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Original Research

Intraoperative Electrical Nerve Stimulation as a Prognostic Tool in Patients Undergoing Peripheral Nerve Neurolysis

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A R T I C L E I N F O

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Purpose: Functional recovery from peripheral nerve injuries remains unpredictable and continues to pose a major clinical challenge to surgeons. This study sought to investigate the utility of intraoperative nerve stimulation following neurolysis surgery as a prognostic indicator of functional recovery.
Methods: A retrospective chart review of adult patients who underwent peripheral nerve neurolysis between September 2021 and December 2022 was performed. A handheld nerve stimulator was used intraoperatively before and after neurolysis. Patients with preoperative motor deficits corresponding to the nerve that underwent neurolysis, intraoperative nerve stimulation, and postoperative follow-up length of at least 3 months were included. Muscle strength as measured by the Medical Research Council scale was used to evaluate nerve function. A scale grade of 0 or 1 meant "no recovery," between 2 and 4 was classified as "partial recovery," and 5 was classified as "full recovery." Fisher exact tests were employed to test for an association between stimulation thresholds and functional recovery.
Results: A total of 27 patients and 45 nerves were included in the study, with a mean follow-up of 8.0 months. Intraoperative stimulation at 0.5 mA was observed in 73% (33/45) of nerves, with 76% achieving full recovery, 18% partial recovery, and 6% no recovery. Two nerves stimulated at 2 mA and one at 20 mA, with both showing partial recovery. In contrast, 22% (10/45) of nerves showed no stimulation, leading to full recovery in 20%, partial recovery in 30%, and no recovery in 50% of cases. A significant ($P < .001$) association was found between stimulation thresholds and functional recovery.
Conclusions: Intraoperative nerve stimulation is strongly linked to functional recovery postneurolysis, demonstrating its potential as a prognostic tool for guiding surgical decisions.
Type of study/level of evidence: Prognostic, IV.

Peripheral nerve injuries (PNI) occur in 2% to 3% of traumatic upper-extremity injuries and involve a predominantly young patient population.[1,2] Patients are plagued by unsatisfactory outcomes, high rates of long-term disability, and great financial burden.[2–4] In-continuity nerve injuries represent a particularly devastating form of nerve injury, as the extent of damage cannot be easily assessed in the acute clinical setting.[5,6] Thus, despite extensive research, recovery after in-continuity nerve injuries and functional outcomes of different surgical interventions remain unpredictable and challenging.[7,8]

Peripheral nerves are thought to exhibit a full conduction block even at the least severe level of nerve injury, neurapraxia, where full recovery has traditionally been expected.[9] This means that acute loss of conductivity does not necessarily indicate poor recovery and unfavorable long-term outcomes opposed to long-term loss of conductivity as is seen in chronic lesions, such as neuromas in-continuity.

Neurolysis is a commonly performed procedure to address in-continuity nerve injuries, which frees the nerve from surrounding scar tissue, releasing external compression.[10] It is used in injuries

