

Neuroprotection Due to Irrigation During Bipolar Cautery

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Objective: To test whether irrigation during bipolar cautery confers thermoprotection from neuronal injury.

Design: A rat animal model (15 rats for each treatment group) was used to test the thermoprotective effects of irrigation during bipolar cautery. In this model, the sciatic nerve was exposed, and a 1-second stimulus was applied using bipolar cautery forceps at 40 or 20 W placed directly on the nerve in the presence or absence of simultaneous irrigation. The effects of cautery were determined on the basis of clinical gait analysis by means of the Sciatic Functional Index, temperature response, and neuropathological findings.

Results: The degree of paresis was reduced with irriga-

tion. Neuropathological examination of the sciatic nerve after cautery showed significant axonal loss (more small than large fibers) with concomitant demyelination, which was partially inhibited by irrigation (χ^2 ; $P = .04$). The mechanism of thermoprotection by irrigation was not the result of a reduction in the temperature spike that followed cautery, but resulted from a reduced temperature response during the 15 seconds that followed 40- or 20-W stimulation with bipolar cautery.

Conclusions: Simultaneous irrigation and bipolar cautery enhance temperature recovery to basal levels and protect the peripheral nerve from the effects of cautery.

Arch Otolaryngol Head Neck Surg. 2000;126:149-153

CAUTERY IS often performed in close proximity to cranial nerves during head and neck surgery. This can result in neural injury beyond the cauterized site. The potential neuromuscular morbidity is underreported in the head and neck literature as well as in that of other surgical fields.¹⁻³

Simultaneous irrigation and bipolar cautery during intracranial dissection is an accepted practice. There are instruments combining irrigation ports and bipolar forceps.⁴ To a large extent, the role of irrigation has been to reduce tissue carbonization that sticks to the poles of the forceps and causes inefficient cautery and multiple breaks in the procedure to clean the instrument. A second possible role of irrigation may be neurophysiological. Studies have shown that temperatures as low as 41°C can produce neural trauma.⁵⁻⁷ In theory then, irrigation should provide an avenue for the tissue bed to be cooled, therefore protecting the neighboring vital structures from thermal injury. These theoretical benefits of irrigation have led to the inconsistent clinical use of simultaneous irrigation and bipolar cautery. The

benefit of simultaneous irrigation has only been theorized. The degree of its effectiveness is unknown and is thus the focus of our study.

Using the rat sciatic nerve, it was demonstrated previously that irrigation during bipolar cautery improves clinical function of the nerve postoperatively.⁸ Our goal was to determine the mechanisms underlying this protective effect. This was accomplished by determining whether bipolar cautery can inflict neuronal injury, and whether simultaneous irrigation confers neuroprotection from thermal injury.

RESULTS

MUSCLE PARESIS

The SFI was used to determine if animals showed muscle weakness on various days following cautery and whether irrigation reduced this degree of paresis. Animals with abnormal findings were defined as those having an SFI of less than -10%. The average SFI for each group of animals on days 1 and 7 after receiving 40- or 20-W cautery is shown in **Figure 1**. At 1 day after exposure to 40-W cautery, there were

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METHODS AND MATERIAL

RATS AND EXPERIMENTAL GROUPS

We used 4 groups of 15 adult male Sprague-Dawley rats, each weighing 300 to 400 g. Two groups of rats had the sciatic nerve on the experimental side exposed to 40-W cautery for a 1-second duration, whereas 2 other groups of rats received 20-W cautery for a 1-second duration. One group receiving 40-W cautery and another receiving 20-W cautery also underwent simultaneous irrigation with room temperature isotonic sodium chloride solution. The irrigation was begun before and ended after the cautery stimulus, and was evacuated using continuous suction. Use of the rats in these studies was approved by our Institutional Animal Care and Use Committee and conformed to the guidelines of the National Institutes of Health.

