Intraoperative Nerve Monitoring During Nerve Decompression Surgery in the Lower Extremity

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Q4

KEYWORDS

• Nerve decompression • Intraoperative neural monitor • Lower extremity
• Peripheral neuropathy

KEY POINTS Q6

- Intraoperative neurophysiologic monitoring (IONM) can be helpful for educating the patient and improving the quality of services provided when nerve decompression is done.
- IONM can give the surgeon better feedback regarding the amount of decompression to be done while performing a neurolysis procedure.
- IONM can give the surgeon objective information regarding changes in nerve function for better medical documentation.
- IONM can provide objective data to further research regarding outcomes of nerve decompressions in the lower extremity.
- IONM can assist the doctor in economizing surgical time when attempting to localize nerves in challenging surgical cases.

Videos content accompany this article at http://www.podiatric.theclinics.com/

INTRODUCTION Q7

It has been estimated that 20 million people suffer from peripheral neuropathy in the United States, many of whom have diabetic neuropathy.[1] Approximately 50% of people with diabetes have some form of neuropathy and those with diabetic neuropathy are at higher risk of disease progression leading to gangrene and amputation.[2] These

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estimates do not include the 38% of the US population who are considered prediabetic. Therefore, between 49% and 52% of the United States population is considered diabetic or prediabetic, and many of these individuals are undiagnosed.[3] Although the most common cause of neuropathy is diabetes, many other individuals suffer from nondiabetic neuropathy. Most of these nondiabetic patients have been diagnosed with idiopathic polyneuropathy. Most of the patients undergoing decompression procedures are nondiabetic among this population. Q8

The concept of nerve decompression for diabetic neuropathy was first described in 1992[4] and for nondiabetic neuropathy in 2006.[5] Decompression for diabetic neuropathy was first reported in the podiatric literature in 2003.[6] More recent studies have been published indicating the significance of decreased rates of amputation and ulcers in diabetics.[7–9] In 2014, Zhong and colleagues[10] published findings showing that in a 1526 subject study many subjects had significant improvement in their nerve conduction velocity as well as their quantitative sensory testing a year and a half after decompression surgery. This group demonstrated similar improvement in 560 subjects at 18 months, in addition to improved motor function and skin ulcer healing.[11] Q9

Despite the published evidence, nerve decompression surgery as a treatment of diabetic and nondiabetic neuropathy still remains controversial. Intraoperative neurophysiologic monitoring (IONM) is useful for an array of applications, not the least of Q10 which is establishing more objective evidence on physiologic change to nerve function. This objective measure will help researchers and clinicians better understand the physiologic changes that occur as a result of nerve decompression surgery among those with peripheral neuropathy.

IONM is used routinely in thyroid and fascial surgery,[12–15] spinal surgery,[16] and otologic skull-based procedures.[17] For all of these procedures, IONM is used to monitor the integrity of the nerves at risk during the procedure. IONM, as presented here, is used not only to monitor nerve integrity but also to determine if nerve decompression improves nerve function. The results also provide additional information to share with the patient.

The common fibular nerve innervates the dorsum of the foot and passes through the anterior lateral compartment, whereas the tibial nerve innervates the plantar aspect of the foot and passes through both the tarsal tunnel and soleal sling. Both of these nerves have a detectable number of motor branches and their function can be measured during a surgical decompression. It is understood that the superficial fibular and deep fibular nerves have motor branches; however, the muscle components are small and it is not practical to monitor them intraoperatively. Because IONM records evoked potentials in muscle, its use is limited to nerves where a significant number of motor branches are located. However, it is not necessary for the patient to experience significant motor impairment for improvement to be noted. This is because it is presumed that the same compression that is causing dysfunction of the motor fascicles is also causing dysfunction to the sensory fascicles. Therefore, improvement in evoked potentials as recorded during IONM will also benefit patients suffering from burning, tingling, and numbness; which are commonly affected sensory modalities.

Introducing nerve monitoring to the surgical arena will often cause a skeptical physician to consider the added time to the surgery as a serious dilemma. However, as the physician becomes more efficient, the added time is minimal (approximately 5–10 minutes) and the benefits outweigh the risks associated with a slightly longer surgery. The following protocol is a very basic overview. Over time, not only should the time it takes to perform IONM be reduced but improvements in consistency should also be improved. This should result in IONM becoming a standard protocol in decompression surgeries. Considering the advantages of nerve monitoring, the following aspects should be considered: improved patient education, improvement in surgical technique and potential results, improvement in documentation, data collection for research purposes, and improvement in the surgeon's ability to locate the nerve to be decompressed.

