Preoperative ultrasound-guided mapping of peripheral nerves

Laboratory investigation

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Object. Surgical exposure of a peripheral nerve can be technically challenging, making the operation more extensive and time consuming, particularly in the treatment of small nerves with an anatomically variable position. This study describes the application of ultrasound to facilitate surgical access and localization of targeted peripheral nerves.

Methods. A preclinical feasibility study was performed at the University of Washington’s Willed Body Program laboratory. Unembalmed cadavers were placed on the dissection table in positions mimicking those typically required for surgical access to specific nerves that can be challenging to localize. A high-frequency portable ultrasound system was used to identify the nerves. An extraneural injection of methylene blue immediately adjacent to the target nerve was performed under ultrasound guidance as the experimental nerve mapping procedure. Surgical dissections through a small skin incision parallel to skin tension lines were guided by the transducer position and angle. Success was determined by the accuracy and rapidity of surgical identification and exposure of the nerve.

Results. Using ultrasound-guided mapping, all anticipated peripheral nerves were correctly identified via a direct approach from the skin incision. This was confirmed by performing an anatomical dissection to expose and identify the intended nerve and its relation to the injected methylene blue dye. In no case was intraneural injection of the dye observed.

Conclusions. Preoperative ultrasound-guided nerve mapping may be useful in facilitating surgical access to a targeted nerve and thereby minimizing tissue dissection and operating time.

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Key Words • ultrasound • nerve mapping • peripheral nerve

Surgical exposure of peripheral nerves requires both in-depth knowledge of human anatomy and meticulous surgical technique. Nevertheless, operative access to a target nerve can sometimes be challenging, making the operation more extensive and time consuming. Individual variations of human anatomy are common and unpredictable, especially with respect to small branches of distal nerves. Surgical access to previously traumatized, severed, or transpositioned nerves with no anatomically constant position may be particularly perplexing. In addition, obesity and other anatomical factors can make peripheral nerve operations even more difficult.

Preoperative neuroimaging may help in the surgical planning and execution of peripheral nerve surgeries. Modern MRI, involving the use of surface coils and higher-field strength magnets, makes it possible to visualize peripheral nerves and associated pathology to the point where such information becomes clinically useful to the surgeon. Although currently MRI is a standard test in diagnostic evaluations, there may be an alternative and faster way to evaluate peripheral nerve abnormalities. Recent technological advances in ultrasonography have improved resolution to the point where peripheral nerves as small as 2 mm in diameter can be visualized, and their relationship to important adjacent structures, such as blood vessels and bony landmarks, can be appreciated. In addition, and in contrast to MRI, ultrasonography can be routinely used in the surgical theater. Therefore, the application of ultrasound in the surgical environment, intraoperative ultrasonography, could therefore be of great benefit in guiding the surgeon to the targeted nerve through smaller incisions in a direct pathway, thereby minimizing surgical operating time and tissue trauma. At present, intraoperative ultrasonography requires special high-frequency transducers and a skilled sonographer to perform the examination. In this article, we validate the concept that preoperative nerve mapping using ultrasono-
nography performed by an anesthesiologist in collaboration with a neurosurgeon can rapidly, directly, and reliably guide the surgical exposure of the nerve of interest.

**Methods**

Six nonembalmed fresh cadavers donated to the University of Washington Willed Body Program were used. No institutional review board approval was required because the donors’ personal health data, excluding biometrics, were not disclosed to investigators.

Human cadavers were placed on the dissection table in positions mimicking those typically required for surgical access to specific nerves often of interest to a peripheral nerve surgeon. Sonographic nerve mapping was performed by the first author, who is experienced in ultrasoundonomic nerve imaging (M.G.). A portable ultrasound system S-Series (SonoSite, Inc.) and either a HFL50 (15–6 MHz) broadband or a HLA 25 (12–5 MHz) “hockey stick” linear transducer were used. Conductive gel was applied to the skin surface. The following nerves were targeted: 1) the radial nerve in the upper arm, 2) the posterior interosseous nerve in the proximal forearm, 3) the superficial radial nerve in the distal forearm, 4) the ulnar nerve across the elbow, 5) the ulnar nerve within the Guyon canal in the hand, 6) the anterior interosseous nerve in the proximal forearm, 7) the lateral femoral cutaneous nerve in the lateral groin region, 8) the saphenous nerve in the lower thigh, 9) the sural nerve at the midcalf level, and 10) the medial and lateral plantar nerves in the foot. The choice of nerves was determined by 3 factors—relative frequency of operative interventions, known variable position, and relatively small diameter. In addition, these relatively small nerves were deemed a suitable model to challenge a sonologist. We felt that if these nerves were easy to find and to map in the laboratory condition, clinically relevant situations (such as traumatized or severed nerve) could be successfully handled. Prior to commencing ultrasonographic nerve mapping of the target nerves, we performed several pilot injections and dissection of the median nerve at the carpal tunnel in the hand.

