Thermographic presentation of cutaneous sensory and vasomotor activity in the injured peripheral nerve

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Impaired function of cutaneous segments of monkey peripheral nerves experimentally blocked by lidocaine anesthesia was clearly visualized by means of elevated temperature measurements obtained on computerized color telethermography. Mean temperature elevations in the segments of anesthetized primate nerves were 2.40°C at the ulnar segment 17 minutes after nerve block, and 1.20°C at the peroneal nerve at 20 minutes. The vasomotor activity of specific nerves, recorded after local anesthesia and displayed by color telethermographic imaging, corresponded to the distribution of sensory segments identified by more cumbersome means. Telethermography is therefore shown to be a useful tool, both qualitatively and quantitatively, in mapping cutaneous distribution of peripheral nerves and for evaluation of peripheral nerve injuries.

KEY WORDS □9 thermography □9 nerve injury □9 sensory examination □9 skin temperature □9 monkey

CHANGES in skin resistance reflecting variations in sympathetic tone were well documented both quantitatively and qualitatively by Richter\(^1\) in experiments conducted in the 1920's through the 1940's. Richter's early experiments showed that surgical or pharmacological sympathectomy produces a large but transient increase in skin resistance. This increase was attributed to change in sweat gland activity and was shown to last from a few days to several months.

Richter's technique of measuring skin resistance involved moving an electrode over a small area of skin, progressing from affected to unaffected regions. As a normal area was reached, the pointer on the ammeter was deflected on the dial. The electrode was then replaced on the abnormal area and again moved toward normal areas in progressively small steps until the line of demarcation between the areas was sharply delineated. Skin resistance measurements were used for the study of injury and regeneration in the sympathetic nervous system,\(^5\) for sympathetic dermatome mapping,\(^3\) and for the study of peripheral nerve injuries.\(^2\) Despite its possibilities for clinical application in objectively documenting sensory changes, the technique was cumbersome and was not widely adopted.

Telethermography has been developed as an alternative technique for recording the normal and pathological status of nerves with cutaneous distribution. The basis for the method, as in Richter's method, is the fact that the sympathetic distribution closely parallels the somatic sensory distribution of nerves. Skin temperature, which is a function of sympathetic vasomotor (not somatic) control, is known to reflect disturbances in peripheral nerve function. Malfunctioning areas are reliably demonstrated by thermographic imaging of skin temperature changes.\(^8\)

The technique of computerized telethermography is complex, but the physical principle is readily comprehended. The method relies on measurement of infrared radiation emitted at the body's surface. The infrared rays that radiate from the skin surface are received by the telethermography device. The apparatus does not come in contact with the skin, so that it is possible to record small surface temperature changes without changing the skin's thermal condition. Moreover, the equipment does not apply any form of energy to the subject, and therefore does not cause harm or irritation to the patient, even after the successive uses that are necessary for detailed examination. With direct measurement of skin temperature at segments corresponding to the known distribution of sensory nerves, telethermography allows quantitation of change in, as well as demarcation of, the area affected by peripheral sensory nerve injury.

Description of Telethermography System

The telethermographic equipment consists of a scanning unit, an output amplifier, a computer processor,
A factor important for thermographic applications is that objects at room temperature or lower (including human skin) emit a range of electromagnetic radiation that is invisible to the human eye. This is in the infrared range of radiation. This infrared radiation is picked up in the telethermographic apparatus by the detector, a transducer that converts incoming infrared rays into electrical signals. The electrical signals are processed and displayed on an imaging CRT (Fig. 1).

The spectral characteristics of infrared radiation are graphed in Fig. 2. For telethermographic applications, it is important to realize that infrared radiation is dependent on the emissivity of an object, which is related to the surface condition of the object. In general, an object with smaller reflectivity tends to possess greater emissivity. The emissivity of skin can be influenced by factors that affect its temperature, such as blood circulation, presence of hair, or humidity on the surface.

The wavelength of infrared radiation of the human body is in the range of 3 to 10 \( \mu \), so a detector must be very sensitive to the narrow band of the total infrared region, which extends from 0.7 to 1000 \( \mu \). In the scanning operation, the detector must respond quickly; that is, it must have a very small time constant. The most commonly used detectors are indium antimonide and cadmium mercury telluride. The former is sensitive to 2- to 6-\( \mu \) waves and the latter is sensitive to 8- to 10-\( \mu \) waves. The narrow band sensitivity assists in eliminating noise outside the desired frequency band. To maintain electrical stability, the detector unit requires a temperature-stabilizing device.

The camera unit includes a scanning mirror and surface-reflecting mirrors or lenses, used as an optical collector for focusing the input onto the detector. For telethermographic quantitation of the temperature of the scanned object, a chopper is used. The chopper is inserted in front of the detector, and causes the input from the object to alternate with input from a control reference heat source installed in the device. Because the control heat source is electrically and automatically adjusted to maintain a specific heat level, it is possible to continuously compare (measure) the temperature of the object against the constant control temperature.
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The horizontal and vertical movements of the scanning mirrors are controlled by individual motors. The scanning movements of the mirror and the horizontal and vertical electron signals into the CRT are synchronized by the sweep generator to process the thermographic image. A built-in computer provides absolute temperature readings from the area of interest. The area of interest can be selected spots or the averaged temperature of thousands of picture elements (pixels). For practical convenience, we term the area of interest a "box."