IONM can be used with great accuracy to identify the location to begin the decompression via the stimulating electrode. Because nerve decompression may be a new technique for many surgeons, IONM is a particularly useful exercise to apply while learning the procedure to help the surgeon become more proficient at performing decompressions. Many lower extremity surgeons are familiar with the anatomy of the tarsal tunnel because this may have been part of their formal training. However, the soleal sling and common fibular anatomy will be unfamiliar for most podiatric surgeons. Practicing IONM in the early phase of the surgeon's technical training will also instill confidence by helping to locate the nerve and by identifying what was, or was not, nervous tissue. This may particularly be the case with the common fibular nerve. The concern of drop foot as an adverse effect of surgery is a motivating factor for nerve monitoring. A revision surgery is another example of when nerve monitoring is useful for localization of the nerve. A revision surgery often results in mistaking fibrotic scar tissue for nervous tissue. Applying IONM can aid in overcoming this obstacle because scar tissue will not produce evoked potentials, whereas the nervous tissue will. This method can help locate the nerve even when it may not be macroscopically visible or other localization methods fail. Additionally, IONM can be useful to avoid trauma to other nearby vital structures, such as blood vessels. This is particularly true with decompression of the soleal sling because the tibial artery and vein of the lower limb lie in this area. For instance, during decompression of the tibial nerve throughout the soleal sling, the stimulating probe is used to help guide the dissection.

The IONM technique can also provide documentation of nerve function at the completion of the surgery, with improvement noted in most cases. Surgeons are formally trained to take intraoperative fluoroscopy during orthopedic procedures as a way to document the results of the surgery before the patient leaves the operating room and is transferred to recovery. This same principle should apply to nerve surgeries. In most cases, the surgeon should be able to appreciate improved nerve function when comparing the predecompression evoked potential value to the post-decompression value. It should be noted that in cases in which nerve monitoring did not show improvement it does not mean that the patient did not improve. It should also be noted that improved muscle contraction in the muscle group being stimulated may also be observed in the operating room. This may be a secondary way to ensure that no damage was done to the involved nerve branch. This may also be documented in the patient's operation report.

Patient education is very important because patients can be shown the results immediately following their surgery while still in the recovery area. Many patients are anxious to hear how successful the surgery was and this can provide them with that information. An educated and satisfied patient can then serve as a source to inform others, as well as their primary care physicians, of the success of their surgery. Therefore, it should be considered standard practice to follow this same protocol in regard to what was done in the surgical arena with a patient's nerves.

If the surgeon is interested in research, IONM can be useful in gaining objective information from the surgery. The more surgeons are engaged in clinical research, the more we will understand which demographic is benefiting more from the surgeries, and the more effective we will be at applying and executing the procedures.

IONM can serve as a tool to show the physiologic benefits associated with nerve decompression as a treatment of neuropathy. Contemporary physicians practice outcome-based medicine and, with objective documentation acquired from IONM, physicians will be confident in the medicine that they are practicing. This IONM documentation is also useful in reassuring patients about the benefits of nerve decompression from an unbiased perspective.

The intraoperative monitoring technique also provides the surgeon with feedback indicating how effective the decompression has been thus far and if to continue decompressing. In some cases, this feedback will indicate that the surgeon should conduct a more thorough neurolysis of the nerve. While the surgeon is performing the neurolysis on a particular tunnel, it is necessary to periodically stimulate the associated nerve to provide the feedback about nerve function as the decompression proceeds. For the less experienced surgeon, this information may also give feedback about how aggressive the neurolysis should be. The feedback may also indicate at which point during the decompression neurolysis is complete and additional decompression would not yield any additional benefit.

