Preoperative transcutaneous electrical nerve stimulation for localizing superficial nerve paths

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Introduction

Accurate localization of superficial nerve paths preoperatively is critical for reducing iatrogenic nerve injury risk intraoperatively, and certain nerves are more prone to such injury.\(^1\)

In a retrospective study of 612 cases of iatrogenic peripheral nerve damage in the trunk or limbs, Khan and Birch reported that four nerves were at a considerably higher risk from damage because of incision and dissection: the spinal accessory nerve at the posterior triangle of the neck, common peroneal nerve at the knee, and median and ulnar nerves at the wrist.\(^1\) The temporal branch of the facial nerve is particularly vulnerable to injury during facial surgical procedures requiring incision in the temporoparietal area\(^2\) because the nerve path over the zygomatic arch is superficial and variable among patients.\(^3\)

Historically, superficial nerve path evaluation was first developed for effective nerve block. For approximately a century after the first nerve block in 1885, injection site was chosen according to anatomical landmarks.\(^4\) However, these landmarks vary among patients and locating an appropriate injection site by needle exploration is invasive and may result in nerve injury.\(^5\) In 1978, La Grange et al. detected the subclavian artery using ultrasound (US) to provide an anatomical landmark for brachial plexus nerve block.\(^6\) In 1994, Kapral et al. applied this US-guided supraclavicular approach for regional anesthesia of the brachial plexus. With time, this nerve localization method for anesthetic injection has been further improved by technological refinements in US.\(^7\) However,
peripheral nerves can be difficult to differentiate from adjacent background structures; the technique requires a certain amount of training and deep knowledge of the distinguishing features of nerves to correctly detect them.

Transcutaneous electrical nerve stimulation (TENS) is a non-invasive technique that localizes target nerves by probing the skin with a pen electrode. Unlike US, TENS can directly stimulate nerves and precisely evaluate nerve paths without specific training. Furthermore, TENS can distinguish motor from sensory nerves objectively by the nature of the patient response (i.e., muscle contraction or sensation). A pen-type TENS system was first reported by Urmey in 2002, and Usui et al. used it to identify the lateral femoral cutaneous nerve for nerve block in 2011.

Here, we used a pen-type TENS system to identify superficial nerve paths before tumor resection or trauma surgery. The device enabled mapping of nerve paths and proved particularly useful for locating nerves in the region of benign tumor dissection.

**Patients and methods**

We evaluated the peripheral nerve path using TENS in 27 patients (17 males and 10 females; mean age: 59.9 years; range: 18–83 years) preoperatively between September 2011 and June 2013 at our institution. Patients were selected according to the risk of intraoperative damage to superficial peripheral nerves, and most surgeries were performed for tumor removal, including
parotid gland tumors, schwannoma, enlarged lymph nodes, and lipoma.

Peripheral nerve localization using TENS

An electrode pen coupled to an electrical nerve stimulator (Stimuplex NHS12; B. Braun http://www.bbraun.com/cps/rde/xchg/bbraun-com/hs.xsl/products.html?prid=PRID00001835) was used for superficial nerve mapping with grounding to either the right or left forearm. The initial stimulating current was 4 mA and was decreased to the minimum current required to elicit a motor response or paresthesia. All electrical stimuli were delivered at 2 Hz and a 1-ms pulse width. Major anatomical landmarks were used for gross localization, followed by careful manipulation of the electrode pen over the skin surface for fine localization. The pen pressure on the skin should be gentle because excessive pressure can shift the nerve position (Fig. 1). Once the target nerve was identified at one position, we tracked its path by repeating this procedure at 1-cm intervals (Supplemental Video 1).

Results

We used the TENS method to localize and map the facial nerve path in 17 patients; accessory nerve in seven; proper palmar digital nerve in two; and median, medial brachial cutaneous, superficial branch of the radial, and lateral cutaneous nerves of the forearm in one patient each.
Mapping accuracy was intraoperatively confirmed in cases where the nerve was exposed, including eight facial, two accessory, two proper palmar digital, one medial brachial cutaneous, and one ramus superficial branch of the radial nerve. These evaluated nerves were precisely under the path markings drawn preoperatively (Supplemental Video 2). However, the nerve path was substantially different from the preoperative markings only in one case, who had numbness at the surgical region resulting from a previous operation.

Three typical cases are described in detail below.

