Ultrasonographic Evaluation of Peripheral Nerves

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Key words
- Peripheral nerve
- Ultrasonography
- Ultrasound

Abbreviations and Acronyms
CTS: Carpal tunnel syndrome
MRI: Magnetic resonance imaging
US: Ultrasonography

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There are a variety of imaging modalities for evaluation of peripheral nerves. Of these, ultrasonography (US) is often underused. There are several advantages of this imaging modality, including its cost-effectiveness, time-efficient assessment of long segments of peripheral nerves, ability to perform dynamic maneuvers, lack of contraindications, portability, and noninvasiveness. It can provide diagnostic information that cannot be obtained by electrophysiologic or, in some cases, magnetic resonance imaging studies. Ideally, the neurosurgeon can use US as a diagnostic adjunct in the preoperative assessment of a patient with traumatic, neoplastic, infective, or compressive nerve injury. Perhaps its most unique use is in intraoperative surgical planning. In this article, a brief description of normal US nerve anatomy is presented followed by a description of the US appearance of peripheral nerve disease caused by trauma, tumor, infection, and entrapment.

INTRODUCTION

Ultrasonography (US) remains one of the most time-efficient and cost-effective diagnostic imaging modalities of peripheral nerves. Historically, the role of US in the diagnosis of nerve injury was limited, largely because of low-frequency transducers. However, with technological advancements in equipment, including the development of high-frequency ultrasound transducers and refinements in scanning techniques, high-resolution imaging of relatively small peripheral nerves is possible with resolutions that are higher than is achievable with clinical magnetic resonance imaging (MRI) scanners. Although electrophysiologic studies provide important diagnostic data in evaluating the relative location and degree of nerve dysfunction, they are limited in their ability to identify morphologic changes associated with a particular type of nerve injury. US can reliably provide this information, and it does so in a painless manner, compared with electrodiagnostic studies.

Compared with MRI, US provides images that are of higher resolution. The axial in-plane resolution of a 10-MHz probe is approximately 150 µm.[1] In comparison, approximate resolution of a common clinical MRI is 450 µm.[2] Clinical imaging transducers can reach frequencies up to 18 MHz, with further improvements in resolution. US is therefore superior in visualizing the ultrastructure of individual nerves and in evaluating small-caliber nerves such as digital nerves. US also allows for assessment of nerves near artificial implants, which may compromise MRI resolution.

Support for the use of US compared with MRI comes from a retrospective study by Zaidman et al.,[3] in which 53 patients with mononeuropathies or brachial plexopathies underwent both US and MRI. Among the 46 patients with neuropathology diagnosed by surgical ($n = 39$) or clinical/electrodiagnostic ($n = 14$) evaluation, US detected neuropathology more frequently than MRI, with a sensitivity of 93% versus 67%. Specificity of both studies was similar (86%). MRI techniques optimized for nerve imaging, such as magnetic resonance neurography and diffusion tractography, may improve the sensitivity of MRI detection of lesions of the peripheral nervous system.[4-8] In a multicenter study of 204 patients,[9] the combined use of US and MRI yielded an overall sensitivity of 76% and a specificity of 96% in detecting brachial plexus disease.

A unique feature of US, and an important advantage over MRI, is the ability to perform dynamic examination of nerves portably. This feature allows its use in both the clinic and the operating room setting. Another important advantage of US is that the acquisition of US images is more time efficient and cost efficient than MRI, especially when evaluating a nerve over a long anatomic region (e.g., the entire length of an extremity), and can be repeated easily. However, new three-dimensional anatomic MRI sequences allow for better profiling of longer stretches of nerves.[10] For patients with contraindications to MRI (e.g., a cardiac pacemaker), US is ideally suited because there are essentially no contraindications to its use. US is also favorable for patients who are claustrophobic and who may not tolerate MRI. US is preferred by patients, even over MRI, as seen in a recent assessment comparing patient satisfaction in patients with full-thickness rotator cuff tears undergoing evaluation by US or MRI; unlike with MRI, patients experience minimal pain or discomfort and receive real-time feedback from the examiner with US.[11]

Despite these advantages, US is not without limitations. The size of the patient, the depth of the nerve, and the presence of bone between the probe and nerve may limit adequate visualization. Also, it does not provide a comprehensive anatomic view of the affected area, as is obtained with MRI. Importantly, US requires specialty training in acquisition and interpretation of images; the quality of the information obtained is operator dependent. In this article, the use of US is described in the evaluation of multiple peripheral nerve diseases, including trauma, neoplasia, infection, and compression, as well as additional nerve-related clinical applications such as regional anesthesia.