PROCEDURE

So how is nerve monitoring done? It must be emphasized that the information presented here is a very general overview. Presented here are the methods for IONM at the tarsal tunnel, the common fibular, and the soleal sling using the NIM 3.0 Nerve Monitoring System (Medtronic, plc, Jacksonville, FL, USA) (Videos 1 and 2). Before Q11 nerve decompression is begun, the following guidelines for setup should be considered. If an ankle or thigh tourniquet is used it may serve as another site of compression and may affect the IONM recordings and, therefore, the procedures are best performed without a tourniquet. It is presumed the external compression will decrease blood flow and oxygen to the nerve tissue, thereby affecting the status of nerve function. Intraoperatively, it has been observed that if a tourniquet is used for around 30 minutes or more this can have a significant impact on the IONM recordings. In an 11 subject pilot study in which IONM was performed both before and after nerve decompression, there was a trend for a geometric drop in percent change in electromyographic (EMG) amplitude with increased tourniquet time (Video 3). At 14 minutes of Q12 tourniquet time the average change in EMG was 538%, whereas at 36 minutes the average change was 68.5% (a drop of 31.5% from baseline).[18] This is consistent with other reports showing ischemic effects on nerve function starting at 25 to 30 minutes.[19] How significant the impact is when tourniquet time is less than 30 minutes has not been determined. If nerve function is impaired, such as when a tourniquet is used, it may be more difficult to achieve an evoked potential. Therefore, more current will need to be applied to get the muscles being recorded to respond. Between the initial recording, before decompression is done, and the final recording, when decompression is completed, a decreased response may be noted. When the common fibular nerve is monitored, the tibialis anterior and peroneus longus muscles are recorded (Fig. 1). When tarsal tunnel or soleal sling surgery is performed, the abductor hallucis and abductor digiti quinti are recorded (Fig. 2). This is accomplished by placement of needle electrodes in each of these muscles (see Fig. 1A) and recording evoked potentials on the NIM monitor (see Fig. 1B). Placement in the abductor hallucis is 1 to 2 cm distal to the navicular tuberosity on the medial aspect of the arch. The abductor digiti quinti is midway between the fifth metatarsal head and the styloid process on the lateral plantar side of the foot. The location of the deep fibular nerve is 4 finger widths (approximately 7.6 cm) distal to the tibial tuberosity and approximately 1 cm lateral to the crest of the tibia. For the peroneus longus, the electrode is placed 3 finger widths (approximately 5.7 cm) distal to the head of the fibula and 1 cm anterior to the fibula. It

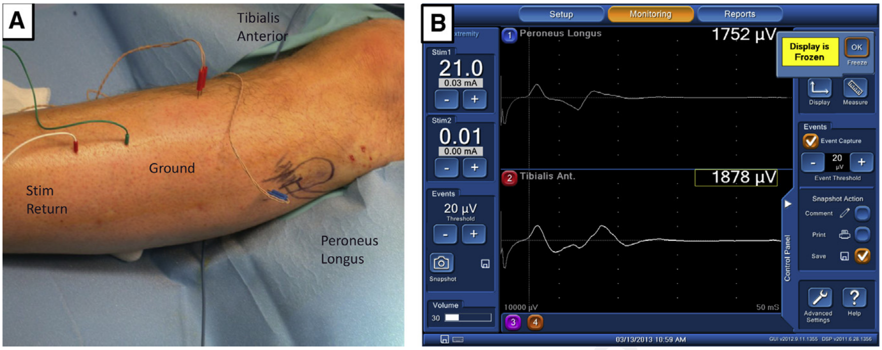


Fig. 1. Common fibular setup. (*A*) Placement of color-coded electrodes. The red electrodes are inserted into the tibialis anterior, the blue electrodes are inserted into the peroneus longus, the ground electrode is between the stimulus return (STIM), and the recording electrodes in an area away from the surgical site. (*B*) Color-coded electrodes relay to the NIM monitor showing the evoked potentials (µV) in the peroneus longus and tibialis anterior.

is recommended to bury the needle recording electrode in the muscle so the hub is resting against the skin (Fig. 3). Some surgeons prefer the technique of bending the needles at the level of the hub once the needles are in the muscle so the hub sits parallel to the skin. Sterile adhesive (ie, Tegaderm) may also be used to adhere the electrode to the skin. Q13 The goal in both setups is to avoid movement of the electrode once recording begins. As the muscle is stimulated and contracture occurs, the needle electrodes may move from a deep to a more superficial position because of the mechanical effect of the muscle on the electrodes. It is important to keep the same electrode positioning in the muscle once the recording protocol has begun. The nerve may be stimulated with currents ranging between 0 mA and 30 mA. In addition to the visual display on the NIM 3.0, a sound is emitted with a higher volume indicating higher evoked potential amplitudes. Each recording electrode in the muscle is color coded to match the color on the monitor of that muscle's response (see Fig. 1). Also, each channel has a different pitch that can be heard from the speaker on the monitor. This allows the surgeon to know how each channel and/or muscle is responding Q14

