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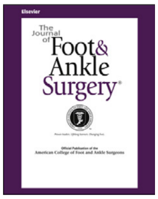

Intraoperative Nerve Monitoring for Tarsal Tunnel Decompression: A Surgical Technique to Improve Outcomes

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ABSTRACT

The aim of the current study was to evaluate the effectiveness of intraoperative neuromonitoring (INM) as an adjunct in performing tarsal tunnel decompression surgery. We reviewed 38 patients who met inclusion criteria. INM was used to measure the voltage of the abductor hallucis and digiti quinti muscles both before and after decompression. Observed changes intraoperatively were acute and within minutes of the decompression performed by the surgeon. Patient outcomes were ascertained from clinical findings and classified as excellent, fair, or poor. Patient outcomes and the voltage change were measured and assessed for association, and statistically significant differences were found between outcome groups. Of the 38 patients, 29 (76%) had excellent outcomes, with a mean change in microvolts of 2088.28 ± 1172.44 (684%) ($p = .0004$) and 2173.24 ± 1228.39 (742%) ($p = .0014$) for abductor hallucis and abductor digiti quinti, respectively. The study supports INM as a useful adjunct in performing tarsal tunnel decompression.

Tarsal tunnel syndrome (TTS) is defined as an entrapment of the tibial nerve and/or its terminal branches, where it passes posterior and distal to the medial malleolus and deep to the flexor retinaculum (1−3). TTS is a common pathology of the foot and ankle characterized by pain, numbness, paresthesias, and varying degrees of motor changes (1−3). Reported surgical treatment results for TTS vary considerably (4,5). Many factors can influence surgical outcomes, including age, duration of disease, presence of space-occupying lesions, body mass index, and presence of metabolic disease (4). Authors have reported that the success rate is highly variable and can often result in recurrent TTS or failure from initial surgical intervention because of incomplete release of the medial plantar, lateral plantar, and calcaneal tunnels (5,6). Yalcinkaya et al (6) reported that failure can result from many causes, but often from lack of appreciation of involved anatomy or from inadequate technique with insufficient tarsal tunnel release. Failed tarsal tunnel surgical decompression is a very frustrating condition for both the surgeon and patient. Reoperation outcomes for failed tarsal tunnel decompression will be less predictable than those for initial surgical treatment (6). Diagnosis of nerve entrapments using nerve conduction velocity/electromyography (NCV/EMG) studies can help identify the level of entrapment but do not ensure successful release of the nerve. We believe that intraoperative neuromonitoring (INM) can improve outcomes in tarsal tunnel decompression.

Although the focus of this retrospective study was on tarsal tunnel decompression, the primary author (G.P.S.) uses INM for a wide range of peripheral nerve surgeries. He believes that the use of INM influences intraoperative decision making in both tarsal tunnel surgery and other peripheral nerve procedures performed in the lower leg, ankle, and foot.

Currently, INM is not commonly used in foot and ankle surgery, but it is common in other surgical specialties. INM decreased the incidence of recurrent laryngeal nerve paresis in repeat thyroid operations compared with nerve visualization alone (7). The use of INM in facial nerve surgery during middle ear and mastoid surgery has been advocated to reduce the risk of facial nerve injury (8). INM has minimized postsurgical complications by reducing the incidence of inadvertent spinal cord injury (9). Complication rates in tarsal tunnel decompression are variable in the literature, but such complications include nerve injury, infection, hematoma, wound dehiscence, and hypertrophic scarring of the incision. We believe that INM in tarsal tunnel decompression can be used to reduce surgical treatment failure and inadvertent nerve injury. The use of a nerve monitor intraoperatively helps the surgeon identify peripheral nerves more easily, because stimulation of nerve either produces muscle contraction or an intraoperative voltage that is recorded by the nerve integrity monitor (NIM) (in the current study, we used a

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Medtronic NIM 2.0 or 3.0 device). INM application in the release of the tibial, medial plantar, and lateral nerves in the tarsal tunnel is an innovative technique to improve outcomes. The NIM transforms muscle activity into audible and visual EMG signals when the nerve is stimulated intraoperatively, enabling evaluation of functional integrity of the neural structures (10). The purported value of using INM is to reduce iatrogenic nerve damage and to provide guidance to ensure complete alleviation of nerve compression.

