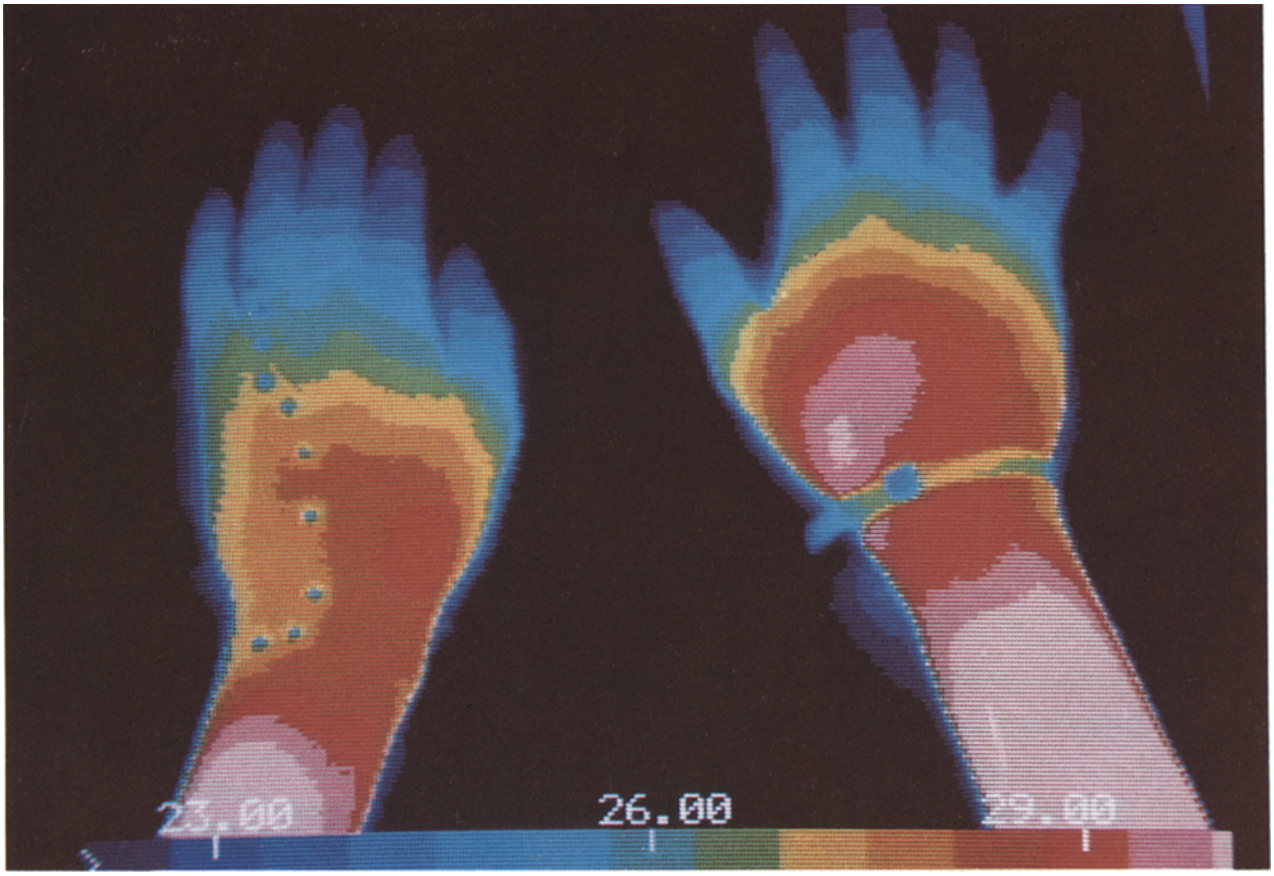

FIG. 2. Thermographic imaging of the cutaneous sensory segment in a patient with gunshot injury of the left ulnar nerve just below the axilla. The nerve was partially injured. There is weakness of the small muscles of the hand and decreased sensation over the little finger side (ulnar nerve side) of the hand. The blue marks show droplets of cold glue placed at the border of the numb area and the area of normal skin sensation. The droplet line matches very well with the thermographically colder area of the little finger side. The top of the right hand (with identification wrist band) has the normal symmetrical rainbow temperature pattern. The color scale used is shown at bottom. Each color change represents a 0.3°C temperature change.

yielded $p < 0.001$ ($t = 6.6$), indicating a significant temperature change in the skin area of the damaged nerve.

For convenience, the patients were divided into two groups, according to the status of their sympathetic nerve function. Group A included those with loss of sympathetic nerve function. These patients had complete loss of sensation in the skin segment relating to the damaged nerve. The skin temperature of the damaged side averaged 1.92° ± 0.939°C higher than the opposite intact limb. This degree of temperature elevation, contrasted with that in the control subjects (Table 1), is statistically significant ($p < 0.001$). Group B included patients with overactive sympathetic nerve function. In this group, the nerve or one of its roots was partially traumatized either by fractured bone fragments or by a ruptured intervertebral disc (lumbar disc herniation). The area of the damaged nerve segment was typically numb, but did not completely lose sensation in all cases. The skin temperature in the area of damaged nerve averaged 0.83° ± 0.411°C colder than the opposite intact segment of the limb or the body. This difference is statistically significant when contrasted to the temperature difference of the control group ($p < 0.0001$) (Table 1).

