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Evaluation of thermography in the diagnosis of selected entrapment neuropathies

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Article abstract—We studied 20 normal subjects, 22 patients with carpal tunnel syndrome, and 15 with ulnar neuropathy at the elbow to compare the diagnostic accuracy of infrared thermography with that of conventional electrodiagnostic studies. We found abnormal thermograms in 55% of patients with carpal tunnel syndrome and 47% with ulnar neuropathy, using 2.5 SD from the normal mean as criteria for abnormality. The abnormalities consisted of either an increase in interside temperature difference in the fingers and hands or an alteration of the normal thenar-hypothenar temperature gradient in the fingers. The sensitivity of thermography was considerably lower than that of conventional electrodiagnostic methods. Moreover, the thermographic abnormalities were nonspecific, and could be misleading as they did not reliably identify the side of lesion or distinguish between median or ulnar nerve involvement. Thus, thermography is not helpful in the diagnosis of these two common entrapment neuropathies.

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Alteration in the function of the autonomic nervous system may occur in patients with peripheral nerve injuries. In patients with polyneuropathies or focal neuropathies, previous investigators have demonstrated autonomic abnormalities, such as loss of sympathetic vasoconstrictor response, diminution of sweat secretion, and alterations in cutaneous temperature.¹⁻³ Alterations in skin temperature probably have attracted the most attention in recent years, largely as a result of the increased availability of infrared and liquid crystal imaging equipment that allows rapid measurement of surface temperature. Thermography, as this technique is called, is advocated by some investigators as the screening test of choice for a large number of neuromuscular disorders including entrapment neuropathies, cervical and lumbosacral radiculopathies, reflex sympathetic dystrophy, and various pain syndromes.⁴⁻⁶ However, other investigators have questioned its clinical usefulness and have been unable to reproduce the remarkably high diagnostic accuracy reported by advocates of thermography.⁷⁻⁹ Thus, its clinical usefulness remains uncertain.

Although current thermographic equipment can permit accurate measurement of small changes in skin temperature, there is a general lack of well-controlled, quantitative studies on the diagnostic accuracy of thermography in neuromuscular disorders. There are even questions as to what constitutes an abnormal thermogram, and conflicting results in normal subjects have been published.^{7,10,11} Furthermore, few published studies involving patients have included a control group of normal subjects.

The diagnostic reliability of thermography in evaluating patients with focal lesions of peripheral nerves can be studied in patients with carpal tunnel syndrome or an ulnar nerve lesion at the elbow. The clinical features of both these lesions are well defined, and electrophysiologic studies are diagnostic in a high percentage of patients with a typical clinical presentation.^{12,13} Presently available data comparing electrophysiologic studies and thermography are difficult to interpret. Herrick and Herrick⁶ studied 55 patients with carpal tunnel syndrome and found an astonishingly high sensitivity of 100% and specificity of 96% for thermography. Unfortunately, in that study as well as in others,¹⁴ there was no control group and the thermographic and clinical criteria for diagnosis were inadequately specified. Better-controlled studies suggest a considerably more modest sensitivity, but these results are available only in preliminary form.^{9,15}

We present the thermographic data we obtained from normal subjects and from patients with carpal tunnel syndrome or ulnar neuropathy at the elbow, and compare the diagnostic accuracy of thermography with that of conventional electrophysiologic studies.

Methods. We used a commercially available thermography unit that is specially designed for medical use (Bales Scientific MCT 7000). Images of the skin surface of patients and control subjects were obtained using a microprocessor-controlled infrared camera. With this thermographic unit, infrared emissions are digitally processed and calibrated in units of surface