The purposes of this study were twofold: first, to show that INM can be a useful tool in assisting to properly identify involved anatomy within the tarsal tunnel, and second, to evaluate the use of INM as an adjunct in performing tarsal tunnel decompression by measuring potential intraoperative increases in EMG of the tibial nerve and its major branches within the tarsal tunnel. We propose that increases in microvolts can be extrapolated to mean that intraoperative function of nerves is improving with surgical decompression. We undertook a retrospective cohort study of consecutive tarsal tunnel decompression cases in which INM was used. The primary author (G.P.S.) emphasizes that measured increases in microvolts obtained intraoperatively for a particular nerve within the tarsal tunnel serve as a guideline for the surgeon. Use of INM in tarsal tunnel surgery is a method to measure and document actual changes in EMG obtained within the tarsal tunnel. The surgeon still must also visually observe gross stimulated movement of the muscles being stimulated.

Patients and Methods

The present study reviewed 38 consecutive patients who underwent tarsal tunnel decompression surgery from June 2010 to June 2016. The study identified 47 eligible patients, of whom 38 met the inclusion criteria. Diagnosis of TTS was based on clinical and laboratory findings. Specifically, patients exhibited pain, a positive Tinel's sign, positive nerve compression test, and paresthesia to the tibial nerve and its branches preoperatively. Preoperative clinical NCV and EMG of the lower extremity were performed on all patients. These studies showed some degree of abnormality on the tibial nerve on the affected side in 38 of 47 eligible patients. (We point out that these preoperative studies were clinical and not intraoperative.) A nerve compression test was positive when the patient experienced symptoms while the examiner placed pressure over the tarsal tunnel for >15 seconds. Exclusion criteria included prior tarsal tunnel surgery; the presence of diabetes mellitus, rheumatoid arthritis, multiple sclerosis, or Charcot-Marie-Tooth disease; a history of ankle, tibia, or tibial plafond open reduction and internal fixation on the operative side; the presence of soft tissue mass; or a normal NCV/EMG study. Before surgical intervention, all patients had undergone conservative treatment that failed. Conservative treatment primarily consisted of any of the following; corticosteroid injections, physical therapy modalities, orthotics, bracing or immobilization, and oral nonsteroidal anti-inflammatory drugs or steroids. Nonsurgical care ranged from 1 to 60 months, with an average of 13 months before surgical consideration.

Surgical intervention was performed by the senior author (G.P.S.) when persistent debilitating symptoms of pain, numbness, and paresthesias interfered with daily activities. Electrically evoked EMG signals were recorded during the surgical procedure with the NIM-Response v2.0 or v3.0 Nerve Integrity Monitor (Medtronic; Xomed, Minneapolis, MN) according to its indication for use. Although this is technically a motor-evoked potential, we refer to it as EMG, as commonly used in the INM literature (11). We point out that with INM, the electrode records the electrical activity of the muscle being tested. Amplitude indicates an improved synchrony of the action potentials arriving to the tested muscles, which increases the amplitude of the response. The myelination does not immediately return to the nerve fibers affected by compression. However, the electricity in the region of the decompression can be faster and have more synchrony after the surgical decompression than before. More simply stated, we believe that with a decrease in compression on the affected nerve fibers, more nerve fibers are able to fire at the same time (greater synchrony). The hope is that with surgical decompression, there is supramaximal stimulation of the nerve, which would represent 100% of the nerve fibers of that nerve. With use of INM conduction, velocity does not necessarily indicate myelination.

The tibial nerve was stimulated with a monopolar stimulating probe (Prass; Medtronic) directly on the nerve (4 Hz, monophasic, 250-ms pulse width). For EMGs recorded before or during decompression, the stimulus current was initiated at 2.0 mA and increased to a maximum of 10.0 mA. EMGs were recorded before surgical decompression, starting with a stimulus of 2.0 mA. Stimulus current was increased, when necessary, to obtain either (a) a satisfactory 4- to 5-fold increase or (b) a current stimulus of 10.0 mA maximum. The surgeon typically was attempting to achieve a 4- to 5-fold increase of EMG value from the value recorded before decompression. When a 4- to 5-fold increase was not achieved, the operative site was then carefully visualized and palpated with the aid of loupe magnification for any additional areas of compression that may not have been decompressed previously.