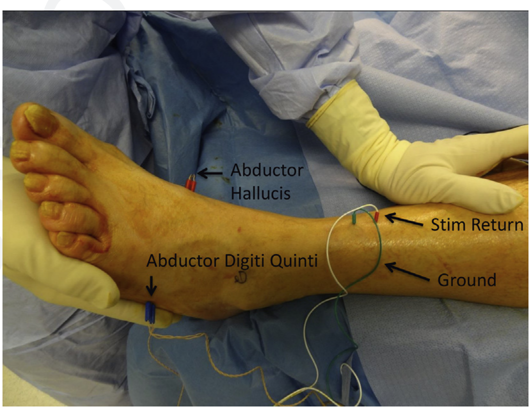


Fig. 2. Tarsal tunnel and soleal sling electrode setup. The setup for the tarsal tunnel and soleal sling is similar to that of the common fibular. Q18

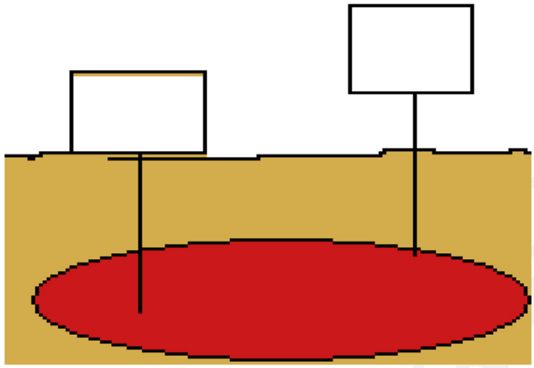


Fig. 3. Placement of the recording electrode. Muscle contracture during stimulation may push the electrode out of the muscle. Observe the electrodes while stimulating to make sure the same depth is maintained or use sterile adhesive to tape them to the leg. Q19

without the need to look at the monitoring screen. The evoked potentials recorded from the needle electrodes are presented in microvolts. If more nerve damage is present, it may be necessary to use more stimulation to get adequate evoked potentials in the muscle group being monitored. Placement of the electrode in the muscle may also need to be adjusted.

The current protocol is as follows. When dissection is down to the soft tissues structures that form the tunnel, the stimulating electrode may be placed on the overlying tissue to help localize the nerve. The location of the area to be tested is proximal to the anatomic site of compression. Once the nerve is located, a small 0.5 cm window is made through the tissue for placement of the stimulating electrode on the nerve. The surgeon then maps the fascicular topography of the nerve by stimulating various sides of the nerve while monitoring the evoked EMG of the target muscles (Fig. 4). Once the locations of the desired fascicles (ie, those innervating the monitored muscles) have been located and everything is ready for testing, the stimulus current is set to zero. The surgeon then maintains the simulating electrode in the same position on the nerve (ie, both along the length and side of the nerve). The amperage is gradually increased until the first evoked potential, or threshold, is recorded. This is then recorded as the initial response. The current, as well as the evoked potential amplitude, is then

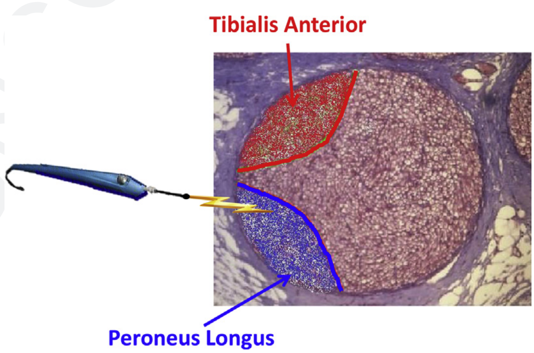


Fig. 4. Nerve fascicles. The simulation (milliampere) is delivered to the nerve fascicle and the corresponding evoked potential (microvolts) is displayed on the neural monitor. Q20