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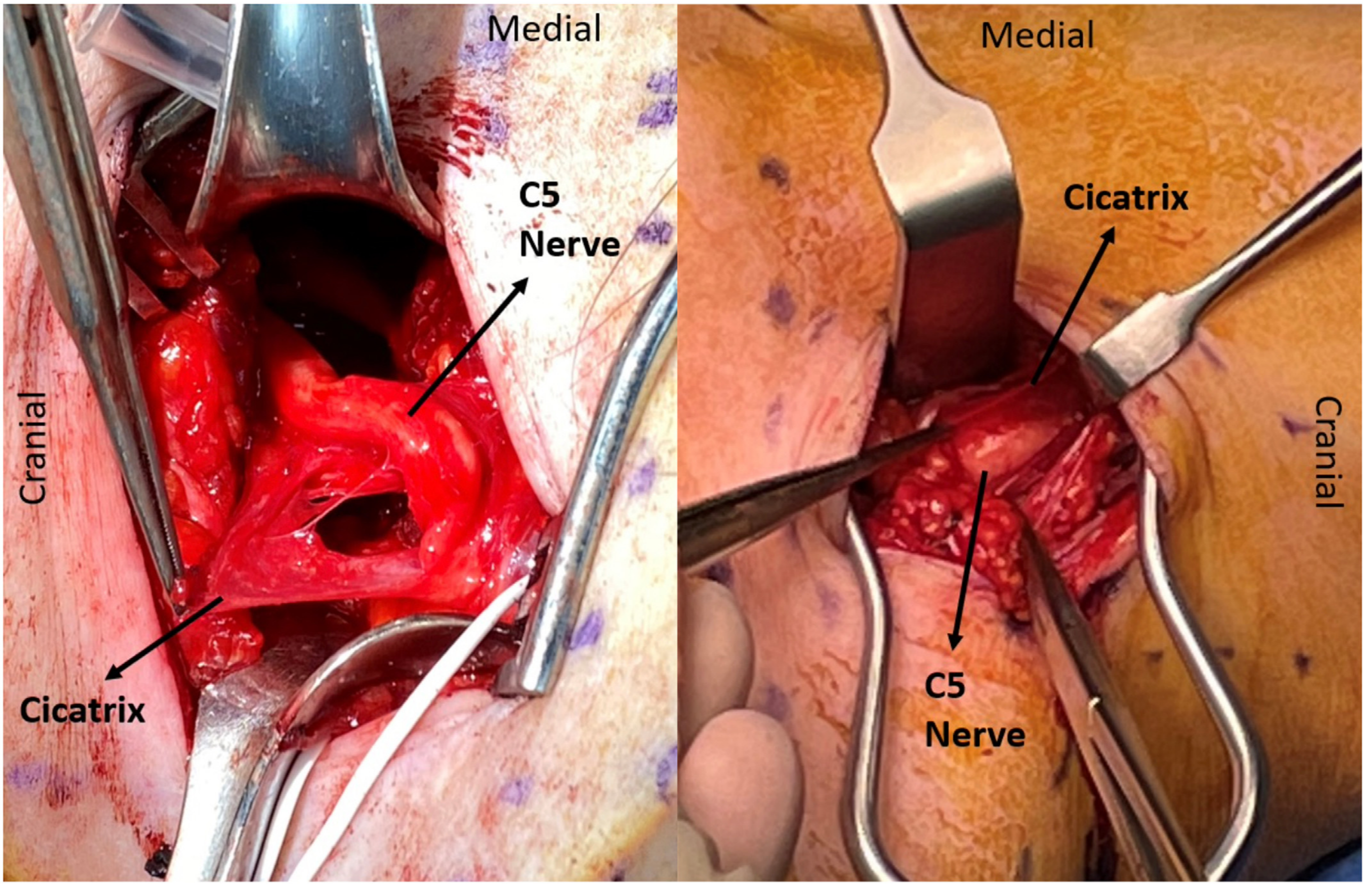

Figure 1. Intraoperative Image showing brachial plexus Neurolysis.

and neuromas that still conduct nerve action potentials distal to the nerve lesion.[10,11] A systematic review and meta-analysis by Chow et al[12] demonstrated that neurolysis of the common peroneal nerve significantly improves ankle extension strength in patients with peroneal nerve palsy, showing a median postoperative Medical Research Council (MRC) score improvement from 1 to 5 in 368 patients, indicating substantial functional recovery. Andrisevic et al[11] reported beneficial results of neurolysis alone in pediatric patients with upper trunk brachial plexus birth palsy who demonstrate more than 50% conduction. In more severe cases with considerably reduced or no conduction across the lesion, nerve transfers or nerve grafting present viable options to improve functional outcomes.[11,13]

Accurate intraoperative assessment is critical to determine the extent of nerve injury and thereby the most appropriate surgical treatment. However, there are currently no well-established tools to assist a surgeon in making this determination and largely relies on surgeon experience and judgment. Intraoperative neurophysiologic monitoring is widely used to identify pre-existing PNIs, as well as to prevent iatrogenic nerve injury by assisting with identification of peripheral nerves during surgical dissection.[14,15] Handheld electrical nerve stimulators provide a quick and easy method to assess nerve conductivity intraoperatively and have been established as safe, reliable and cost-effective alternatives to traditional EMG.[16,17] Despite widespread use of handheld electrical stimulators, the current literature holds little to no evidence on whether they can be used as a prognostic tool to predict functional recovery following neurolysis surgery. An easily accessible intraoperative indicator of outcomes could serve as a decision-making tool, guiding surgeons on whether neurolysis alone is appropriate or nerve transfers or grafts are necessary.