When the primary surgeon (G.P.S.) determines that there is no further surgical dissection to be done external to the tibial nerve and its branches, a decision is made to undertake endoneurolysis (internal neurolysis). This intraoperative decision is based on the amount of dissection already performed, measurements obtained before and after decompression, and any palpable or visible intraneural fibrosis. For the purposes of maintaining continuity of technique and the purposes of this study, no patients that underwent endoneurolysis were included in this study. The primary author (G.P.S.) finds the need to perform internal neurolysis infrequently when the patient has not had prior tarsal tunnel surgery on the operative limb. As mentioned, none of the potentially eligible patients in this study had prior tarsal tunnel on the limb that underwent surgery. Branches of the tibial nerve were also stimulated during each procedure for confirmation of neural structures and to document nerve function, but the measurements for comparison before and after decompression were done on the tibial nerve within the tarsal tunnel.

We recorded the maximum milliamperes introduced to the abductor hallucis muscle and the abductor digiti quinti muscle and the associated voltage both before and after decompression. Current was delivered to the nerve tested. Outcomes were subjectively rated as excellent, fair, and poor based on clinical findings and function at time of follow-up using the American College of Foot and Ankle Surgeons (ACFAS) rearfoot scoring patient questionnaire (12). There were 50 points possible, and an excellent score was represented by a score of 50; fair, 40 to 49; and poor, ≤39. The range of patient follow-up is from 6 to 72 months (mean 18.16 months).

Surgical Technique

Patients were placed in the supine position, and tourniquet hemostasis was not used in any cases. The primary author (G.P.S.) routinely applies a nonsterile thigh tourniquet before the procedure in case an intraoperative complication requires elevation of the tourniquet to reduce blood loss. A tourniquet is not used for the reason that it can negatively impact accurate use of INM: the NIM is affected by vascular flow, as perfusion affects peripheral nerves and their conduction. In addition, the primary surgeon (G.P.S.) believes that use of a tourniquet impairs the ability to properly identify peripheral nerve and vascular structures. Inadvertent trauma to these structures can be minimized with both use of INM and nonuse of a tourniquet. In addition, the primary surgeon used loupe magnification during the surgical procedure for all patients in the study.

This study used an orthodromic technique in stimulation of the nerves and generating an impulse. We are not aware of any value with antidromic nerve conduction when using a NIM. Other important considerations regarding surgical technique are as follows: ambient temperature within the operating room (OR), use of local anesthetics with or without vasoconstrictors, and relaxing/paralyzing agents used by the anesthesiologist. We recommend a typical ambient OR temperature and have not found temperature within the OR to adversely affect use of the NIM. Local anesthetics can affect the accuracy and effectiveness of the NIM; therefore, the primary surgeon (G.P.S.) recommends only a small volume (<8 cc) of local anesthetic be used to anesthetize the tarsal tunnel preoperatively. Routinely, a small volume (2 to 4 cc) of 0.5% bupivacaine with epinephrine and 2% lidocaine without epinephrine are both used in a mixture for preoperative injection proximal and into the tarsal tunnel. The small volume of local anesthetic with epinephrine has been found to reduce bleeding within the operative site without adverse effects on use of the NIM. When necessary, an additional amount of local anesthetic with epinephrine (1 to 3 cc) is used intraoperatively to reduce oozing within the operative site. It is not recommended to allow the anesthesia provider to administer intraoperative muscle-relaxing or -paralyzing agents. This obviously will affect muscle function and make use of the NIM inaccurate. No patients in this study were given these types of medications intraoperatively. We further discuss some of these considerations in the Discussion section.

For nerve stimulation, subdermal needle electrodes were placed in the muscle bellies of the abductor hallucis and abductor digiti quinti muscles (Figs. 1 and 2). Ground and stimulator anode electrodes were placed on the lower leg in the tibialis anterior or gastrocnemius muscle belly as distal as possible before the muscle becoming tendon or fascia (Fig. 3). Spontaneous and evoked EMG was used intraoperatively to monitor and assess the medial and lateral plantar divisions of the tibial nerve during surgery. At the time of surgical decompression, baseline EMG amplitudes were measured by stimulating the tibial nerve. This was done by performing dissection to the flexor retinaculum. Next, a small window or partial transection was made into the flexor retinaculum overlying the tarsal tunnel to obtain predecompression recording on the tibial nerve. This was done with the nerve stimulating probe. Next, complete flexor retinaculum release was performed, and additional dissection was performed to afford exposure to the tibial nerve and its branches within the tarsal tunnel so that the muscles could once again be assessed for EMG amplitude. Once gross dissection was afforded down to the tibial nerve and branches, all further dissection was performed using loupe magnification with fine-tipped instrumentation.