recorded (saved) on the monitor. The current is gradually increased, maintaining the same position of the electrode on the nerve until the evoked potential values plateau. The stimulus current and evoked potential amplitudes are again recorded and this will serve as the baseline recording. When the evoked potentials have plateaued, this indicates that all the fascicles of the nerve being stimulated are fully saturated with current (**Fig. 5**). This process is then repeated with the other muscle being tested. The predecompression nerve function is assessed for both muscles (**Fig. 6**). After determining the baseline evoked potential for each muscle, as well as the corresponding amperage to achieve it, the nerve decompression is performed. The recording can be used during the decompression to assess how the neurolysis is progressing and to help determine if more decompression is needed. Once the surgeon has completed the nerve release, a final recording is made for each muscle using the same stimulus probe location on the nerve and the same current settings (**Fig. 7**). To get a good recording of each muscle, 3 variables need to be considered: location of the stimulating electrode on the nerve, the location of the needle electrode in the muscle being recorded, and the amplitude of the stimulus delivered through the stimulating electrode. It should be stressed that if the surgeon is having difficulty getting a good recording from the muscle at the beginning of the process, the recording needle electrode should be moved. The process for this is to use 1 hand to stimulate the nerve with the stimulating electrode and the other hand to move the position of the recording electrode in the muscle. While doing this, the surgeon may listen and watch for a larger response on the monitor. To move the recording needle electrode, either remove it and place it through the skin at another location along the muscle or redirect at different angle beneath the skin (**Fig. 8**). Other variables to be considered are the electrodes that are used and the type of stimulating probe. In early protocols, the stimulator was a ball-point probe; however, the hockey stick–shaped probe (**Fig. 9**) is more frequently used because it has been shown to more successfully saturate the nerve fascicles (**Fig. 10**). The better saturation is achieved because of the relatively large surface area of the stimulating probe. Spreading the current over a larger area has

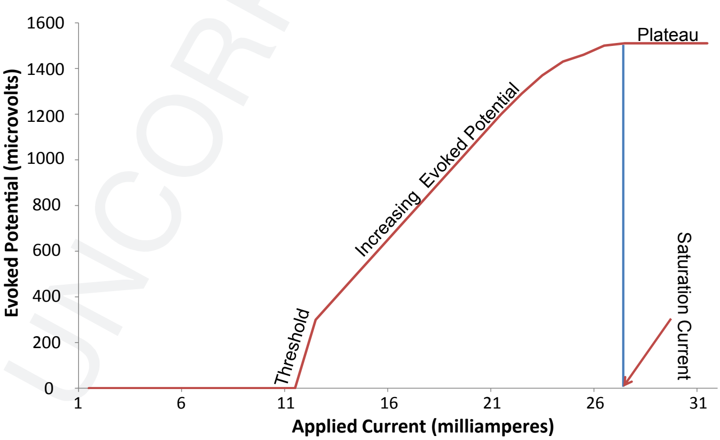


Fig. 5. Stimulus saturation. As more current is applied to the nerve that is being tested, the first evoked response noted in the muscle is labeled threshold and, as more current is applied, evoked potentials increase in amplitude until a point of saturation is reached. This point of saturation is the lowest amount of current that will stimulate all of the nerve fascicles resulting in a plateau.