SURGICAL PROCEDURE

The surgical procedure was conducted as previously described.⁸ Great care has been taken to eliminate significant variables throughout this experiment. Briefly, animals were anesthetized using intraperitoneal ketamine hydrochloride (160 mg/kg) and xylazine hydrochloride (3 mg/kg). Using randomization, a limb was designated the experimental limb and the other, the control limb. The left limb routinely underwent operation first. After shaving the hind quarters, the sciatic nerve was exposed. Each sciatic nerve dissection was performed by one of us (J.D.) without direct handling of the nerve. To ensure there was no inadvertent stimulation during dissection, a motion

detector was used on the foot. If the dissection caused stimulation of the nerve, which elicited limb movement and detection, the animal was not included in the study. The temperature probe was secured with a 4-0 suture directly beneath the nerve proximal to the first branching without intervening tissue between it and the nerve. The bipolar cautery forceps were lowered onto the nerve and held in place straddling the temperature probe with direct contact to the nerve. The stereotactic device held the tips at a constant 2-mm intertip distance, as well as holding the tips in contact with the nerve. Position was confirmed throughout by loop magnification. If this animal belonged to the irrigation group, room temperature 0.9 isotonic sodium chloride solution was delivered to the tissue bed at a constant flow using a syringe pump (Harvard Apparatus, Holliston, Mass) with a curved sinus suction serving as the irrigation port. Irrigation was started before the cautery stimulus and was shut off after the stimulus had finished. A field suction provided evacuation of the irrigant so as not to flood the field and to ensure the bipolar tips were not completely submerged in irrigation. A cautery unit (Valleylab Force II; Valleylab, Boulder, Colo) on a precise setting for bipolar cautery was used to provide the stimulus. The impulse was delivered for 1 second. The control limb received identical surgical exposure and placement of instrumentation, but did not receive the bipolar cautery stimulus. The control and experimental sides were allowed to recover for 20 seconds with continuous recording of the temperature. The skin incision was closed with metal staples, and the animals were allowed to recover.

Although use of instrumentation minimized variability in experimental procedures, procedures that remained

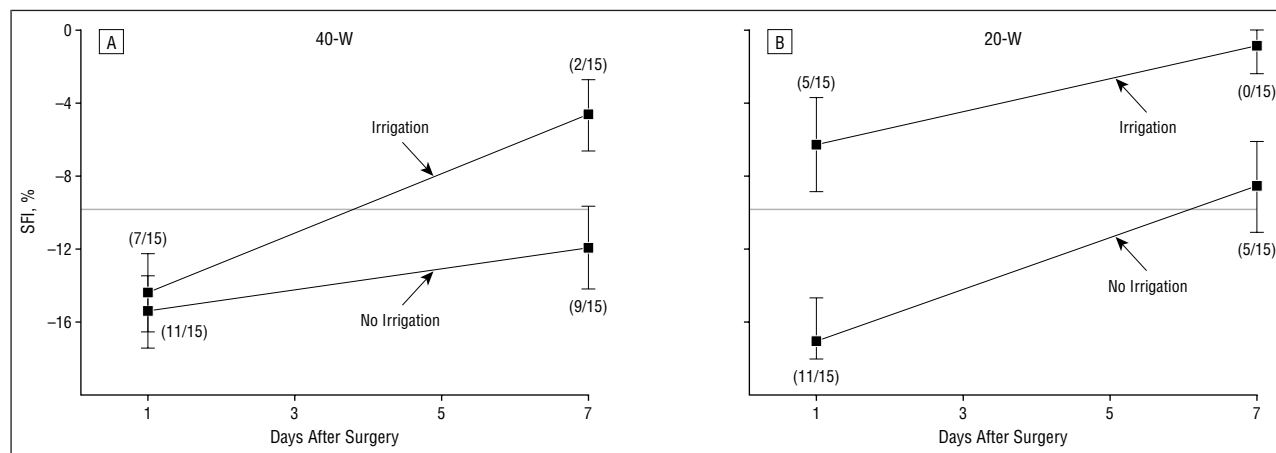


Figure 1. Enhanced clinical recovery in rats when irrigation is combined with 40- or 20-W stimulus. Results are given as mean (\pm SE) Sciatic Functional Index (SFI) values on postoperative days 1 and 7 for groups of rats that received a 40- (A) or a 20-W stimulus (B) with or without isotonic sodium chloride solution irrigation. Proportions of animals in each group that exhibited paresis are given in parentheses. Paresis was defined as any SFI of less than -10% (dashed lines).