Thermographic Imaging of Cutaneous Sensory Segments

Based on the findings of a normal stability of temperature difference between sides of the body and its alteration due to injury, and using the method outlined above, 32 impaired peripheral nerves were carefully examined in 30 patients. In a majority of the cases, the thermogram and the sensory segment matched well, particularly in Group A (Figs. 2 and 3). In Group A patients, the temperature of the completely numb area was always warmer than that of the surrounding area of decreased skin sensation. The temperature of the

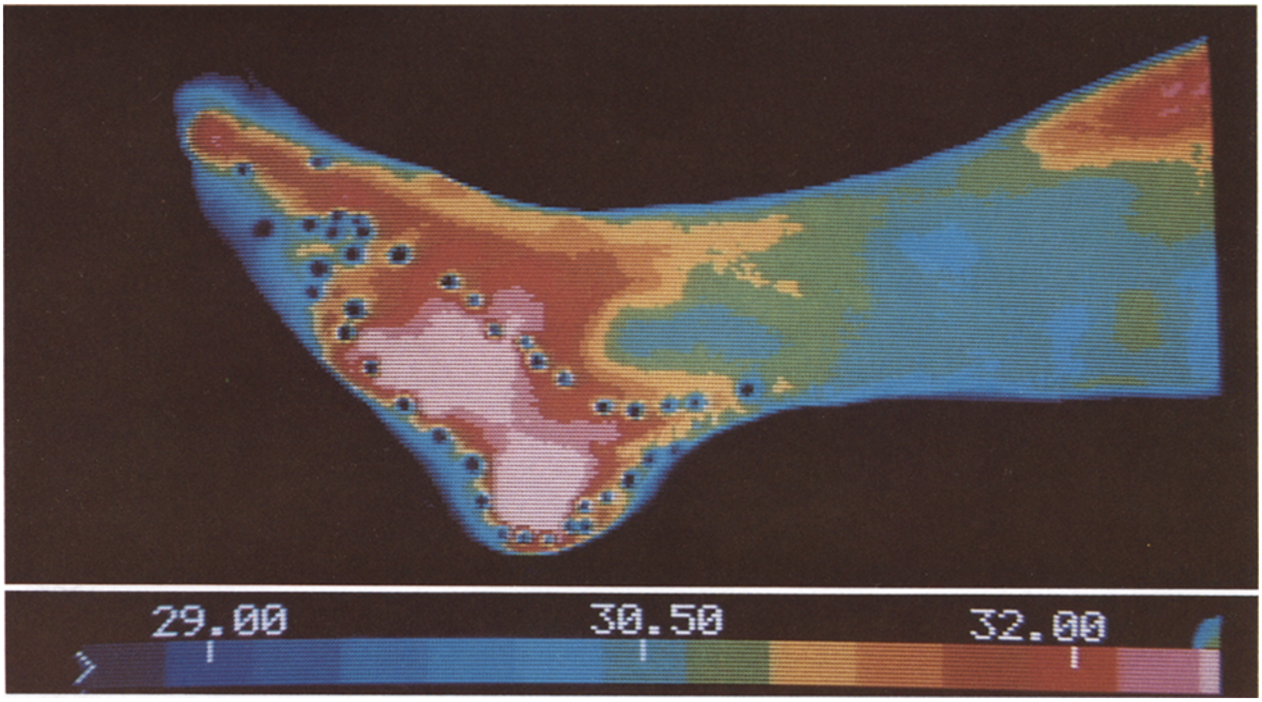

FIG. 3. Thermographic imaging of the cutaneous sensory segment of the inner side (big toe side) of the right foot after surgical section of the sural nerve halfway between the ankle and knee. The nerve was transplanted to repair the radial nerve. The chain of cold glue droplets outlines the area of total loss of sensation. The thermographic image and the blue glue droplets matched particularly well in the arch and heel of the foot, and less well toward the ankle joint.

damaged area gradually merged with the normal area in a rainbow pattern. In Group B patients, the cutaneous segment of interest was often colder than the surrounding skin.

Discussion

Skin temperature varies widely from time to time and with vasomotor alteration, but our results show precisely that there is almost no temperature variation between corresponding sites on different sides of an individual's body. The implication of these results is that, in a normal person, the detection of a significant temperature difference between corresponding sites on opposite sides of the body is highly suggestive of nerve impairment.[3,6] Extrapolation from experimental results gives temperature findings that are significant warnings or indications of nerve injury or disease. By using different color codes (in this case, a spectrum from blue for colder areas to red for warmer areas and pinkish white for the warmest areas), temperature changes reflecting the degree of circulation and the concomitant degree of numbness (sensibility) can be displayed as a color thermographic image. This approach is not completely new. In 1940, Guttmann,[2] using the starch-sweat test, achieved one of the earliest demonstrations that an area of altered sweat-gland activity (sympathetic nerve activity) corresponded well with an area of sensory impairment.