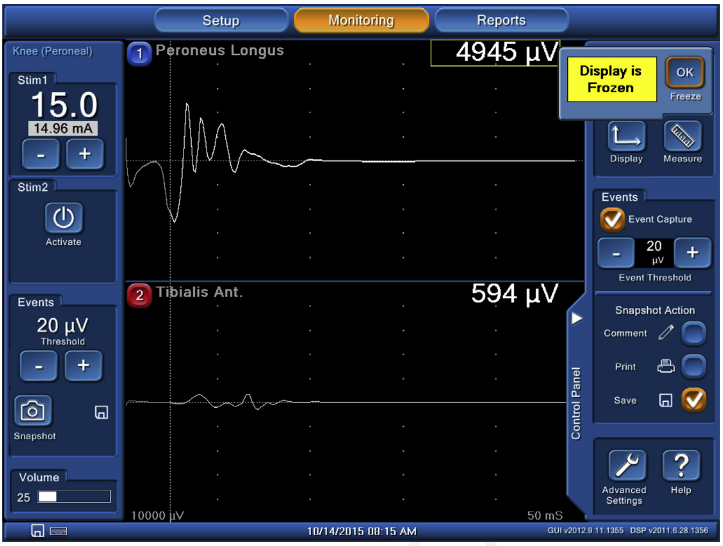


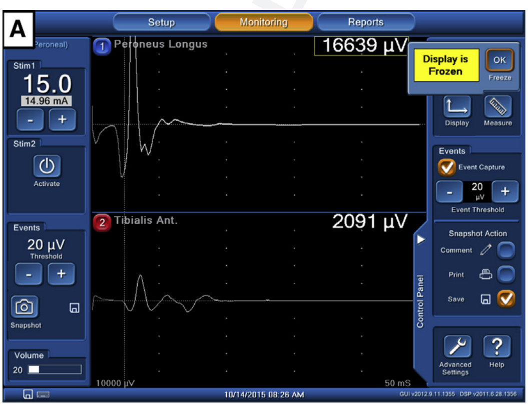
Fig. 6. Common peroneal nerve predecompression. Values showing evoked potential readings of the tibialis anterior and peroneus longus before the nerve decompression.

improved the consistency of recordings. Future improvement of the stimulating probe design and recording electrodes may be considered.

DISCUSSION

Once the decompression is completed, it is not uncommon to see significant improvement in the final recordings compared with the initial (baseline) recordings. This technique allows the surgeon to gather objective feedback throughout the surgery regarding the success of the decompression. If minimal change has taken place between the predecompression and postdecompression recordings then more

A



B

	Time	PL (μV)	TA (μV)
Pre	8:15AM	4945	594
Post	8:26AM	16639	2091
Change		11694	1497
% Change		336.5%	352.0%

Fig. 7. Common peroneal nerve postdecompression. (*A*) The final recording is made by stimulating the same location on the nerve at the same current settings. (*B*) Change of microvolts (μV) in the evoked potential of the peroneus longus (PL) and tibialis anterior (TA) between predecompression (Pre) and postdecompression (Post). Q21

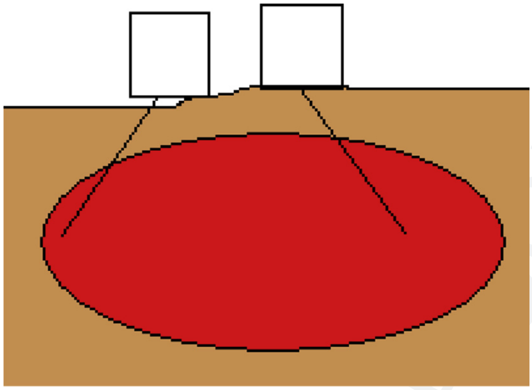


Fig. 8. Placement of recording electrode. To change the depth of the recording electrode in the muscle, angle needle laterally but keep the hub at the skin surface.

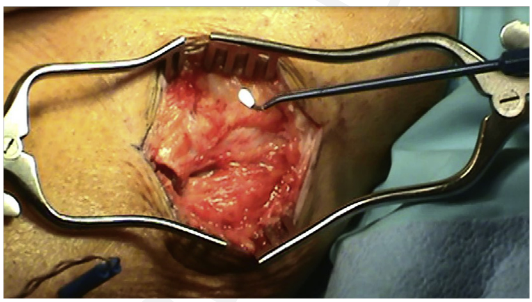


Fig. 9. Intraoperative nerve stimulating probe. The hockey stick probe before nerve stimulation.

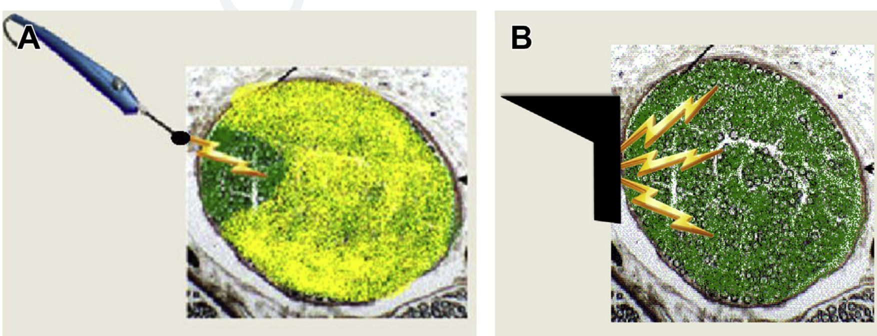


Fig. 10. Saturation. (*A*) Ball tip probe showing saturation of fewer fascicles (*green*). (*B*) The hockey stick–shaped probe increases the surface area and results in complete saturation of fascicles.