no significant differences in the mean SFI values for animals that did or did not receive simultaneous irrigation. At this time, 11 of the 15 animals in the nonirrigation group showed paresis, whereas 7 of the 15 animals in the irrigated group showed paresis ($P = .13$). On day 7 following cautery, the mean SFI for the nonirrigation group remained abnormal, whereas the mean SFI for the irri-

gation group was significantly greater ($P = .02$) and within the normal range. Nine of 15 rats in the nonirrigation group had paresis, whereas only 2 of 15 in the irrigation group had abnormal findings ($P = .007$).

The effect of irrigation in animals receiving 20-W cautery was evident on days 1 and 7 (Figure 1). On day 1, the mean SFI for the nonirrigation group was in the

subject to human error were the dissection, placement and securing of the temperature probe, and lowering the bipolar forceps down just to touch the nerve. These steps were all performed with 2.5× loop magnification to increase accuracy and minimize variability. Other steps that were used to minimize variability included the use of an pulse generator (EG&G Ortec; Seven Hills, Ohio) capable of timing to 1 one thousandth of a second to deliver the 1-second bipolar stimulus. The irrigation was kept at a constant temperature and was delivered at a constant rate, as well as being evacuated by a field suction so as not to pool in the wound.

ANIMAL EVALUATION

Each animal underwent evaluation first by intraoperative monitoring of field temperature. The areas of the temperature elevation curves were compared between irrigation and nonirrigation groups using the *t* test. Second, the motor capability of the lower extremity was evaluated clinically via gait analysis. Gait was compared quantitatively by analyzing foot tracks with the Sciatic Functional Index (SFI).^{9,10} Each animal made hind foot prints while walking down a track lined with undeveloped x-ray paper. The tracks were produced 3 times for each animal, preoperatively and postoperatively on days 1 and 7. The SFI was computed by measuring 4 factors on each footprint for the control and experimental sides. The measured factors for the experimental (E) vs the normal (N) sides were the distances between the toes of opposite feet (TOF), the paw length (PL), toe spread 1 through 5 (TS), and intermediate toe spread 2 through 4 (IT). These numbers were then applied to the following formula:

$$\text{SFI} = \frac{(\text{ETOF} - \text{NTOF})/\text{NTOF}}{4} + \frac{(\text{NPL} - \text{EPL})/\text{EPL}}{4} + \frac{(\text{ETS} - \text{NTS})/\text{NTS}}{4} + \frac{(\text{EIT} - \text{NIT})/\text{NIT}}{4} \times 220/4$$

Values greater than or equal to -10% signified normal function. Values less than -10% signified varying degrees of paresis, with -100% corresponding to total paralysis. This allowed for the following 2 mutually exclusive groups to be formed: those that were normal and those that showed muscle weakness. Binomial statistical analysis was used to compare the number of animals with paresis among the various treatment groups. The *t* test was used to compare the mean SFI values.

Finally, neuropathological examination of the sciatic nerve was used to evaluate the thermoprotective effect of irrigation during bipolar cautery. On postoperative day 7, each animal was killed using pentobarbital sodium overdose. The sciatic nerve from each side was dissected and placed in 10% buffered formalin and subsequently stained with combined Luxol fast blue and hematoxylin and eosin (LHE) and with the modified Bielschowsky silver method. These stain the myelin and axons, respectively. Each of the sciatic nerves was evaluated on a 3-point scale (where 0 indicates normal) for damage. For the LHE-stained sections that were used to look at myelin breakdown, the opposite side that did not receive the bipolar cautery stimulus was used as an internal control and received a rating of 0. For mild to moderate myelin breakdown, a rating of 1+ was given. Severe myelin breakdown or local infarction of the tissue received a rating of 2+. For axonal loss, a similar rating scale was used, with the control side receiving a rating of 0 and the experimental side being rated 1+ for mild axonal damage and loss and 2+ for severe axonal damage.

