The Effect of Radiofrequency Current and Heat on Peripheral Nerve Action Potential in the Cat*

Frank S. Letcher, M.D.,† and Sidney Goldring, M.D.
Division of Neurosurgery, Washington University School of Medicine, St. Louis, Missouri

The use of radiofrequency (rf) current to produce cord lesions in percutaneous cordotomy prompted this study. The purpose was to see if the diameter of nerve fibers determined their sensitivity to rf current. Such differential sensitivity of nerve fibers to other forms of energy and manipulation is documented. Compression, cold, and anodal polarization all block the large A fibers first. By contrast, high voltage alternating current and local anesthetics depress C fibers before the A group.

Evidence indicates that peripheral nerve fibers maintain their size ranges in post-synaptic spinal cord projections. Thus, it is probable that any demonstrable relationship between fiber size and sensitivity to rf current in peripheral nerve would hold true for spinal cord. Since the effect of rf current is due to the heat that is generated, the effect of graded hyperthermia was also examined.

Methods

In vitro observations were made on 19 saphenous nerves from 11 cats. Under moderate Nembutal anesthesia, the nerve was dissected from the inguinal ligament to below the knee, producing a nerve specimen of from 5 to 10 cm in length. It was laid across electrodes in a chamber maintained at a temperature of 37°C. The nerve specimen was kept moist by periodic spraying with warm Tyrodes solution. Both stimulating and recording electrodes were 18-gauge silver wires, and a distance of 2 to 7 cm separated stimulating from recording leads. A Grass stimulator was used to deliver 0.2 msec square waves through a General Radio isolation transformer at a frequency of 1/sec. Two stimulus strengths were used, one to elicit the alpha-beta and delta elevations (10% above an intensity that elicited a maximal delta response) and another for the C elevation (about 10% above an intensity that evokes a maximal C wave). The compound action potential was recorded monophasically by placing the recording electrodes on either side of a crushed segment near one end of the nerve. A recording period was limited to 30 minutes, and consisted of recording control responses after each lesion induction. To determine the rate of spontaneous deterioration of nerve responsiveness in these in vitro preparations, serial recordings were carried out for 1-hour periods in several nerves in which no lesions were induced.

A Grass LM 3 Lesion Maker was used to pass rf current through a pair of 18-gauge silver wires that made contact with the nerve opposite each other. A drop of Tyrodes solution enclosed the two electrodes with the nerve between to prevent drying. The segment of nerve across which current was passed was approximately 1 mm in width; a discrete lesion was thus produced. The low intensity rf current was applied in small increments until a decrease in the height of any of the elevations of the action potential was observed. It was found that the wattage necessary to produce changes in the compound action potential was just below that necessary to begin the coagulation of egg albumin, with the same electrode separation used. Current pulses lasted from 15 to 60 seconds.

A small plastic chamber with a volume of 0.4 cc was used to produce heat lesions. The heat chamber which enclosed the nerve between stimulating and recording electrodes was filled with saline previously heated to temperatures from 37° to 60°C. The length of nerve in contact with the saline was about 1 cm. A temperature of 37°C was used ini-

Received for publication November 29, 1967.

* Aided by U.S. Public Health Services Grants NB 04513 and 5-T5-GM-1608-10 (Medical Student Research Training Grant) and the Allen P. and Josephine B. Green Foundation.
† Present address: U.S. Naval Hospital, Philadelphia, Pennsylvania.
Peripheral Nerve Action Potential

tially and then the temperature was increased in small increments. It was possible to fill the chamber with heated saline and remove it rapidly. For each temperature tested the saline was in contact with the nerve for 15 to 60 seconds.

Results

Effect of Rf Current. Three fiber groups were systematically evaluated: the alpha-beta, delta, and C. In the controls (nerves kept at 37°C and not subjected to rf current or heat lesions), all elevations maintained 100% of the resting amplitude for 30 minutes and at least 50% of the control level for 1 hour (Fig. 1). As the nerve died, all elevations decreased proportionately and simultaneously.

Carefully graded low-intensity rf currents were necessary to produce the observations to be described. Intensities that were only 15 to 20% above the level that produced the earliest detectable change abolished the entire response. Following an rf lesion which caused all elevations to disappear from the record it was possible to record a normal response in the same nerve once again. This was done by replacing the recording electrode so as to exclude the area of the lesion from the nerve segment separating stimulating and recording leads. No change in stimulus parameters was necessary and amplitudes of all response components were those which one would expect from a freshly excised nerve in which no lesions had been induced. Thus, in some nerves we made more than one set of observations.