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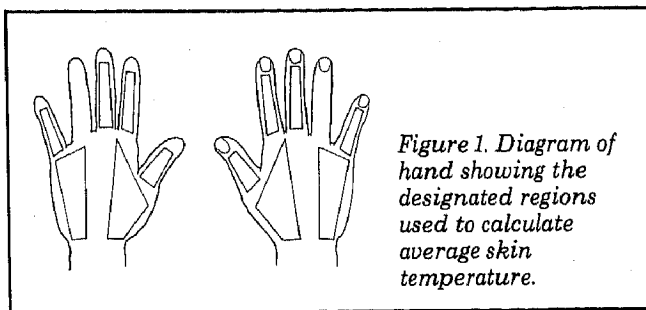


Figure 1. Diagram of hand showing the designated regions used to calculate average skin temperature.

temperature. In addition to the usual visual display with surface temperature encoded on a color scale, the average temperature of any designated region of the skin can be directly measured with a resolution of 0.05 °C.

Our test procedures were based on guidelines proposed by Wexler and adopted by the Academy of Neuro-muscular Thermography.¹⁶ All subjects were studied in an air-conditioned room maintained at a steady temperature between 20 and 23 °C. Care was taken to eliminate air drafts near the subject. Each subject was allowed to undress and equilibrate for 20 minutes in the cool room. Three sets of thermographic images were then taken at 15-minute intervals. Each set of images consisted of anterior and posterior views of the upper limbs and trunk, as well as a close-up view of the palmar and dorsal aspects of the hands and digits.

Patients were selected from referrals to our Clinical Neurophysiology Laboratory. All patients were examined by one of us (usually Y.T.S.), and only those in whom we made a confident clinical diagnosis of carpal tunnel syndrome or ulnar neuropathy at the elbow were included. The diagnosis of carpal tunnel syndrome was based on a history of pain and paresthesias in the hand and fingers, and physical findings that localized the pathology to the median nerve, eg, sensory alteration or weakness in a median nerve distribution, Tinel's sign with percussion of the median nerve at the wrist, or the reproduction of symptoms by Phalen's maneuver. Ulnar neuropathy was diagnosed in patients with paresthesias or numbness in an ulnar nerve distribution, usually accompanied by weakness in ulnar-innervated muscles. In those patients without weakness on examination, the diagnosis of ulnar neuropathy at the elbow was not made unless there was percussion sensitivity at the cubital tunnel or the ulnar groove, or exacerbation of symptoms with elbow flexion.

Twenty-two patients with carpal tunnel syndrome and 15 with ulnar neuropathy were then evaluated by both thermography and conventional electrophysiologic testing. Thermography was always performed first, to avoid the potential effects of the electrophysiologic examination on skin temperature.

All thermograms were interpreted by one of us (M.J.A.) without knowledge of the clinical diagnosis or electrodiagnostic results. In order to provide a quantitative measure of thermographic abnormalities and to assist the visual interpretation of the color images, each subject's skin surface was divided into standard regions and the average temperature of each was calculated. We chose regions that cover the shoulders, arms, and dorsal and palmar aspects of the hands and fingers (figure 1). Normative values for these regions were obtained from 20 normal subjects who were studied under identical conditions.

The traditional approach to the interpretation of thermograms is to compare skin temperature between corresponding regions of the two sides. Our normative data for interside temperature differences are shown in table 1. The difference was greater in distal than in proximal regions of the body. For

Table 1. Interside difference in skin temperature in 20 normal subjects

Skin region	Interside difference (°C)	
	Mean \pm SD	Range
Posterior neck	0.16 \pm 0.16	0-0.5
Posterior shoulder	0.22 \pm 0.14	0-0.5
Lateral shoulder	0.37 \pm 0.25	0-1.0
Lateral upper arm	0.32 \pm 0.22	0-0.8
Dorsal forearm	0.32 \pm 0.22	0.1-0.9
Volar forearm	0.37 \pm 0.17	0.1-0.7
Palm—hypothenar	0.31 \pm 0.26	0.1-1.1
Palm—thenar	0.46 \pm 0.27	0-0.8
Dorsal hand—ulnar	0.37 \pm 0.33	0-1.2
Dorsal hand—radial	0.35 \pm 0.29	0-1.4
Palmar, first digit	0.45 \pm 0.34	0.1-1.2
Palmar, second digit	0.49 \pm 0.31	0-1.2
Palmar, third digit	0.45 \pm 0.30	0-0.9
Palmar, fifth digit	0.41 \pm 0.25	0.1-0.8
Dorsal, first digit	0.42 \pm 0.37	0-1.3
Dorsal, second digit	0.40 \pm 0.39	0-1.3
Dorsal, third digit	0.38 \pm 0.34	0-1.4
Dorsal, fifth digit	0.48 \pm 0.34	0-1.2