abnormal range, whereas the mean SFI for the irrigation group was significantly greater ($P = .01$) and within the normal range. Eleven of the 15 animals in the nonirrigation group showed paresis, whereas only 5 of 15 animals in the irrigation group showed paresis ($P = .03$). On day 7, the mean SFI for the irrigation and nonirrigation groups was within normal range, but the value for the nonirrigated group remained significantly lower ($P = .04$). At this time, the number of animals with abnormal findings was 5 of 15 for the nonirrigation group, and 0 of 15 for the irrigation group.

TEMPERATURE RESPONSE FOLLOWING BIPOLAR CAUTERY

The effect of irrigation on the temperature response to bipolar cautery was assessed. Field temperatures were elevated in all animal groups, and there was no significant difference in the mean maximal temperature that was attained in the irrigation vs nonirrigation groups (data not shown). The overall temperature response was calculated by using image analysis to determine the area under the temperature curve that was produced during the 15 seconds following cautery. A comparison of the field temperature curves for the irrigation and nonirrigation groups showed that irrigation significantly reduced the temperature response during 15 sec-

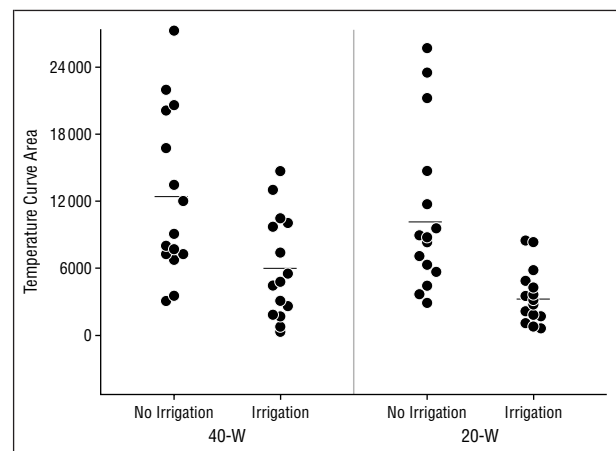


Figure 2. Irrigation reverses the temperature response to cautery. The field temperature under the sciatic nerve was taken during bipolar cautery in the presence or absence of irrigation. The area under the temperature curve was quantitated using image analysis. The area of the temperature curve for each rat is shown in random units of area for the first 15 seconds after cautery. Horizontal lines indicate the mean temperature curve areas for each group.

onds after 40-W cautery (**Figure 2**) ($P = .004$). Similarly, irrigation reduced the temperature response during the 15 seconds after 20-W cautery (Figure 2) ($P < .001$).