In 21 of 22 instances (15 nerves), rf current caused the delta and C elevations to disappear before the alpha-beta wave. At the time of disappearance of the delta and C elevations, the alpha-beta deflection was 10%

![Fig. 1. Control: fate of compound action potential of saphenous nerve in absence of rf current or heat lesions. Interelectrode distance 4 cm. Stimulus strength in A and B, 2 v; in C, 20 v. Records at higher gain are shown in B to permit a more valid comparison of delta amplitudes; the top of the alpha-beta elevation is off the tube face at this amplification. Records in C are on a much slower time line to permit detection of C wave. On this time line the alpha-beta and delta components fuse with the shock artifact. The irregular unit activity seen riding the baseline in C is due to repetitive discharge of alpha fibers which can occur at stimulus intensities necessary to produce C elevations. Records in Column 1 were taken immediately after placing nerve in the chamber. Records in Columns 2, 3, and 4 were taken 15, 30, and 60 minutes after the start of recording. In this and all subsequent figures, vertical arms of right angles are voltage calibrations (in µV); horizontal arms are time calibrations (in msec).](image)
to 20% of its control amplitude (Fig. 2). In the single instance in which this differential effect was not observed, all three response components failed simultaneously after the first application of rf current. It is reasonable to assume that current intensity was too high to produce a graded effect.

In four nerves, rf current also differentially affected the delta and C elevations. That is, the delta component disappeared before the C fiber response. Additional current abolished the C elevation, leaving only the alpha-beta wave (Fig. 3).

**Effect of Heat.** The results were similar to those obtained with rf current. In three of four nerves heat abolished the delta and C waves before the alpha-beta elevation. In all three instances the delta group failed before the C fiber response (Fig. 4). As with rf current, in the nerve in which this differential effect was not observed, all three response components failed simultaneously after the first application of heat.

In another nerve a single observation was made which is believed important and worthy of reporting. After a single application of *heated* saline no change in any of the response elevations occurred (Fig. 5, Column 1 and 2). Instead of applying additional heated solution, the nerve was permitted to fail spontaneously. Response components disappeared in the same order as that observed when serial applications were made. Five minutes after saline application (Column 3), the delta wave disappeared, both alpha-beta and C elevations being unchanged. After 15 minutes (Column 4), alpha-beta and C waves showed an amplitude reduction, and after 20 minutes (Column 5), only the alpha-beta wave remained. At 40 minutes there was no response.

**Discussion**

The observation that rf current and heat produce identical changes was anticipated since rf current alters tissue through the heat

---

**Figure 2**. Effect of rf current on compound action potential of cat saphenous nerve. Interelectrode distance 4 cm. Stimulus strength in A and B, 2 v; in C, 20 v. At arrows labeled "RF", radio frequency current was passed and records were taken immediately thereafter.
Fig. 3. Effect of rf current on compound action potential of cat saphenous nerve. A and B show the alpha-beta and delta elevations; stimulus strength, 5 v; C shows C fiber response; stimulus strength, 15 v. Arrows labeled "RF" indicate rf current was passed and records taken immediately thereafter. After second passage of current the delta wave has disappeared (Column 3); alpha-beta and C elevations are still present. After additional current the C wave also disappears leaving only the alpha-beta elevations (Column 4); records made at higher gain to show that no vestige of C wave remains.

that it generates.1 The greater heat sensitivity of the smaller fibers was also expected because of the known reverse effect of cold.5,7

The finding that rf current (heat) blocked the delta group before the C fibers indicates that other factors besides fiber size determine heat sensitivity. If fiber size were the only determinant, C fibers should fail first, since the largest fibers (alpha-beta) are the most resistant. Procaine in dilute solution affects peripheral nerve similarly. It blocks both delta and C fibers before the alpha-beta group, but causes the smallest delta fibers to fail before the still smaller diameter C group.11

The manner in which the nerve failed following a single application of heated saline (Fig. 5) suggests that the heat-induced failure has kinetics resembling a toxic process which acts through metabolic interference. A greater vulnerability of a particular enzyme or enzyme system in one group of fibers as compared to the other could account for the observed differential failure.12

The amount of rf current or heated saline necessary to block delta and C fiber conduction also caused a reduction in the alpha-beta elevation. Even so, it might be possible to use heat to produce chronic nerves devoid of any functioning pain fibers but having enough large fibers for transmission of the other kinds of sensory information. Such preparations would be useful for studying sensory mechanisms of the central nervous system and could also provide a rationale for application of heat to certain pain problems. We are currently carrying out in vivo studies of this sort.
Fig. 4. Effect of heat on compound action potential of cat saphenous nerve. Interelectrode distance 6 cm. Stimulus strength in A and B, 1 v; in C, 10 v. Arrows labeled “S” indicate heated saline was applied. Arrows in C identify C wave. The large deflection at beginning of each trace in C is shock artifact. In Column 3, the delta wave has been abolished. In Column 4, only the alpha-beta elevation remains.

Fig. 5. Effect of heat on compound action potential of cat saphenous nerve. Interelectrode distance, 5.5 cm. Stimulus strength in A and B, 1 v; in C, 10 v. Arrow labeled “S” indicates that heated saline was applied. Records in Columns 3, 4 and 5 were obtained at 5, 15 and 20 minutes respectively, after application of heated saline.
Peripheral Nerve Action Potential

Summary

The effect of rf current and of heat on the compound action potential of peripheral nerve was studied in 19 cat saphenous nerves (in vitro preparations). Both rf current and heat block the smaller delta and C fibers before the alpha-beta group. The delta and C fibers are either blocked simultaneously or in sequence, with the delta group failing before the C fibers. The studies suggest the possibility of using heat to modify nerves (in chronic animals for physiologic studies, and in certain pain problems) so that they have no fibers that transmit pain.

References