the interpretation of each patient's data, we set the upper limit of normal at 2.5 SD above the mean in our control subjects. This upper limit was approximately 1.3 °C for the fingers, 1.1 °C for hands, 1.0 °C for arms, and 0.6 °C for the posterior trunk.

The electrophysiologic examination consisted of conventional motor and sensory conduction studies of the median and ulnar nerves and needle EMG of the abductor pollicis brevis (for patients with carpal tunnel syndrome) or first dorsal interosseous and abductor digiti minimi (in patients with suspected ulnar nerve lesions). The results of the nerve conduction studies were compared with normal values previously obtained in our laboratory, with limits set at \pm 3 SD. The electrophysiologic data were interpreted by one of us (usually R.K.O.) without knowledge of the thermographic findings.

Results. An interside temperature difference exceeding the upper limit of normal was seen in nine of the 22 patients with carpal tunnel syndrome and four of the 15 with ulnar neuropathy. In these abnormal studies, one or more of the fingers was always involved, and the palmar and dorsal surfaces were affected to a similar degree. The hand was affected in only six patients with carpal tunnel syndrome and two with ulnar neuropathy, and the more proximal limb was not affected in any patient. Regardless of the nerve affected clinically and electrophysiologically, temperature asymmetry between the two hands was sometimes seen in either median or ulnar innervated fingers, or both (figure 2). Although the fingers of the more symptomatic hand were frequently warmer than those of the contralateral side (9 of 13 cases with abnormal thermograms), the more symptomatic side was sometimes cooler and could not be reliably identified from the thermographic data.

When patients with carpal tunnel syndrome and those with ulnar neuropathy were compared as groups with our controls (Mann-Whitney U Test), no statis-

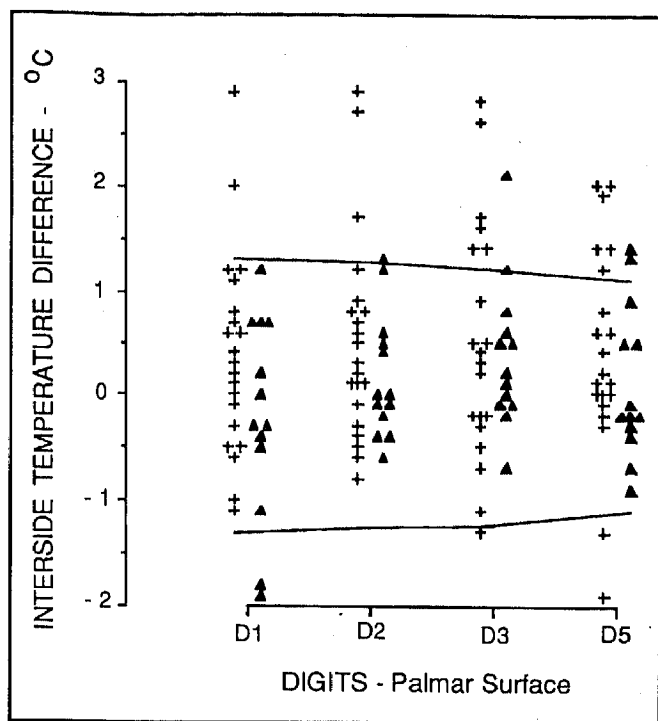


Figure 2. Interside difference of skin temperature over the palmar surface of fingers in 21 patients with carpal tunnel syndrome and 13 with ulnar neuropathy. A positive sign indicates a warmer skin temperature on the side with more severe clinical symptoms and signs. Three patients with relatively symmetric clinical symptoms and signs are excluded from this figure. The upper and lower limits of normal are 2.5 SD from the normal mean and are shown by solid lines. Crosses represent patients with carpal tunnel syndrome and filled triangles represent those with ulnar neuropathy. D1 = thumb; D2 = index finger; D3 = middle finger; D5 = little finger.