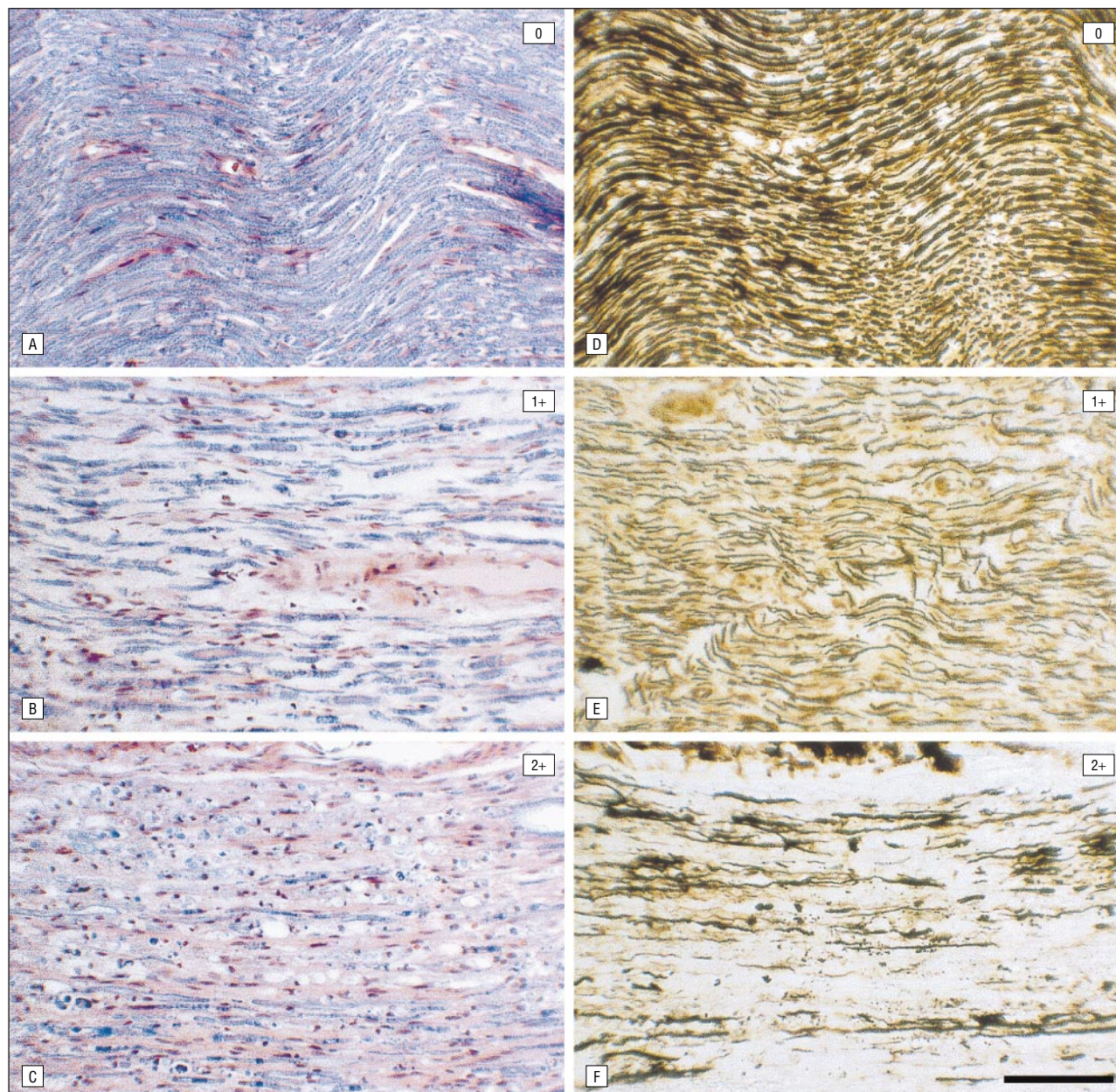


Figure 3. Representative photomicrographs of sciatic nerves and the pathologic rating scale used for analysis of nerve damage. The combined Luxol fast blue and hematoxylin and eosin stain was used to visualize myelin sheaths (panels A-C). A, Normal myelinated nerve (0); B, mild to moderate myelin damage (1+); and C, severe myelin damage (2+). The modified Bielschowsky silver stain was used to visualize axons (panels D-F). D, Normal axons (0); E, mild axonal loss (1+); and F, severe axonal damage and loss (2+). (Original magnification of all parts, $\times 200$.)

NEUROPATHOLOGICAL ASSESSMENT OF THE NEUROPROTECTIVE EFFECT OF IRRIGATION

Neuropathological examination of the cauterized sciatic nerves was conducted in a double-blind fashion. In the absence of irrigation, nerves from animals that were exposed to 40- or 20-W cautery showed prominent nerve damage. This was manifested by a loss of myelin and axons (2⁺ level of injury) in 8 of the 11 animals examined. An example of 2⁺ myelin loss is shown in **Figure 3** (part C). Figure 3 (part F) also shows an example of 2⁺ axonal loss. In contrast, the irrigated group (n = 9) was protected from this level of neuronal injury. Of the 9 animals that received irrigation, only 3 had 2⁺ damage. A

1-tailed χ^2 analysis¹¹ between the irrigated and nonirrigated groups gave a P value of .04. On the axonal stains, it appeared that the nonirrigated group had greater small- than large-fiber loss.