neurolysis may need to be considered. In addition to an increased evoked potential after decompression, the surgeon may also observe a louder sound originating from the NIM machine and increased muscle contracture. In cases in which an improvement in evoked potential is not noted after decompression, it is advised to note the improvement of contracture that is visually observed. For example, the authors found that decompression of the common fibular nerve did not yield improvements in evoked potentials for all who had surgery. In a paper submitted for publication on a 40 subject retrospective study, 82% of limbs showed improvement and 73% of the monitored muscles showed improvement. (JC A, et al: Acute improvement in intraoperative EMG following common fibular nerve decompression in patients with symptomatic diabetic sensorimotor peripheral neuropathy: 1. EMG results. Restor Neurol Neurosci. Submitted for publication.) It is important to note that there were no serious adverse effects (ie, death, myocardial infarcts, or stroke), no unanticipated adverse events, no adverse events requiring intervention, and no adverse events related to the NIM. Although improved EMG was not seen in every case in the study, it is striking that it was seen at all considering it was recorded within 1 minute after decompression and in patients with chronic diabetic neuropathy (mean disease duration: 12.1 ± 9.9 years). (JC A, et al: Acute improvement in intraoperative EMG following common fibular nerve decompression in patients with symptomatic diabetic sensorimotor peripheral neuropathy: 1. EMG results. Restor Neurol Neurosci. Submitted for publication.) Further, recovery of the nerve will continue in most patients and is typically seen in follow-up visits, even in cases in which no improvement was seen intraoperatively. Additional work is needed to develop and implement a rigorous protocol along with improvement of the recording techniques and modifications to the stimulating electrodes. The concept of IONM is still improving and further studies are needed to improve consistency and accuracy. Q15

SUMMARY

IONM can be a useful adjunct protocol to assist the surgeon performing nerve decompression procedures. The surgeon must be flexible in the approach to using it. Initially, IONM can be used to localize the nerve and indicate how successful the surgery was postdecompression. It should be noted that a surgeon interested in using IONM for research purposes needs to follow a more rigorous and strict protocol than described here. Furthermore, lower extremity surgeons will find IONM a useful tool in the surgical arena to provide useful feedback to themselves, their patients, and as objective evidence to document the results of the surgery.

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SUPPLEMENTARY DATA

Videos related to this article can be found at http://dx.doi.org/10.1016/j.cpm.2015.12.003. Q16

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Q13	Please provide manufacturer name and location for "Tegaderm" or omit and just use generic "sterile adhesive." See "Sterile adhesive (ie, Tegaderm) may also…"
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Q15	The names of the first three authors must be present before 'et al.' Therefore, please provide the names of the first three authors and retain 'et al.', or delete the phrase 'et al.' in submitted reference and also provide complete author name for "JC A". Please see throughout.
Q16	As per the editorial remarks, "Please check Video legends and update as needed. Legends were composed by the Publisher."
Q17	As per the reference style of this journal, the names of the first three authors must be present before 'et al.' Therefore, please provide the names of the first three authors in Ref. 18 and retain 'et al.' for subsequent author names, or delete the phrase 'et al.' in Ref. 18.
Q18	In Fig. 2 legend, "Here the abductor hallucis is indicated by the red electrodes and the abductor digiti quinti is blue" was deleted because it is unnecessary because this was indicated in the figure itself. Please verify or amend.
Q19	In Fig. 3 legend, "Tegaderm" was changed to "sterile adhesive." If the manufacturer and location are added at the mention in the main article—see "Sterile adhesive (ie, Tegaderm) may also…"—the brand name can be reinstated here.
Q20	In Fig. 4 legend, "mAMPS" and "µvolts" were expanded to "milliampere", "microvolts" respectively. Please verify or correct.
Q21	Abbreviations in Fig. 7 (µV, Pre, Post) were expanded in the legend. Please verify or correct.
	Please check this box or indicate your approval if you have no corrections to make to the PDF file ☐

Thank you for your assistance.