The CRT image can be either monochromatic, typically black and white (gray tone), or a multicolored display. In multicolored display each color can represent a certain degree of temperature; for example, each color can amount to one-tenth of a degree's difference from the adjacent color. Some devices provide simultaneous displays of two images on a CRT. This technique may be clinically useful; for example, the left half of the CRT can display an image of a set prior to a drug therapy and the other half of the screen display an image after the treatment.4

Materials and Methods

In a series of experiments, we used computerized telethermographs* to document temperature changes resulting from local anesthetic block of peripheral nerves of two Rhesus monkeys. The Rhesus monkey was chosen for its anatomical similarity to man, both in body habitus and in peripheral nerve anatomy. The sites selected for injection were: 1) the median nerve at the anteromedial elbow; 2) the ulnar nerve at the posteromedial elbow; 3) the peroneal nerve at the head of the fibula; and 4) the posterior tibial nerve at the popliteal fossa.

Because skin temperature changes can result from environmental fluctuations, the laboratory temperature was maintained at 24°C ± 2°C, with approximately 40% humidity. In addition, the monkey was positioned to avoid contact with surfaces that were colder or warmer than room temperature. The monkey was restrained comfortably and sedated with intramuscular injections of ketamine hydrochloride (Ketaset) as needed. Baseline measurement of nerve conduction velocities (Fig. 3) and thermograms were then carried out for each nerve and its corresponding distribution.

Each nerve was localized by electrical stimulation with a hypodermic needle, which was positioned so that stimulation provoked the appropriate muscle activity. The stimulating apparatus was then removed, and the hypodermic needle left in place; 3 ml of 1% Xylocaine (lidocaine hydrochloride) was injected through the needle. Following injection, thermograms of both limbs were made at intervals ranging from 1 to 50 minutes.

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

![Fig. 3. Baseline and post-injection compound potentials of the hypothenar muscle, upon electrical stimulation (S) of the right ulnar nerve at the elbow. No potential is detectable after anesthetic right ulnar nerve block.](image)

The thermogram of the contralateral limb served as a control for the affected distribution of the anesthetized nerve. The mean temperature of each thermogram was calculated at each time interval. These calculations are represented graphically in Fig. 4. Approximately 25 minutes after the injection, nerve conduction velocities were again recorded at sites duplicating those used for baseline recordings, but with injection sites now interposed along the original course (Fig. 3).

Results

The description of our experimental observations is limited in this report to the ulnar and peroneal nerves. Results obtained with the remaining nerves were essentially identical, so the observations need not be repeated for every nerve.

Ulnar Nerve

Figure 5 left illustrates the effects of the anesthetic block on the ulnar nerve. The mean temperature elevation was 1.05°C at 10 minutes and 2.40°C at 17 minutes after the nerve block (Fig. 4). The temperature changes were distributed in the medial two digits, but there is also some lateral spread of effect noted at 20 minutes. The amplitude of the compound potential of the hypothenar muscle dropped from 18,000 mV to zero, a result consistent with effective nerve block (Fig. 3).

Peroneal Nerve

The maximal mean temperature elevation after blocking the peroneal nerve was 1.20°C and occurred...
FIG. 4. Graphic representation of temperature change in control and anesthetized limbs (with an ulnar nerve block). In this animal and in one other, a concomitant rise in the temperature of the contralateral control limb occurred during the test period. This finding is probably attributable to low initial temperature recordings for both limbs at the start of imaging, due to increased sympathetic activity in response to manipulation of the animal (positioning, nerve conduction recordings, and localization of the injection site). As the animal became calm, its stress response lessened, resulting in warming of both extremities.

The thermal pattern corresponded well with the distribution of the sensory segment of the peroneal nerve over the dorsal foot.

We considered the possibility that mechanical compression by the injection volume could be partly responsible for the results seen. To test this possibility, we injected the same volume of saline in the vicinity of the posterior tibial nerve at the malleolus. It was demonstrated by thermography that, after saline injection, there was no detectable effect on the vasomotor activity.

Discussion

Richter’s pioneering studies led to the search for methods to objectively demonstrate impaired segments of sensory and sudomotor activity of injured peripheral nerves. Despite clinical thermographic observations suggesting the possibility of thermographically imaging the sensory segment of injured nerves, previously there has been no animal experimentation to validate this possibility.

Our experiments show clearly that anesthetically blocking a peripheral nerve affects both somatic and sympathetic components. The effect on somatic distributions is demonstrated by the change in the nerve conduction of the injected nerve. The coexisting effect on the sympathetic component of the nerve is shown by the temperature changes seen on the thermographic imaging. By injecting lidocaine, we effectively performed a pharmacological transection of each nerve fiber. As one would expect, sympathetic input for vasoconstriction was abolished, leading to vasodilation and
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Increased blood flow to the area of sympathetic distribution. Increased blood flow resulted in increased skin temperature, which was displayed qualitatively and quantitatively by the thermogram. The fact that the temperature patterns observed correlate well with known cutaneous sensory nerve distribution lends further support for use of thermography as an indirect means for studying sensory nerve disturbances.

These experiments enabled us to demonstrate the known cutaneous sensory segment of four peripheral nerves by indirect means. They demonstrated once again the parallel course of somatic sensory and sympathetic nerve fibers and the dependency of skin temperature on vasomotor tone. Therefore, this interrelationship can be capitalized upon in evaluation of sensory disturbances, as reflected in color changes on thermographic imaging.

Conclusions

Thermography is a useful tool for objective documentation of sensory and sympathetic dysfunction in peripheral nerves with cutaneous projections. Our results, drawn from experiments in which sensory nerves were pharmacologically transected, allow the conclusion that partial injury to a peripheral nerve is demonstrated by surface thermographic imaging of the distribution of the nerve. Based on these findings in an animal model, our optimism has grown for the applicability of computerized telethermography as a safe noninvasive convenient means for quantification of peripheral nerve injury.

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References


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