Case 1

A 61-year-old man was scheduled for left auxiliary subcutaneous tumor removal first diagnosed 2 years earlier. At the time of surgery, Tinel’s sign was positive and paresthesia was detected in the middle and ring fingers.

We suspected that the tumor was a schwannoma derived from the median nerve. Using TENS, we identified the median nerve at the distal edge of the tumor. However, we obtained no response to stimulation directly over the tumor site; therefore, we suspected that the median nerve passed under the tumor. We could also detect the medial brachial cutaneous nerve by stimulating the skin over the tumor site, suggesting that this nerve passed above the tumor. Contraction of the dominant target muscles identified the median nerve, and numbness over the dominant dermatomes
identified the median brachial cutaneous nerve. During surgery, we confirmed the anatomical path
defined preoperatively. Surgery was performed without incident. Mild paresthesia of the middle
finger was observed postoperatively but has since improved.

Case 2

A 28-year-old woman presented with soft tissue sarcoma on her posterior neck. In another
hospital, it was initially considered a benign tumor but recurred after removal. We performed wide
excision of the tumor with a 3-cm margin from the previous surgical scar, with special care not to
damage the accessory nerve crossing the incision line. Using TENS, we identified the right
accessory nerve path by stimulus-evoked movement of the trapezius muscle. The position of the
accessory nerve was confirmed after incision, and the nerve was carefully preserved during tumor
excision. After tumor removal, we covered the exposed nerve with a local flap and placed a skin
graft on the remaining defect after confirming the pathological surgical tumor margin. There were no
deficits of upper arm function or accessory nerve paralysis postoperatively (Fig. 2).

Case 3

A 45-year-old man presented with compartment syndrome of the left forearm and skin
ulceration on left forearm and dorsal side of the hand due to a stonefish (Synanceia) bite. Relaxation
incisions were performed on his left forearm in another hospital. Since then, he felt numbness in his left thumb and the index and middle fingers. Thus, we speculated that the superficial branch of the radial nerve was injured. However, we tracked the path of the superficial branch of the radial nerve at the radial side of the ulcer and suspected nerve continuity to a distal region using TENS. During surgery, we confirmed continuity but found that the nerve was 2 mm radial to the preoperative markings. We believe that this positional gap arises in sensory nerve injury, because localization depends on patient reports rather than objective evaluation of a motor response.

**Discussion**

The present study evaluated the accuracy of superficial nerve localization using a pen-type TENS system before tumor resection or trauma surgery. Using this non-invasive method, we identified all target nerve paths from evoked motor and/or sensory responses and the positions evaluated were precise in most cases.

Till date, US has been most commonly used as the device for searching nerves.

A major advantage of US is the ability to identify small nerves, including the digital nerves and those approximately 2 mm in diameter. However, with US, it can be difficult to discriminate a nerve from other similar structures, and a certain amount of experience is required to detect nerves accurately. In addition, the smaller the diameter of the peripheral nerve, the more
difficult it is to detect using US, and motor nerves cannot be differentiated from sensory nerves.

Magnetic resonance imaging (MRI) is also increasingly used for peripheral nerve path mapping. A primary advantage of MRI is the capacity to estimate the nerve path relative to a large overlying tumor.\textsuperscript{10} and several reports demonstrated good efficacy in identifying facial nerve paths.\textsuperscript{11,12,13} Intraparotid facial nerve segments appear as linear structures of low signal intensity surrounded by fat, and they can be identified in the perpendicular segment and followed distally.\textsuperscript{11} However, one limitation of MRI at 3 Tesla is its limited spatial resolution, leading to frequent false-positive results in nerves with diameters of <2 mm. Another limitation is that cutaneous nerves/nerve branches of <1 mm in diameter cannot reliably be visualized by tractography.\textsuperscript{15} On the other hand, the newest MRI of 7 Tesla has already been used to produce high-definition images of various anatomical areas,\textsuperscript{17} and it measures 1–1.5 mm in diameter, which corresponds to the diameter of cutaneous nerves in humans.\textsuperscript{16} The specific absorption rate is higher, and susceptibility artifacts are more pronounced at 7 Tesla than at 3 Tesla or 1.5 Tesla.\textsuperscript{18} However, the number of side effects is increased at 7 Tesla compared with that at 1.5 Tesla,\textsuperscript{18} and Theysohn et al. reported vertigo as the most pronounced sensation at 7 Tesla.\textsuperscript{19}

Although recent advancement in MRI provide superior resolution and have made the technique more useful for nerve mapping, the diagnostic skills and experience in using the technique are still required. Moreover, neither US nor MRI provides information on nerve continuity or which
peripheral nerve branches dominate specific muscle segments or dermatomes.