tically significant difference was found in any of the thermographic measures ($p > 0.05$). Similarly, although patients with unilateral signs and symptoms had higher mean interside difference in skin temperature than those with bilateral involvement, the difference was not statistically significant.

In both patients and control subjects, the first three digits, especially the thumb, generally had a higher skin temperature than the little finger (figure 3). This thenar-hypothenar temperature gradient was altered in some patients with carpal tunnel syndrome and ulnar neuropathy, usually in the direction of a relative warming of the median innervated fingers. Although an excessive decline in the thenar-hypothenar temperature gradient could be caused either by a relative warming of the median innervated fingers or by cooling of the little finger, in most cases it was impossible to tell which was responsible. A temperature difference greater than 2.5 SD above the normal mean was seen in ten cases of carpal tunnel syndrome and five cases of ulnar neuropathy (figure 3).

Overall, thermography was abnormal in 12 of 22 (55%) patients with carpal tunnel syndrome and seven of 15 (47%) patients with ulnar neuropathy. In the same patients, electrophysiologic studies were abnormal and con-

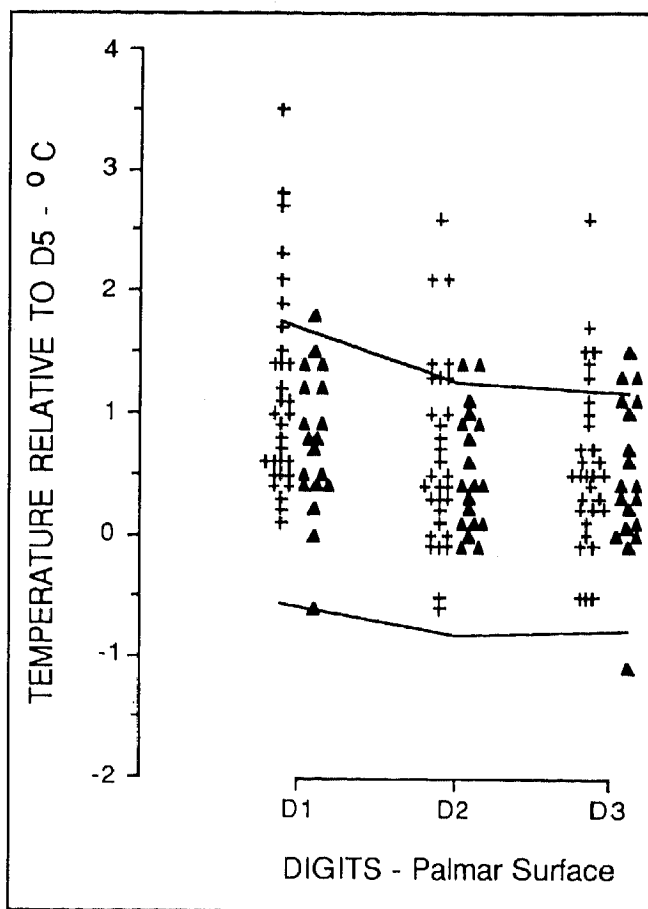


Figure 3. Comparison of skin temperature between median innervated fingers and little finger. Temperature differences are measured relative to the little finger. Only data from the palmar surface of symptomatic hands (31 limbs with carpal tunnel syndrome and 19 with ulnar neuropathy) are included. The upper and lower limits of normal are 2.5 SD from the normal mean and are shown by the solid lines. Crosses represent patients with carpal tunnel syndrome and filled triangles represent those with ulnar neuropathy. Abbreviations are the same as for figure 2.