COMMENT

Very few controlled studies have examined the possibility that bipolar cautery may be an insulting agent for nerve morbidity.¹⁻³ We hypothesized that bipolar cautery could inflict neuronal injury and that simultaneous irrigation would be thermoprotective. The effects of cautery in the presence or absence of irrigation was determined on the basis of the following 3 factors: clinical gait analysis by

means of the SFI, field temperature response, and neuropathological findings. The SFI was considered to be important for quantitative analysis of the effects of cautery and irrigation on clinical outcome, whereas the other factors provided insight into mechanisms that might have contributed to such clinical outcomes.

Exposing rats to 40- vs 20-W cautery resulted in thermal injury based on all 3 of the factors used to measure injury. A clinical difference was observed between animals exposed to cautery with and without irrigation. Those animals that were exposed to simultaneous irrigation and bipolar cautery had a reduced frequency of weakness as well as a faster clinical recovery time when compared with those not receiving irrigation.

Studies to elucidate mechanisms by which irrigation lessened the extent of cautery-induced paresis implicated irrigation's dampening of the temperature response. Although the thermoprotective effects of irrigation were not the result of its capacity to temper the rise of field temperature during cautery, irrigation resulted in a more rapid reversal of the temperature rise. This was quantitated by a lower temperature-response curve, and was observed at 40- and 20-W cautery.

Assessment of the mechanisms by which including irrigation with bipolar cautery results in improved clinical recovery also showed a neuroprotective effect. Like in the central nervous system, it appears that thermo-protection (lowered temperature) can lead to less damage to peripheral nerves. Lowered body temperature can protect against anoxic changes and localized infarction due to low blood flow. This is thought to result from lowered metabolic demand at the lower temperature. Whether a similar mechanism can be invoked with supranormal temperatures and cooling of peripheral nerves is not known and may be an area for future investigation.

Although our study showed favorable effects of irrigation during bipolar cautery, it did not incorporate analysis of the impact of irrigation on bipolar cauterizing efficiency. This study could not evaluate the effect on cauterization because the dissections were atraumatic down fascial planes, and the only item being cauterized was the sciatic nerve. The favorable effect of irrigation seen in our study could be attributed to less localized current because the irrigation dilutes it or to a more rapid recovery from the exposure to high temperatures. Our results support the latter possibility, since temperature was similarly spiked in the irrigation and nonirrigation groups. However, the temperature returned to baseline levels more rapidly in the animals receiving irrigation.

We attempted to reproduce clinical situations by using simultaneous evacuation so that the bipolar forceps was not sitting in a pool of irrigation. It is clinically evi-

dent that the use of irrigation in a bloody field with bipolar cauterization does 2 things. First, the bipolar tips stay cleaner with less carbonization, and second, the bleeding vessel is usually seen more efficiently. The significance of our results is that there are frequent encounters in otolaryngological procedures where there is a need for thermal application in regions of inextinguishable nerves. This emphasizes the importance of identifying measures, such as irrigation, to minimize thermal injury. In fact, our results are likely to be applicable not only to bipolar cautery, but also to other thermal instruments, such as the laser, or to the thermal injury that can occur when drilling.² Our study with the rat sciatic nerve model suggests that in each of these instances of potential thermal injury, simultaneous room temperature irrigation can result in a more rapid reversal of the temperature response and, in turn, reduced nerve damage.

Accepted for publication September 15, 1999.

We thank Michael Raffin, PhD, for the statistical analyses of the results, and Rosann Grahovac for assisting in the preparation of this manuscript.

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