If a marginal increase in amplitude was recorded, continued dissection was performed, including release of any impinging superficial and deep abductor hallucis muscle fascia in the operative area including the porta pedis. After additional dissection of the tissue surrounding the tibial nerve, intraoperative testing was again performed. It is important to note that the surgeon stimulated the same location (within 1 cm) on the nerve tested before and after decompression. Readings were obtained for both the abductor

Fig. 1. Appropriate placement of the abductor digiti quinti muscle electrodes.

Fig. 2. Appropriate placement of the abductor hallucis muscle electrodes.

hallucis and the abductor digiti quinti muscles. If an increase in EMG amplitude was not seen, further nerve decompression was performed with dissection of associated medial and lateral plantar branches and any surrounding entrapment (Fig. 4). If an increase was obtained, the surgeon then decided to either continue dissection and further release of entrapment or stop with dissection and begin closure. This decision was based on the amount of increase obtained on either muscle as well as clinical judgment and the amount of dissection already performed. The surgeon typically hopes for at least a 4- to 5-fold increase from predecompression levels. If the surgeon was able to obtain a substantial increase in amplitude, then it was believed the decompression was adequate.

Fig. 3. Appropriate placement of the ground electrode. U marks the tibial tuberosity, and X marks the tibialis anterior muscle belly, where the ground electrode would be placed.

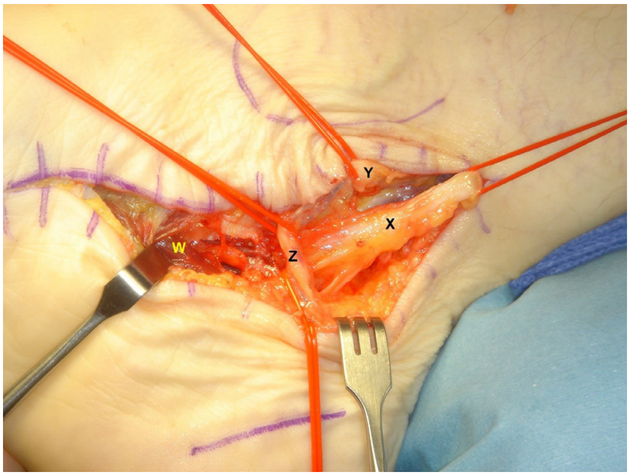

Fig. 4. Anatomic findings during a tarsal tunnel release. The nerve-stimulating probe would be placed along the posterior tibial nerve during decompression. W, abductor hallucis muscle belly; X, posterior tibial nerve and branches; Y, posterior tibial artery; Z, calcaneal branch of the posterior tibial artery.

We emphasize that the postdecompression recordings were performed immediately (within 1 to 2 minutes) on the tibial nerve. This is important, because in most patients the symptoms and entrapment have been present for several years.

In this study, there were no patients that did not have some increase in EMG amplitude. However, some increases were small. We emphasize that although a 4- to 5-fold increase was an intraoperative goal, any increase in amplitude is typically a positive indicator of improvement because of how quickly measured amplitudes are obtained during the surgical procedure. For example, a 3-fold increase in predecompression numbers is inferred to provide a better outcome than a 2-fold increase. In many patients, there was a substantial increase in EMG amplitude acutely and intraoperatively after decompressing the nerve. We also emphasize that improvements in EMG intraoperatively are only an indicator of good clinical outcome, not a measure of good clinical outcome alone. It is expected that there would be improvement over time as well. Although only anecdotally, the primary surgeon (G.P.S.) has observed this clinically over the many years this technique has been used and refined. No level 1 studies have been done to date that determine how to interpret intraoperative improvement in EMG in the tarsal tunnel. The primary surgeon has observed that postoperative complications such as hematoma or major wound dehiscence can alternatively negatively influence clinical outcomes despite recorded intraoperative increases.