NORMAL US APPEARANCE

Evaluation via US anatomically spans a large extent of a nerve course. For example, in the US survey of the brachial plexus, evaluation can be performed from the spinal nerves and trunks of the brachial plexus to the digital nerves and is limited only by the user's knowledge of regional anatomy and topography. Some general landmarks include the brachial artery in the arm for the median nerve, the ulnar artery at the wrist for the ulnar nerve, the medial epicondyle at the elbow for the ulnar nerve, and the anterior and middle scalene muscles and proximal subclavian artery for the supraclavicular portion of the brachial plexus. In the lower extremity, evaluation is limited in the proximal lumbar plexus in the abdomen and pelvis because of the deep location of the nerves. However, the proximal sciatic and femoral nerves can be visualized without restriction. Knowledge of the muscle groups, tendons, and blood vessels is essential. Some important landmarks include the popliteal artery for the distal sciatic nerve and the posterior tibial artery for the posterior tibial nerve at the ankle.[12] Although these anatomic landmarks are helpful to the ultrasonographer, they cannot replace the knowledge of the individual anatomic course of each nerve, including expected changes associated with trauma or surgery. In addition, several anatomic variations of peripheral nerves exist and may confuse the inexperienced ultrasonographer.

The distinct anatomic components of a nerve are uniquely represented on ultrasonographic imaging. Typically, a high-frequency linear array probe (8–18 MHz) is used for nerve US. When assessing a nerve with US, axial images are generally the most useful for depicting anatomy of a nerve and detecting disease. In the axial plane, a nerve appears as a hypoechoic structure with small round or oval hypoechoic areas, which correspond to individual nerve fascicles separated by hyperechoic septae, representing intervening perineurium, giving a honeycomb-like appearance to peripheral nerves (Figure 1).[13] Individual nerves decrease in caliber from proximal to distal as they branch, and considerable variability also exists among nerve fascicles.[14] The cross-sectional area of a nerve is used in various disorders as an important diagnostic marker of nerve disease.[15-17]

Longitudinal images of a nerve show a so-called fascicular pattern, namely a hypoechoic tubular structure interspersed with hyperechoic lines representing the perineurium. Assessment in the longitudinal plane is more challenging technically because of the curving nature and small size of peripheral nerves. Following a nerve in this plane is particularly helpful to show abnormal contour or a change in nerve caliber. The nerve is differentiated from surrounding muscle, which is less echogenic than nerve. The caliber of the neighboring hypoechogenic muscle, compared with the contralateral side, can provide clues as to the health of the muscle and whether significant neuropathy leading to atrophy has resulted. Tendon, in contrast to muscle, is more echogenic than nerve, with a tightly compact fibrillar appearance.[18] Dynamic motion of the limb can also help differentiate nerve from tendon. Color Doppler imaging is useful in distinguishing nerve from vessel. In addition, it can also detect nerve disease in the case of various compressive or inflammatory neuropathies in which hypervascularity and vascular congestion occur. Normally, no internal blood flow should be detected by US within a nerve fascicle.[19]

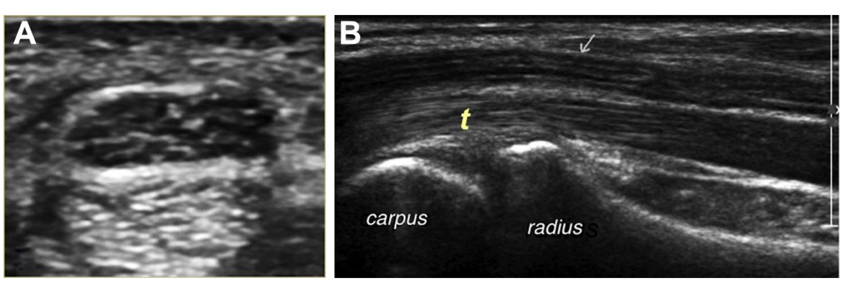

Figure 1. Normal ultrasonograph of a peripheral nerve. Transverse (**A**) and longitudinal (**B**) images of the median nerve (*arrow*) showing typical honeycomb appearance in the transverse plane and tubular morphology with an internal fascicular pattern in the longitudinal plane. t, flexor tendon.

TRAUMATIC NERVE INJURIES

In 1941, Seddon[20] classified nerve injuries based on 3 main types of nerve fiber injury: neurapraxia, axonotmesis, and neurotmesis. Neurapraxic injury is verified on US as a swollen nerve with a hypoechoic appearance; however, axonotmetic and neurotmetic injuries are difficult to reliably distinguish using US and often require surgical exploration with intraoperative electrophysiologic assessment of the damaged nerve segments. Both neuromas-in-continuity and stump neuromas can be visualized as focal thickening or mass-like lesions at nerve ends (Figure 2).[21] Cokluk et al.[22] described US findings in 14 patients with traumatic peripheral nerve injuries as axonal swelling, stump neuroma, nerve interruption, and surrounding scar tissue. Zhu et al.[23] also described 7 types of traumatic nerve injuries based on US visualization of the nerve fascicle, perineurium, epineurium, and peripheral tissues with 93.2% accuracy. In the case of gunshot wounds or shrapnel injuries, US is able to localize intraneural foreign particles and allows for surgical planning.[24] US is particularly advantageous in these cases because the presence of metallic fragments often precludes the use of MRI and affects the quality of computed