After successful ultrasonographic localization of the target nerve, the transducer was positioned in such way that its footprint aligned with the planned skin incision, which was oriented parallel to the skin tension lines. A 25-gauge hypodermic needle was inserted and directed to the target nerve either in plane (parallel to the course of the nerve) or out of plane (perpendicular to the course of the nerve) and 0.1 ml of methylene blue was injected adjacent to the most superficial and central position of the target nerve (Fig. 1). Skin-to-target distance was recorded using the caliper tool while applying minimal pressure to the surface of the skin. In addition, when significant depth of dissection was anticipated (such as for the saphenous nerve in the subsartorial space), an additional 0.1–0.2 ml of methylene blue was sequentially injected as the needle was withdrawn to provide a colorized pathway to the nerve. A small skin incision was made, guided by the transducer position and angle, and a combination of sharp and blunt dissection was performed to expose the targeted nerve. Particular attention was directed to preservation of adjacent structures (such as blood vessels and muscles) by using surgical retractors and vessel loops. Once the nerve of interest was exposed, another investigator evaluated the accuracy by performing additional exposure and validating the topographic anatomy.

**Results**

On all occasions the methylene blue dye staining was easily seen and targeted nerves could be localized rapidly either by simply dissecting linearly until the nerve was found or, in cases in which a trail of dye was deliberately left, by merely following the blue-stained tissue. No additional skin incision or elongation of performed incisions was needed. The nerves were found at the predetermined depth and position as visualized by the ultrasound image. Examples of peripheral nerve sonograms are presented in Fig. 2. Examples of dissections with methylene blue staining of target nerves are presented in Fig. 3. All dye injections were extraneural and did not result in any mechanical distortion of the nerve. When the dye-targeted nerves were removed and visually inspected only epineurium staining was apparent (Fig. 4).
Ultrasound mapping of peripheral nerves

Discussion

This is the first experimental preclinical cadaveric study to demonstrate that ultrasound-guided peripheral nerve mapping can reliably and rapidly facilitate surgical access to a target nerve.

Preoperative imaging may be helpful in identifying relevant anatomy and planning surgical access. Magnetic resonance neurography (MRN) is a recently developed technique that allows detailed imaging of peripheral nerve pathways and pathology. However, MRN is a costly and time-consuming method that only provides static imaging. Any changes in limb position will result in different relative anatomical relationships, hampering intraoperative localization.

Ultrasonography is an alternative imaging method for localization and examination of peripheral nerves. Its limitations include a narrow and unsteady field of view and operator-dependent accuracy. However, ultrasonography has certain advantages over MRN. It is portable and cost-effective, so it can be used wherever the patient may be. It also allows serial examinations over almost any anatomical region so that a long length of a nerve can be studied under dynamic conditions where changes in body position or orientation may influence the nerve’s location. Finally, technical advances have made the resolution of ultrasound equal to or in some cases superior to MRN when studying nerves encased by scar or located near arteries or hardware and when examining intraneural architecture. Several studies have shown the value of ultrasound in providing pathoanatomical diagnosis preoperatively, thereby helping in surgical planning and decision making. Preoperative imaging of nerve pathology and its anatomical location has been suggested as a valuable tool that facilitates surgical dissections. When used intraoperatively, it could help in improving surgical outcomes by reducing tissue trauma and surgical time. Intraoperative ultrasonography has facilitated the removal of brain tumors by providing real-time intraoperative localization of masses and guiding cortical incision and extent of resection. Several publications have addressed its use in peripheral nerve surgery. Koenig et al. showed that high-resolution, high-frequency intraoperative ultrasonography was accurate in grading peripheral nerve injuries as confirmed by intraoperative electrophysiological recording and stimulating. Perhaps the lack of radiologists trained in peripheral nerve sonography and/or deficiency of such training among peripheral nerve surgeons can explain why ultrasonography has not been more widely used in the operative setting. Ultrasonic localization of a target peripheral nerve could be performed preoperatively outside the surgery suite (for example, in the radiology suite) by a trained sonographer. In addition, non-radiology specialists, such as anesthesiologists, can help surgeons to localize peripheral nerves.