We emphasize that the use of INM in performing initial tarsal tunnel decompression does influence and guide intraoperative decision making. Starting with a predecompression measurement and then proceeding with periodic measurements of voltage on the nerve provides the surgeon with intraoperative feedback of nerve integrity and guides the surgeon to perform more dissection of the flexor retinaculum if inadequate release is present, in addition to further dissection of deeper structures within the tarsal tunnel. Anatomy in this region can be highly variable, and having the ability to intraoperatively stimulate a peripheral nerve and obtain a measurement can be useful. As stated above, the goal was to obtain a 4- to 5-fold increase in measurement before and after decompression. Dissection that affords the surgeon an increase in voltage is paramount in intraoperative decision making. It allows the surgeon a quantitative means, instead of solely a visual means, of determining that the nerves within the tarsal tunnel are adequately decompressed of their impingement. Although the primary surgeon strives for a 4- to 5-fold increase as stated, a voltage of ≥3500 μV indicates that no further dissection is needed. This has been determined through operative experience and communication with other surgeons who use the same technique.

When the surgeon has performed dissection that would expect to provide adequate decompression and there is not a significant increase in voltage increase obtained intraoperatively, the outcome may be poor due to continued damage to the nerve, and it is unlikely to improve postoperatively. In this situation, the surgeon can choose to perform endoneurolysis by dissection of epineurium of the tibial nerve or its branches. The primary surgeon has performed endoneurolysis when this situation was encountered in a small number of patients, but for continuity of technique used, such patients were not included in this study. As stated previously, one of the goals of this study was to introduce the use INM in tarsal tunnel surgery and demonstrate how it can influence intraoperative decision making and potentially reduce intraoperative and postoperative complications and improve outcomes. However, the use of INM in determining the need for endoneurolysis in tarsal tunnel decompression could aid in confirming its usefulness in tarsal tunnel surgery. This technique may be especially helpful in revision cases where scarring has occurred.

There were no cases in the study where there was no recorded voltage obtained by stimulation of the tibial nerve or its branches. If the surgeon did encounter this, then it would serve as an alert to 1 of 2 potential problems: (a) the NIM and muscle probes are malfunctioning or set up improperly; or (b) the peripheral nerve is permanently damaged and not conducting an impulse. If the surgeon were to encounter the latter, then this may be a situation where the surgeon may need to consider other techniques such as peripheral nerve graft techniques or implantation of nerve into muscle or bone. These techniques are beyond the scope of this study. Nonetheless, the surgeon must take into serious consideration when considering these techniques, because the affected peripheral nerve may or may not have motor function.

Preoperatively, all patients received 1 dose of prophylactic intravenous antibiotics. No patients were given prophylactic oral antibiotics to be taken postoperatively. Tourniquet hemostasis was not used in any cases. (However, as a precaution, in all cases, the surgeon applied a nonsterile thigh tourniquet before the procedure in the event of an intraoperative complication requiring elevation of the tourniquet to reduce blood loss.) After closure of subcutaneous and cutaneous tissue, a dry, sterile dressing was applied. In addition to the normal sterile dressing, cotton batting was applied over the sterile dressing and secured with Ace wraps extending from the toes to the knee for a large well-padded dressing. Fiberglass or plaster splints were not used on any dressings.

Patients were non-weightbearing until the first postoperative appointment (6 to 9 days). Patients were then allowed to toe touch for transfers with the aid of a postoperative shoe applied over the well-padded dressing until suture removal, typically at 2.5 to 3 weeks postoperatively. After suture removal, patients were allowed to be weightbearing, as tolerated, in a postoperative shoe with the incision protected with padding and Ace wraps. Permissible weightbearing was postponed with any delayed healing of the surgical site. At 4 to 5 weeks, patients could to return to regular shoe gear as tolerated. Range of motion exercises were initiated after the first postoperative visit.

Statistical Analysis

Analysis of variance (ANOVA) was used to test for association between the mean abductor hallucis change in voltage with patient outcome and for association between the mean abductor digiti quinti change in voltage with patient outcome. The level of statistical significance was set at $p = .05$. ANOVA also was done comparing all 3 outcome groups predecompression, postdecompression, and change. In this study, the ANOVA probability was used to quantify the statistical difference in the outcome values between the poor, fair, and excellent groups for each muscle tested.

Table 1
Patient demographics (N = 38)

Variable	Value
Sex	
Male	13 (34.2)
Female	25 (65.8)
Age (yr)	47.9 ± 6.85
Body mass index (kg/m^2)	26.7 ± 2.84
Laterality	
Right	20 (52.6)
Left	18 (47.3)

Data are n (%) or mean ± standard deviation.