This study sought to investigate the utility of intraoperative nerve stimulation following neurolysis surgery as a prognostic indicator of functional recovery.

Materials & Methods

This study was approved by an Institutional Review Board (Study-24-00473). The charts of all adult patients who underwent peripheral nerve neurolysis by one of two senior authors (M.R.H. or S.M.K.) between September 2021 and December 2022 were reviewed. A monopolar handheld electrical nerve stimulator (model Guardian, Checkpoint Surgical LLC, Independence, Ohio) was used intraoperatively to stimulate the nerve of interest at preset current levels of 0.5, 2, and 20 milliamps using a pulse-duration of 100 microseconds (Fig. 1). Stimulation was increased from the lowest current level to the highest until movement of the target muscle was observed. The level at which stimulation occurred was documented in the operative report. Patients who had documented preoperative motor deficits corresponding to the nerve that underwent neurolysis, documentation of intraoperative nerve stimulation values, and a postoperative follow-up length of a minimum of 90 days were included for analysis.[18,19] Motor strength as measured by the MRC Scale for Muscle Strength was used as a surrogate to evaluate nerve function.[20] A postoperative MRC scale grade of 0 or 1 was classified as “no recovery”, between 2 and 4 was classified as “partial recovery”, and 5 was classified as “full

Table 1
Demographic Data of Included Patients

Demographics	N (%)
Sex (F)	15 (56)
Race	
Black	9 (33)
White	7 (26)
Hispanic	6 (22)
Other	5 (19)
Mean (SD)	
Age at surgery (y)	45.3 (18.8)
Time from symptoms to surgery (mo)	5 (18.3)
Final follow-up length (mo)	8 (4.8)
BMI	29 (8)

BMI, body mass index.

recovery". Fisher exact tests were employed to test for a significant ($P < .05$) association between stimulation values and outcomes of recovery.

Results

The charts of 142 patients were reviewed, and 27 patients and 45 nerves were included in this study with a mean follow-up period of 8.0 months. The mean age at time of surgery was 45.3 years and the mean body mass index was 29.0 with 55.6% of patients being women (Table 1). The mean time from injury or onset of symptoms to surgery was 5 ± 18.3 months, with the shortest time to surgery being 1 month and the longest 84 months. Nine patients underwent brachial plexus exploration with neurolysis of 24 terminal branches. The remaining 18 patients underwent neurolysis of a total of 21 other peripheral nerves including the femoral, common peroneal, tibial, supra- and subscapular, axial, radial, median, musculocutaneous, long thoracic, and spinal accessory nerves. The overall mean preoperative MRC grade was 2.6 ± 1.7 (Table 2).

Thirty-three of the total 45 nerves (73%) showed intraoperative stimulation at 0.5 mA. One nerve stimulated at 2 mA and one at 20 mA, whereas the remaining 10 nerves did not induce target muscle movement at any stimulation level (22%). Of the 33 nerves that stimulated at 0.5 mA, 25 nerves demonstrated full motor recovery at 12 weeks (76%), 6 nerves showed partial recovery (18%), and two nerves (6%) showed no recovery (Fig. 2). One median nerve stimulated at 2 mA and one axillary nerve at 20 mA, both demonstrating partial recovery. Of the 10 nerves exhibiting no stimulation, 2 demonstrated full recovery (20%), 3 showed partial (30%) functional recovery, and 5 nerves (50%) exhibited no recovery at the latest follow-up. Fisher exact test revealed a strong association of stimulation levels and functional recovery ($P < .001$). An analysis of outcomes of nerves exhibiting no stimulation versus stimulation at 0.5 mA (excluding nerves stimulated at 2 mA and 20 mA) further revealed a strong association of stimulation at 0.5 mA and favorable outcomes, whereas no stimulation at any level was strongly associated with no or only partial functional recovery ($P = .001$) (Table 2).