Ultrasonographic mapping of peripheral nerves could be extremely helpful to the peripheral nerve surgeon in a number of clinical scenarios. A superficial nerve could be mapped by marking the skin overlying its course. Ultrasound-guided placement of a guidewire has been utilized for localization of painful neuromas. Deeply located peripheral nerves, or those with variable course, or associated tumors could be localized and a surgical pathway marked using the injection of a medically acceptable dye. For example, methylene blue was used for intraoperative staining of the vagus nerve; the dye was applied onto the surgical field where it improved identification of nervous tissue due to selective dye uptake. This method demonstrated the usefulness of staining biological tissue with methylene blue, but it has not been routinely used in surgical practice. Gofeld et al. used methylene blue in cadavers to illustrate the accuracy of ultrasound-guided injection of the cervical sympathetic chain. Ultrasound-guided methylene blue injection has also been used to localize tumors or to guide sentinel node biopsy. Although theoretically local injection of methylene blue could result in tissue toxicity, adverse effects of extraneural injections are unlikely due to the minimal volume injected.

Preliminary work on patients is showing the utility of intraoperative ultrasonography in helping to more precisely and rapidly localize deeply situated nerve sheath...
tumors as well as nerves with surgically variable locations and trajectories, such as the lateral femoral cutaneous nerve. We have performed several surgeries on patients using the described technique to localize the lateral femoral cutaneous nerve, which in some cases had an aberrant medial location. When the nerve could not be localized during a first surgery, ultrasound-guided methylene blue mapping was successfully used to find the nerve during subsequent surgery (Fig. 5). Intraoperative ultrasonography was also used to guide the placement of a peripheral nerve stimulation lead (Fig. 6), and we found that it greatly facilitate surgical access to the nerve while minimizing the length of the surgical incision.

This study did not compare a standard surgical approach to ultrasound-guided exposure of peripheral nerves and associated pathology. Although it seems intuitively evident that intraoperative ultrasonography would be of surgical benefit, a randomized trial comparing an ultrasound-guided approach versus a standard conventional surgical approach is necessary to definitively demonstrate its clinical benefit. Indeed the best way to introduce a new methodology is to compare it to an accepted existing one. Studies comparing analgesic nerve blocks using either ultrasound guidance or nerve stimulation have concluded that both methods have similar usefulness and effectiveness.12–14 Nevertheless, there has been a move toward the ultrasound-guided regional anesthesia based predominantly on a notion of superiority of an image-guided bedside practice versus surface anatomy approaches utilizing essentially blind injections.13,16,19

Ultrasound neurography is a simple, inexpensive, safe, and practical neuroradiological method that may be helpful in peripheral nerve surgery. In our study, we combined the use of ultrasonography and injection of methylene blue dye for localization of specific peripheral nerves. The combined method can provide surgeons with a useful roadmap to precisely localize, expose, and treat a wide range of peripheral nerve pathologies including entrapments, tumors, and traumatic neuromas and nerve injuries.

Conclusions

Preoperative ultrasound-guided peripheral nerve mapping is a promising technique facilitating surgical access to peripheral nerves that often have variable anatomy and pathology. Clinical studies are needed to definitively demonstrate its clinical benefits.

Disclosure

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References


Fig. 5. Methylene blue mapping of the lateral femoral cutaneous nerve. Left: Sonogram showing needle inserted distal to the inguinal crease into the so-called “fat pad” containing the nerve. Right: Surgical exposure of an aberrantly located lateral femoral cutaneous nerve. The stained nerve is lifted prior to neurectomy. FL = fascia lata; SM = sartorius muscle.

Fig. 6. Intraoperative peripheral nerve stimulation. A paddle surgical lead (white arrows) is being placed under the ulnar nerve (open arrows) that was preoperatively mapped with methylene blue.
Ultrasound mapping of peripheral nerves


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