Results

Of the 38 patients, 25 (65.8%) were women and 13 (34.2%) were men, with an average age of 47.9 ± 6.85 years (Table 1). The average body mass index was 26.7 ± 2.84 kg/m^2, and the affected limbs were 20 (52.6%) right and 18 (47.3%) left (Table 1). The mean stimulus current used was 5.60 ± 1.8 mA (range 2 to 10). The preoperative abductor hallucis voltage mean of 379.71 ± 269.98 μV (range 40 to 990) increased to 2047.29 ± 1370.21 μV (range 168 to 4600) after surgical decompression. The mean change in voltage for abductor hallucis was 1670.47 ± 1270.94 μV (40 to 440) (Table 2). The preoperative abductor digiti quinti voltage mean of 410.97 ± 616.37 μV (range 50 to 4000) increased to 2169.42 ± 1716.83 μV (range 140 to 8800) after surgical decompression. The mean change in voltage for abductor digiti quinti was 1761 ± 1335.21 μV (range 40 to 4800) (Table 2). The number of patients with outcomes of excellent, fair, and poor were 29, 4, and 5, respectively (Table 3).

From the statistical analysis, the amplitude is much greater in the excellent group than in the poor and fair groups. Comparison of patient outcomes with mean change in abductor hallucis voltage revealed a 2088-μV change in the excellent group, 282 μV in the fair group, and 336 μV in the poor group, with a p value of .0004 (Table 3). Comparison of patient outcomes with mean change in abductor digiti quinti voltage revealed a 2173-μV change in the excellent group, 246 μV in the fair group, and 563 μV in the poor group, with a p value of .001 (Table 3).

No intraoperative complications were observed. Seven postoperative complications (18%) were observed during follow-up consisting of 2 (5%) cases of superficial infection, 4 (10%) mild surgical wound dehiscence, and 1 (2%) postoperative hematoma. Superficial infection was resolved with oral antibiotics, and incision dehiscence with local wound care. The hematoma had to be drained surgically without any further complications. Despite some patients being categorized as having a poor or fair results, no patients in the study reported a limp due to pain, without shoes on, at the time of follow-up.

Discussion

Limited research has been done regarding INM and its application in lower-extremity surgery (11–14). Anderson et al (11) performed an excellent study on acute improvement in EMG after common fibular nerve decompression in patients with symptomatic diabetic sensorimotor peripheral neuropathy. The study was very promising, in that it showed near-immediate improvement in evoked EMG amplitudes. Thirty-eight legs (82.6%) demonstrated EMG improvement 1 minute after nerve decompression. Sixty muscles (fibularis longus and tibialis anterior) were monitored, with 73.3% improving in EMG amplitude. Overall, mean change in EMG amplitude represented a 73.6% improvement. Levine et al (13) presented a study in poster format on 11 patients

Table 2
Muscle voltages before and after decompression with average stimulus

	Before Decompression	After Decompression	Mean change
Abductor hallucis (μV)	379.71 ± 269.98 (40 to 990)	2047.29 ± 1370.21 (168 to 4600)	1670.47 ± 1270.94 (40 to 440)
Abductor digiti quinti (μV)	410.97 ± 616.37 (50 to 4000)	2169.42 ± 1716.83 (140 to 880)	1761 ± 1335.21 (40 to 4800)
Stimulus (mA)	5.60 ± 1.8 (2 to 10)		

Data are mean ± standard deviation (range).

Table 3
Mean change in muscle voltages stratified by patient satisfaction (N = 38)

	n (%)	Abductor hallucis (μV)	Abductor digiti quinti (μV)
Excellent	24 (63.2)	2088.28 ± 1172.44 (684)	2173.24 ± 1228.39 (742)
Fair	9 (23.6)	282 ± 291.58 (211)	246 ± 120.87 (178)
Poor	5 (13.2)	336 ± 430.15 (175)	562.6 ± 1056.76 (224)
ANOVA *P* value		.0004	.0014

Abbreviation: ANOVA, analysis of variance.
Data are mean change ± standard deviation (%) unless noted otherwise.

with diabetic peripheral neuropathy in which 73% and 55% of patients exhibited increased amplitude intraoperatively with decompression of the common fibular (peroneal) nerve and tibial nerve, respectively. We found only 2 prior reported studies using INM in tarsal tunnel decompression in nondiabetic patients, with both sets of results presented in poster format (14,15). In the poster presented by Rodrigues-Colazzo et al (14), patients underwent revisional tarsal tunnel surgeries, and although values were not given, they reported an increase in amplitude in all 7 cases. The authors' current study is an extension of the poster presented by Still and Jolley (15).