firmed the clinical diagnosis in 24 of 31 (77%) symptomatic limbs with carpal tunnel syndrome and 15 of 18 (83%) with ulnar neuropathy (table 2). In contrast to thermography, the clinical diagnosis was confirmed electrophysiologically in 19 of 22 (86%) patients with carpal tunnel syndrome and 13 of 15 (87%) with ulnar neuropathy. The sensitivity of thermography was similar between patients with unilateral and bilateral clinical findings and did not depend on the presence or absence of pain (table 3). In general, there was little correlation between the severity of electrophysiologic and thermographic abnormalities, although the thermogram was abnormal in all four patients with carpal tunnel syndrome who had severely reduced amplitude of antidromic sensory action potential to the second digit ($<5 \mu V$). Two cases of carpal tunnel syndrome and one case of ulnar neuropathy had normal electrophysiologic studies but abnormal thermograms, although the thermographic abnormalities were not specific for the side or the nerve involved and did not permit a diagnosis to be made.

Table 2. Electrodiagnostic studies in 22 patients with carpal tunnel syndrome and 15 with ulnar neuropathy at the elbow

	Criteria for abnormality	Number (%)
Carpal tunnel syndrome		
Total no. of symptomatic limbs studied		31 (100%)
Slowing of sensory conduction: palm to wrist segment	<42 m/sec or >12 m/sec slower than ulnar nerve	21 (68%)
Reduced amplitude of antidromic SNAP to second digit	<15 μ V	11 (35%)
Prolonged median distal motor latency	>4.5 msec or >1.5 msec relative to ulnar nerve	21 (68%)
Reduced thenar CMAP amplitude	<5 mV	4 (13%)
Denervation in abductor pollicis brevis		11 (35%)
Total no. of limbs with abnormal study		24 (77%)
Ulnar neuropathy		
Total no. of symptomatic limbs studied		18* (100%)
Decreased amplitude of antidromic ulnar SNAP	<10 μ V	10 (56%)
Motor conduction slowing across the elbow	<40 m/sec or >12 m/sec slower than forearm segment	9 (50%)
Decreased amplitude of ulnar CMAP	<5 mV	7 (39%)
Denervation in ulnar hand muscles		11 (61%)
Total no. of limbs with abnormal study		15 (83%)
NCV Nerve conduction velocity. SNAP Sensory nerve action potential. CMAP Compound muscle action potential. * In one patient with bilateral symptoms, only the most symptomatic side was studied.		

When the same thermographic criteria (2.5 SD from the normal mean) were applied to our control group, positive results were obtained from two of the 20 (10%) asymptomatic subjects. Electrodiagnostic studies were not performed on these two subjects because of the lack of clinical symptoms and signs. Moreover, the thermographic abnormalities observed in them were mild (within 3 SD from the population mean).

Discussion. We and others,^{6,16} have found an increase in interside temperature difference of the hands and digits in some patients with carpal tunnel syndrome or ulnar nerve lesion at the elbow. Interpretation of inter-

Table 3. Correlation of thermographic abnormalities with clinical and electrophysiologic findings in 22 patients with carpal tunnel syndrome and 15 with ulnar neuropathy

	Thermography	
	Abnormal	Normal
Patients with carpal tunnel syndrome		
Unilateral clinical symptoms and signs	7	6
Bilateral clinical symptoms and signs	5*	4
Dysesthesias or pain	7	7
Denervation on electromyography	4	4
Reduced median SNAP amplitude	4	5
Normal electrophysiologic study	2	1
Patients with ulnar neuropathy		
Unilateral clinical signs and symptoms	6	5
Bilateral clinical signs and symptoms	2*	2
Dysesthesias or pain	1	2
Denervation on electromyography	5	5
Reduced ulnar SNAP amplitude	3	3
Normal electrophysiologic study	1	1
* Abnormalities present on one side or both sides. SNAP Sensory nerve action potential.		