Discussion

Recovery after peripheral nerve and brachial plexus injury and outcomes of peripheral nerve neurolysis remain inherently unpredictable. Despite the well-established intraoperative use of handheld electrical nerve stimulators, the current literature contains a paucity of evidence on whether electrical stimulation or lack thereof following peripheral nerve neurolysis is associated with functional recovery. This retrospective chart review revealed a strong association of intraoperative nerve stimulation with functional recovery, demonstrating favorable outcomes and high rates of full motor recovery when nerves can be stimulated at the lowest current setting of 0.5 mA, whereas 80% of nerves recover either only partially or not at all when no stimulation is seen even at the highest current level following neurolysis. These findings indicate that handheld electrical nerve stimulators have the potential to predict outcomes of neurolysis surgery and assist surgeons in intraoperative decision making when determining which nerve injuries require neurolysis only versus more aggressive treatments such as nerve grafting. Future prospective studies are needed to verify those findings and determine the exact predictive ability of intraoperative nerve stimulation.

This study had several limitations. The retrospective nature of this study did not allow us to include a large sample size for each level of electrical stimulation. Thus, the 2 and 20 mA stimulation levels could not be effectively addressed in this study. Additionally, there is no standardized documentation system for electrical nerve stimulation values in patient charts and operating reports, which makes many patients ineligible for retrospective enrollment in chart review studies because of missing or incomplete stimulation parameters. Further, our senior authors often chose to proceed with nerve transfer surgery if no intraoperative stimulation could be observed, making those patients ineligible for enrollment in this study. This created an inherent selection bias, potentially increasing the rate of successful outcomes. Another potential source of bias is a highly variable follow-up time among patients, as those with satisfactory results generally required a shorter follow-up period.

Our study focuses on a controversial topic: microsurgical neurolysis of the brachial plexus and peripheral nerve is a procedure with uncertain results.[21] It is a treatment option primarily for lesions in continuity with external compression.[22] To date, no easily accessible and cost-effective diagnostic tool reliably differentiates lesions that will benefit from neurolysis from those requiring more extensive surgical intervention.[7,23] Furthermore, no prognostic method is currently able to predict outcomes following peripheral nerve injury and surgical intervention.[6,7] Other than serial clinical evaluation by a knowledgeable and experienced surgeon, current diagnostic tools used to evaluate PNI include more traditional electrophysiological methods such as nerve conduction tests or EMG, neuropathology methods such as nerve biopsy, radiological methods such as magnetic resonance imaging, and more recently, ultrasound.[24–26] However, those assessments have severe limitations and their abilities to predict nerve recovery has yet to be proven.[7] Traditional EMG is associated with low accuracy and high cost, limiting its utility and intraoperative availability.[27,28] Biopsies inherently cause structural damage to the nerve, and tools for diagnostic nerve imaging such as second harmonic generation collagen microscopy and indocyanine green fluorescent imaging are far from being able to be clinically employed, despite promising results in animal trials and early case reports.[29–31]

This retrospective clinical study evaluates whether postoperative outcomes following neurolysis surgery are linked to the level of electrical stimulation required to induce target muscle movement using a clinically available handheld nerve stimulator. Our findings demonstrate that there is a strong association between electrical conduction of peripheral nerves and favorable outcomes following neurolysis surgery. Vice versa, inability to induce nerve action potentials even at high stimulator settings is strongly associated with poor to no functional recovery, indicating a potential need for nerve transfers and nerve grafts, as neurolysis alone is likely to fail to restore function in those patients. The long mean time to surgery of 5 months suggests that most nerve injuries were chronic and that postoperative improvement of nerve function was a result of neurolysis surgery, rather than the result of spontaneous regeneration following neurapraxia. However, the two nerves which showed full motor recovery despite no

Table 2
Included Nerves Grouped by Stimulation Threshold

Nerve	Total, N (%)	Preoperative MRC, Mean (SD)	Stim at 0.5 mA, N (%)	Full Recovery, N (%)
Peroneal	10 (22)	1.8 (1.9)	7 (70)	5 (71)
Axillary	7 (16)	1.3 (1.6)	5 (71)	4 (80)
Radial	7 (16)	2 (1.7)	4 (57)	3 (75)
Median	6 (13)	2.8 (1.6)	5 (83)	4 (80)
Musculocutaneous	3 (7)	1.3 (1.5)	2 (67)	2 (100)
Ulnar	3 (7)	2 (1)	2 (67)	2 (100)
Suprascapular	3 (7)	2.7 (2.3)	3 (100)	2 (67)
Femoral	2 (4)	3.5 (0.7)	2 (100)	2 (100)
Tibial	1 (2)	0	0	0
Long thoracic	1 (2)	0	1 (100)	0
Subscapular	1 (2)	3	1 (100)	0
Spinal accessory	1 (2)	4	1 (100)	1 (100)