The NIM device can be used with the aid of the OR staff. The benefit of using INM is to aid the surgeon in correctly identifying tibial, medial plantar, and lateral plantar nerves. This proves especially useful in revision surgeries or in situations of chronic compression that involve entrapment of the nerve in scar tissue (7,10). Furthermore, it may also aid in intraoperatively determining the extent of release required for favorable outcome. In the present study, we monitored the change in voltage of abductor hallucis and the abductor digiti quinti to help identify whether further decompression was necessary.

Wilson (16) evaluated the cost-effectiveness of use of INM in facial nerve surgery in middle ear and mastoid surgery. Their study strongly favored the use of INM for cost and reducing the probability of facial nerve injury. Use of INM in thyroid surgery, specifically to reduce injury to the recurrent laryngeal nerve (RLN), has been adopted over many years. Despite a very low rate of adverse events to the recurrent laryngeal nerve in thyroid surgery, currently there is wide usage of INM within the United States and European Union. In 2013, 53% of general surgeons and 65% of otolaryngologists used INM in some or all of their cases (17). A survey of German surgical departments reported that >92% of surgeons used INM during cases of thyroidectomy (17). In addition, German practice guidelines suggest that INM should be considered for all cases of thyroid surgery (17). Multiple studies were conducted that convinced the field of otolaryngology that the use of INM in thyroid surgery would benefit the patient and their practice.

An article on clinical practice guidelines published in 2013 by The American Academy of Otolaryngology outlined several key points regarding the use of INM: (1) it should be considered in selected high-risk thyroidectomies; (2) use of INM can lower rates of paralysis when used in cases of thyroid cancer or retrosternal goiter; (3) INM results in nerve identification of RLN 100% of the time and aid in identifying a RLN that is difficult to identify, which is estimated to be in 25% of cases; (4) INM aids in dissection once the nerve is identified and aids in elucidation of mechanism and site of nerve injury; 5) INM aids in injury identification to a nerve and postoperative nerve prognostication; and 6) INM provides information on neuropraxic nerve injury as well as nerve branch motor versus sensory fiber content. This information is not available through visualization alone (18). This was also similarly outlined in an International Standards Guideline Statement on use of INM in thyroid and parathyroid surgery (19). A unique and interesting study by Al-Qurayshi et al (20) strongly suggests that INM has a cost-effective advantage in bilateral thyroid surgery. They stated that INM information should be incorporated in thyroid surgery to guide the intraoperative decision-making process (20). Training in the use of INM for head and neck surgeons has not been well provided in certain areas. However, an Italian study discussed the fact that when provided with training for use of INM in thyroid surgery, 100% of participating surgeons expressed a desire to continue use of the technique and INM in their practice, and 67% agreed it should be used for all cases of bilateral thyroid surgeries (21).

We believe that INM in tarsal tunnel surgery could potentially be used more often, with appropriate training. Although the issue has not been analyzed, we believe the use of INM in tarsal tunnel surgery is cost-effective as well, since it could potentially reduce the chance of nerve injury, improve outcomes, and reduce OR time. In addition, we have used this technique and intraoperative results obtained with INM to serve as a prognostic indicator that is communicated to the patient after surgery. We also wish to emphasize that in this study, the postdecompression EMG measurements were taken very shortly (within 1 to 2 minutes of the decompression) and relatively shortly after the predecompression recordings (within 30 minutes). This suggests that the mechanism of the improvement was due not to changes in synaptic density or strength, circuitry of the target muscles, or metabolic neuropathology, but mainly to mechanical release of the compression around the nerve and its vasa nervorum (11). However, further studies need to be performed to further test this hypothesis.

We believe that the use of INM may reduce the risk of injury to the tibial, medial, and lateral plantar nerves. The use of INM during tarsal tunnel decompression does not substitute for adequate surgical technique but merely provides the surgeon with an adjunct to routine visual identification and functional assessment (10). However, we emphasize how valuable the use of INM can be as an intraoperative tool. Nerve structures are expected to be found in predictable places and to have predictable connections, but there are important limitations to these assumptions. Dellon (22) identified at least 4 different branching patterns within the tarsal tunnel.