The pen-type TENS system obviates these problems by providing path information on nerves of ≤1 mm in diameter, with simple differentiation of sensory and motor nerves from the motor response or region of sensory response. We were able to evaluate the position of the nerve relative to the tumor tissue and surrounding nerves easily and accurately. We could follow the nerve path to the periphery using this system and establish continuity when the nerve passed through or under the tumor. Moreover, TENS does not require transcutaneous insertion of a stimulating needle, a procedure with some risk of damage to the target nerve.16 We thus suggest that this system is suitable for most preoperative peripheral nerve mapping applications.

Few reports evaluated TENS-based nerve mapping for plastic surgery. Takeishi reported accurate localization of facial nerves using a bipolar-type TENS probe.17 However, we suggest that a monopolar electrode would be more accurate because the space between the poles of a bipolar-type TENS electrode could stimulate non-target nerves or muscles. In contrast, the 3-mm tip diameter of the pen-type electrode used in our study may have reduced the error between the preoperative prediction and confirmed path.

TENS is an easy, less time-consuming, non-invasive technique that requires no special training for nerve searches. Our patients did not require anesthesia and only felt slight numbness. TENS allowed us to precisely identify the target nerve and its path and to inform patients about
potential complications. In addition, unlike other conventional methods, TENS could preoperatively detect the continuity of damaged sensory nerves suspected with neurotmesis.

Limitations of TENS include difficulty in tracking nerves that pass under tissues such as tumors or parotid glands. Sakai et al. used US and TENS in combination to identify the greater auricular nerve and found that identification was problematic in 29 of 100 patients, mainly in women and obese patients. Capdevila reported that stimulation was given at 4 cm and 5 mA, and stimulation arrived at the deep part than in getting skin wet with saline. TENS is ineffective for patients such as our Case 3, who was unable to report sensations accurately because of nerve damage. Stimulation of non-target nerves and muscles is also possible if the pulse width or current intensity is too high (Table 1).

To perform this procedure smoothly, we suggest first approximating the nerve position using an electrical current of 4 mA and then gradually reducing the current for finer mapping. It is important that pen pressure on the skin is gentle because excessive pressure can shift the nerve position. Other than these, it is a simple procedure to perform and the nerve position can be detected accurately. We could detect not only the nerve path but also the position of the nerve relative to the tumor.

**Conclusion**
Nerve paths could be accurately mapped preoperatively using TENS, as confirmed by direct visualization of the nerve during surgery. Except for the patient with sensory numbness, there were no substantial differences in the predicted and actual nerve paths. This stimulation device is easy to use and can provide highly accurate mapping of nerves for surgical planning. In conclusion, TENS is a useful tool for non-invasive nerve localization and makes tumor resection safer and smoother.

Funding

None.

Conflicts of interest

None.


16) Takehiko T, Masaya N, Masayuki Y, et al. Visualization of peripheral nerve degeneration and


Figure legend

Figure 1a: The Stimuplex® NHS12 nerve stimulation device

Figure 1b: Electrode pen for nerve stimulation

Figure 1c: The tip of the electrode pen should be placed on the skin surface gently, and it creates a slight fossette.

Figure 2a: We identified the path of the right accessory nerve (↑) preoperatively

Figure 2b: Immediately after beginning the surgery, the accessory nerve(↑) was identified just under the mapping(▲). We could preserve it well.

Figure 2c: The accessory (↑) nerve was maintained and no dysfunction was noted postoperatively.

Supplemental video 1: We detected the facial nerve from the movement of the frontal belly. We tracked its path by repeating this procedure at intervals of 1 cm.

Supplemental video 2: We could identified the facial nerve just under the mapping.

Table 1: Pros and cons of TENS
Pros

• easy to perform and can be used at any location.
• short period of examination time.
• no special training.
• noninvasive.
• do not require anesthesia.
• no discomfort.
• detection of the continuity of damaged sensory nerves.

Cons

• difficulty in tracking nerves at deep layer.
• possibility of non-target nerve or muscle stimulation.
• limited evaluation to the patient who cannot report their accurate sensation due nerve injury.