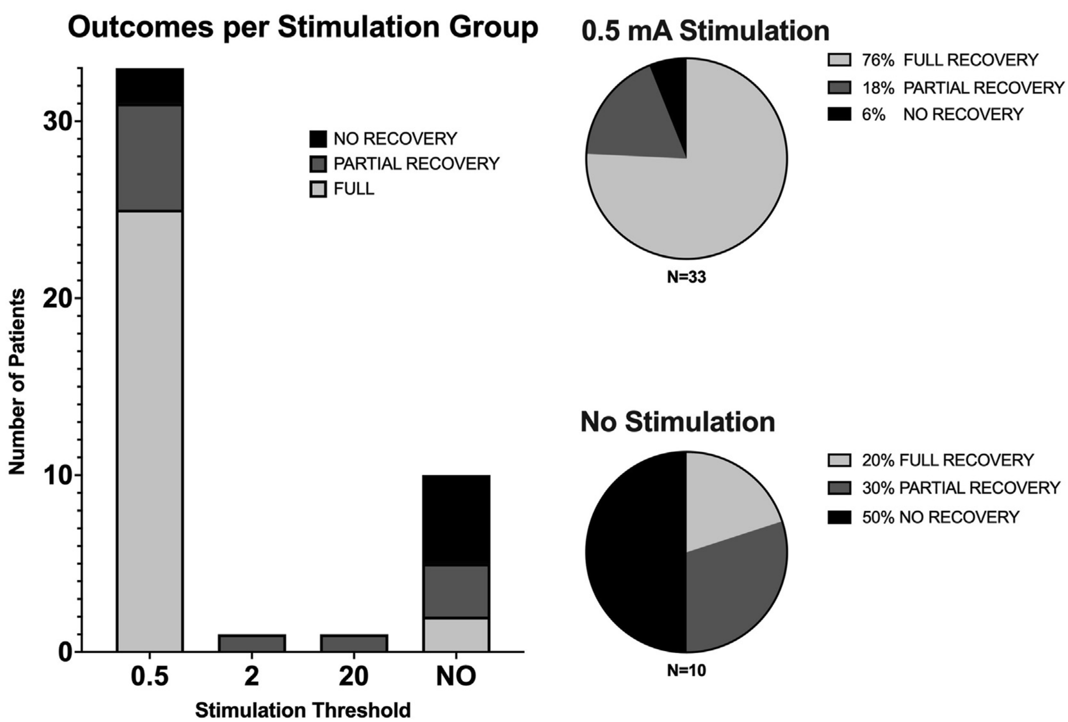

Figure 2. Included nerves organized by stimulation threshold. Although most nerves that generated a muscle reaction at 0.5 mA demonstrated full motor recovery, 80% of nerves that showed no stimulation at any current did not or only partially recover.

intraoperative muscle response at any stimulation threshold underwent neurolysis one and three months after the onset of symptoms. It is possible that the lack of stimulation in these nerves was primarily because of ongoing neurapraxia, which might have recovered spontaneously. We did not see a difference in stimulation or recovery patterns between upper and lower-extremity nerves. This suggests that handheld nerve stimulators are useful in various nerves, including both brachial plexus roots as well as lower-extremity peripheral nerves. Future research should investigate the predictive potential of intraoperative nerve stimulators in larger prospective studies and investigate the association of stimulation required for muscle movement and long-term outcomes following other surgical techniques such as nerve grafting and nerve transfers, in addition to neurolysis.

Conflicts of Interest

Paul J. Cagle, MD is a paid consultant for Arthrex and Exactech. Michael R. Hausman, MD is a cofounder and shareholder of Checkpoint Surgical, LLC. Steven M. Koehler, MD is a committee member of the American Society for Surgery of the Hand (ASSH) and a stockholder and member of the medical advisory board for Reactiv, Inc. The following individuals have no conflicts of interest or sources of support that require acknowledgment: Christoph Schroen, Yufan Yan, Christian Awah, and Unwana Abasi.

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