The limitations of our study include the small sample size, which may have limited the ability to identify a statistically significant difference before and after decompression. In addition, we are unable to assess the effect of local anesthetic on before and after decompression because of the limited data obtained during the retrospective analysis. Data was also limited in regard to stimulus intensity, which started at 2.0 mA and increased at the beginning of the procedure before decompression only when necessary to obtain a response. The range was 2.0 to 10.0 mA. It should be noted that direct nerve stimulation parameters are different from those used for conventional nerve studies. Since the nerve is being stimulated directly, the stimulus intensity required to depolarize a normal nerve will be less than that typically used percutaneously (23). Current spread is also increased with higher stimulation intensity levels on a peripheral nerve. Therefore, stimulation intensity should be kept as low as possible (23). In some instances of chronic compression or use of intraoperative local anesthetics, the intensity may need to be increased.

The use of local anesthetics will affect readings obtained with INM (23). However, the volume of local anesthetic to cause an effect is not known. We also emphasize that a tourniquet was not used in any cases in this study. Typically, the technique is done without use of a tourniquet so that nerve function is not impaired during use of INM. A tourniquet affects nerve function and can produce complete conduction block in motor and sensory fibers within 20 minutes (23). We emphasize the importance of making the anesthesiologist aware of use of INM by the surgeon before the planned procedure, because the use of muscle relaxers or paralyzing agents will have an impact on EMG results (19). It is strongly recommended to not use these agents with use of INM in lower-extremity surgery. Neuromuscular blockade will likely reduce the EMG amplitude and make nerve monitoring less sensitive to impending neural injury. Similarly, neuromuscular blockade may also reduce amplitude of evoked responses (19).

For all patients in this study, the NIM was operated by 1 of 2 trained technicians, both familiar with use of INM in tarsal tunnel surgery. Alternatively, the surgeon can choose to have OR staff assist with use of the NIM instead of using a technician. This of course is dependent on both the OR staff and surgeon being comfortable operating the NIM without a technician present. There is a cost associated with use of INM services. This is usually billed in increments of time that the technician is present for the procedure. In most cases, this cost can be billed to the patients' health insurance. Cost can be reduced by not using a trained technician if the surgeon and OR staff are familiar with operation and use of a NIM device. Because a NIM is used often by other surgical specialties, many facilities have one in the facility available for surgeons to use. If not, the surgeon must arrange for the device to be brought to the OR for the procedure. Alternatively, if a surgeon simply wants to stimulate a peripheral nerve without obtaining a motor evoked potential reading with voltage, there are other intraoperative stimulators that are commercially available. These simply provide nerve stimulation electrically that allows the surgeon to see muscle contraction and identify a neural structure. However, these single-use devices are also associated with a cost that is higher compared to using a NIM with a technician present.

A limitation of this study is that there are no published normative data for EMG of the tibial nerve intraoperatively using INM. However, the study shows objective data with a substantial increase in amplitude intraoperatively using a nerve monitor that is used globally for thyroid, otolaryngology, and spinal procedures. The same stimulation parameters were used before and after decompression, making normative EMG levels less relevant for the purposes of this study. The patients in the study had compression neuropathy, which can often make a peripheral nerve require greater stimulus currents to elicit a response from the nerves tested. In reality, compromised or compressed nerves often do not behave normally (personal communication, S. Yamasaki, Ph.D.). We also emphasize that normative data are not yet available or published for INM. However, we emphasize that this was a before-and-after study design: we were looking for changes before and immediately after surgical decompression in the tarsal tunnel. Therefore, we argue that not having published normative data for INM in the tarsal tunnel is irrelevant for the purposes of this particular study.

We emphasize that use of a portion of Module 3 of the ACFAS Scoring Scale is a significant limitation of the study for 2 reasons. First Module 3 has not been validated in any publication, and only the subjective portion of the scale was used with categorization into poor, fair, and excellent (done arbitrarily by the authors). However, we followed recommendations from the ACFAS scoring scale user guide previously published (12). In the user guide, it states there are instances in which investigators may need to remove or add sections in a module to more accurately reflect the proposed study design. The limitation of Module 3 of the ACFAS Scoring Scale is further discussed in an article by Cook et al (24). Therefore, we emphasize that this particular study is an exploration—a first attempt—and should prompt further research in INM in tarsal tunnel surgery.

In conclusion, the results obtained from the present study showed a statistically significant association between the change in muscle voltage of the abductor hallucis and abductor digiti quinti, as obtained by INM, and patient outcomes. This approach to tarsal tunnel decompression aids the surgeon in intraoperative decision making, and overall is an indicator or predictor of better patient outcomes.

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