For convenience of interpretation of the color thermography, three types of nerve impairment can be considered. The first type is complete interruption of all the nerve fibers, including sympathetic fibers. This results not only in loss of sensation in a discrete area of the skin, but also in loss of sympathetic control of the blood circulation in the same area. The second type is mixed: sympathetic function is partially impaired, since neighboring intact nerve fibers are superimposed on the territory of the injured nerve. In the third type, several neighboring nerves are interrupted, but isolated areas supplied by intact nerves can be demonstrated to have normal sympathetic function. It is reasonable to expect that thermography of cases of the first type will show the area of increased temperature in pinkish white or red, surrounded by a blue to green area, which means that there is a warm area surrounded by a colder area (see Fig. 3). Pinprick examination reveals that these areas have a loss of sensation but gradually acquire decreased and then normal sensation. In cases of the second type, the thermogram usually shows a diffuse area of warmer temperature surrounded by a colder zone. In the third type, the thermogram is expected to show a colder area in the center surrounded by an increased temperature zone.

The sympathetic nerve can also develop a pathologically overactive state (as in our Group B patients) due to irritative lesions, as in partial nerve injury or compression neuropathy (for example, when a broken bone presses on a nerve). Compression of the nerve roots in the spinal canal (as in lumbar disc herniation) requires special consideration. These nerve roots do not contain sympathetic nerve fibers in the spinal canal portion, but they are joined by sympathetic nerves outside the canal at some distance from the site of herniation. Therefore, the sympathetic nerve malfunction is not caused by the compression directly, but from reflex activity at the spinal cord level, as a result of the irritation to its corresponding sensory nerve.[6] The involved limb often has a cold area that appears to correspond to the nerve root distribution.

Because of the complexity of the normal skin temperature pattern and possible anatomical variations, the sensory examination and thermographic imaging should be evaluated in conjunction with good clinical judgment. It should be noted that skin temperature may change as the sympathetic nerve recovers. Initially, the damaged nerve segment of the skin may be warmer (usually for the first few months) and then become colder thereafter.[10] Sometimes, initial warmness may rapidly return to normal temperature.

With these precautions in mind, we can conclude that thermographic imaging of the cutaneous sensory segment is a clinically useful, sensitive, technique that makes possible the objective evaluation of what was formerly the patient's subjective expression of sensation. The prototype computerized color thermograph, with its capability to quantify sensory change, is a revolutionary application of thermography that should prove valuable in clinical diagnosis and that has already been used as an aid in the evaluation of disability claims.

Acknowledgments

The author wishes to thank Ms. Maria Coughlin for the preparation of this manuscript, David Edwin, Ph.D., for statistical advice, and Ms. Madalena Davis for typing the manuscript.

References

1. Brelsford KL, Uematsu S: Thermographic presentation of cutaneous sensory and vasomotor activity in the injured peripheral nerve. **J Neurosurg 62:**711–715, 1985
2. Guttmann L: Topographic studies of disturbances of sweat secretion after complete lesions of peripheral nerves. **J Neurol Psychiatry 3:**197–210, 1940
3. Pochaczevsky R, Wexler CE, Meyers PH, et al: Liquid crystal thermography of the spine and extremities. Its value in the diagnosis of spinal root syndromes. **J Neurosurg 56:**386–395, 1982
4. Rasmussen TB, Freedman H: Treatment of causalgia. An analysis of 100 cases. **J Neurosurg 3:**165–173, 1946
5. Richter CP, Woodruff BG: Lumbar sympathetic dermatomes in man determined by the electrical skin resistance method. **J Neurophysiol 8:**323–338, 1945
6. Uematsu S: Telethermography in the differential diagnosis of reflex sympathetic dystrophy and chronic pain syndrome, in Rizzi R, Visentin M (eds): **Pain Therapy.** Amsterdam: Elsevier, 1983, pp 63–72
7. Uematsu S, Hendler N, Hungerford D, et al: Thermography and electromyography in the differential diagnosis of chronic pain syndromes and reflex sympathetic dystrophy. **Electromyogr Clin Neurophysiol 21:**165–182, 1981
8. Uematsu S, Long DM: Thermography in chronic pain, in Uematsu S (ed): **Medical Thermography, Theory and Clinical Applications.** Los Angeles: Brentwood, 1976, pp 52–68
9. Wexler CE, Small RB: Thermographic demonstration of a sensory nerve deficit. A case report. **J Neurol Orthoped Surg 3:**73–75, 1981
10. White JC, Sweet WH: **Pain and the Neurosurgeon. A Forty-Year Experience.** Springfield, Ill: Charles C Thomas, 1969, pp 87–98

Manuscript received March 26, 1984.

Accepted in final form November 28, 1984.

Address reprint requests to: Sumio Uematsu, M.D., Department of Neurosurgery, Johns Hopkins University School of Medicine, 600 North Wolfe Street, Baltimore, Maryland 21205.