side differences could be complicated by the frequent presence of bilateral lesions in entrapment neuropathies. In addition, any asymmetry of skin temperature may be related to either increase or decrease in temperature of the median or ulnar innervated skin, or both, regardless of which nerve is affected clinically or electrophysiologically. Therefore, reliable distinction between carpal tunnel syndrome and ulnar neuropathy, or even identification of the symptomatic side, is difficult on thermographic grounds alone. A second abnormal thermographic pattern was seen when median-innervated fingers were compared with the ulnar-innervated finger of the same hand: this was an alteration in the normal thenar-hypothenar temperature gradient in some patients. This change represented a similarly nonspecific abnormality that did not reliably identify the site of lesion.

With thermographic criteria that provided an acceptable false positive rate (2.5 SD from the normal mean), we found thermographic abnormalities in 55% of patients with carpal tunnel syndrome and 47% of patients with ulnar neuropathy. This is lower than the diagnostic yield from conventional electrophysiologic studies. Moreover, electrophysiologic examination has the additional advantage of reliable localization of the site of lesion. While electrophysiologic studies are clearly the diagnostic tests of choice, thermography was nonspecifically abnormal in three of our patients with normal neurophysiologic findings. The possibility therefore remains that thermography may have some value in those patients with equivocal neurophysiologic abnormalities but an otherwise typical clinical syndrome. Furthermore, various stress tests, such as hand immersion in cold water and provocative limb postures, may conceivably improve the yield of thermography.^{2,16} However, our preliminary experience employing Phalen's maneuver in eight patients with carpal tunnel syndrome did not provide any further information.

Large myelinated fibers may be preferentially affected in compressive lesions of the peripheral nerves. However, our observations as well as those from other physiologic and anatomic studies^{1,17} suggest that disturbances of unmyelinated autonomic fibers also occur in compression neuropathies. Although the pathophysiologic mechanisms responsible for the skin temperature changes are not well understood, dysfunction of the sympathetic nerve fibers is generally assumed to play a major role. Sympathetic nerve fibers are readily demonstrable in the median and ulnar nerves and the digital arteries of the hand.¹⁸ Local anesthetic block of a peripheral nerve or spinal root produces regional vasodilatation, probably as a result of release from the normal vasoconstrictor tone of sympathetic fibers.^{19,20} The results of partial injury to peripheral nerves are less predictable; either skin warming or cooling can occur, probably depending on the nature and the severity of the lesion.^{2,10} This ambiguity obviously imposes constraint on the interpretation of the thermograms, as it is difficult to tell whether one side is abnormally colder or the contralateral side is abnormally warmer.

The cutaneous vasomotor fibers probably have a distribution similar to the cutaneous sensory fibers of the nerve. For instance, novocaine block of the median or ulnar nerves produces skin warming that coincides with the anesthetic area.¹⁹ Using venous occlusion plethysmography, Aminoff demonstrated that the normal vasoconstrictor response to inspiration was impaired in the index finger but preserved in the little finger in patients with carpal tunnel syndrome.¹ In contrast, the thermographic abnormalities reported here are not confined to the cutaneous innervation of the involved nerve. The reason for this is not clear, although a possible explanation is that partial nerve injuries may trigger spatially nonspecific autonomic reflexes. One such reflex is the generalized vasoconstriction that has been observed after intraneural microstimulation in human subjects.²¹

In conclusion, thermography in the format presently recommended by the Academy of Neuro-muscular Thermography is not sufficiently sensitive to substitute for conventional electrophysiologic studies in the evaluation of carpal tunnel syndrome and ulnar neuropathy, and adds little additional information in most cases. Previous favorable reports are probably a result of insufficient attention to proper experimental control. Whether thermography has a role in the evaluation of other neuromuscular disorders is currently under investigation. Until there is better standardization of testing procedures and equipment, it is important to obtain control data in normal subjects before patients are studied by thermography.

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