Neuromuscular Ultrasound in Common Entrapment Neuropathies

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EDUCATIONAL OBJECTIVES  Upon completion of this monograph, the reader will acquire skills to: (1) describe basic ultrasound findings in various common entrapment neuropathies and develop an understanding of the clinical utility of these tests, and (2) develop an understanding of the focal anatomy of the described entrapment neuropathies as it relates to ultrasonic findings.

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ABSTRACT: Neuromuscular ultrasound involves the use of high-resolution ultrasound to image the peripheral nervous system of patients with suspected neuromuscular diseases. It complements electrodiagnostic studies well by providing anatomic information regarding nerves, muscles, vessels, tendons, ligaments, bones, and other structures that cannot be obtained with nerve conduction studies and electromyography. Neuromuscular ultrasound has been studied extensively over the past 10 years and has been used most often in the assessment of entrapment neuropathies. This review focuses on the use of neuromuscular ultrasound in 4 of the most common entrapment neuropathies: carpal tunnel syndrome, ulnar neuropathy at the elbow and wrist, and fibular neuropathy at the knee.

Neuromuscular ultrasound is a rapidly evolving field in which high-resolution ultrasound is used to diagnose, prognosticate, and guide therapeutics in individuals with neuromuscular conditions. Ultrasound of muscle for diagnostic purposes was first described in the early 1980s in children with muscular dystrophy and spinal muscular atrophy. In 1988, Fornage first described ultrasonographic examination of peripheral nerves, and in 1991, Buchberger and colleagues were the first to assess the accuracy of neuromuscular ultrasound for the diagnosis of a focal nerve disease, carpal tunnel syndrome (CTS). Since then, over 100 articles have been published on the use of neuromuscular ultrasound for evaluation of focal entrapment neuropathies, and the aim of this report is to discuss and summarize its use in 4 of the most common entrapment neuropathies.

Abbreviations: CTS, carpal tunnel syndrome
Key words: clinical neurophysiology; fibular nerve ultrasound; median nerve; ulnar nerve; entrapment neuropathy

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FIGURE 1. On the left is a 17 MHz linear array transducer and on the right is a 5 MHz curvilinear transducer. The higher frequency transducer on the left is more often used in neuromuscular imaging, but the lower frequency transducer may be needed for deep structures, such as the proximal sciatic nerve.
rim of the nerve, erring to the inside of the rim (Fig. 2). Instead of the “free hand” technique, some use the “ellipse” program available with most ultrasound devices to fit an ellipse over the nerve, which then produces an area measurement. In either the cross-sectional or longitudinal view, the diameter of the nerve can be measured using the “straight line” tool. It is important to angle the transducer so that it is perpendicular to the nerve when obtaining the cross-sectional image, otherwise the area may be increased artificially (Fig. 3). Similarly, when measuring the diameter of a nerve in the sagittal plane it is important that the transducer be positioned to image through the thickest portion of the nerve, so a true diameter is obtained and is not lowered artificially (Fig. 3).

COMMON ULTRASOUND FINDINGS IN ENTRAPMENT NEUROPATHIES

When ultrasound was first used to evaluate entrapment neuropathies, it was thought that perhaps the most common finding would be nerve flattening or pinching, but it was quickly realized this was not the case. While flattening or pinching of the nerve can sometimes be identified with entrapment, the far more common and reproducible finding is nerve enlargement just proximal to the site of entrapment. This enlargement is typically fusiform, rather than discretely focal, and it is important to identify the point of maximum enlargement when assessing the degree to which the nerve is enlarged (Fig. 4). The cutoffs most commonly used to define nerve cross-sectional area enlargement include: (1) an area more than 2 standard deviations above the mean reference value, and (2) an area 1.5 times or greater than an unaffected portion of the same nerve. While the cause of nerve enlargement is not completely understood, it is suspected to result from axoplasmic damming, which is seen in models of entrapment and chronic nerve compression. In addition, there is likely an inflammatory and/or vascular component that contributes to nerve enlargement, as corticosteroids injected near an

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**FIGURE 2.** The left and right images are the same, and they show a cross-sectional view of the median nerve at the wrist. The image on the right shows the trace method that is used to obtain the nerve cross-sectional area.

**FIGURE 3.** (A) The cross-sectional area measurement of a nerve. The transducer on the left is perpendicular to the nerve, and the smallest and most accurate cross-sectional area is depicted below the nerve. On the right the transducer is angled and not perpendicular, so the area is artificially elongated and increased. (B) The nerve (oval) is seen in cross-section, and the transducer is placed to obtain a longitudinal image of the nerve. The transducer on the left is placed correctly to image the middle of the nerve, which results in an accurate diameter. The transducer on the right is incorrectly off-center, which artificially lowers the measured diameter of the nerve.
enlarged nerve can reverse some degree of enlargement within a week of injection.\textsuperscript{7,8}  
While nerve enlargement just proximal to the site of entrapment is the most common ultrasonographic finding detected in entrapment neuropathy, other findings have been reported. These include changes in nerve echotexture (they become hypoechoic), shape (flattening and pinching at site of entrapment), fascicle size (enlargement of single or multiple fascicles within the nerve), and vascularity (increased within the nerve).\textsuperscript{8–10} Changes in nerve mobility are also reported with entrapment, but these are not uniform; there is decreased mobility in CTS and possibly increased subluxation in ulnar neuropathy at the elbow.\textsuperscript{11,12}  
Structures near the nerve of interest should be assessed with ultrasound to determine if there are anatomical explanations for the entrapment, such as cysts, tumors, aberrant muscles, etc. In addition, chronically denervated muscle may become hypoechoic and atrophied, so imaging of muscles distal to the entrapment, both those innervated by the affected nerve and innervated by unaffected nerves, can be informative.

Now that ultrasonographic standards and typical findings in entrapment neuropathies have been described, the rest of this review will focus on the neuromuscular ultrasound evaluation of 4 of the most common entrapment neuropathies.

**MEDIAN MONONEUROPATHY AT THE WRIST**

The most common entrapment neuropathy is of the median nerve at the wrist, which causes CTS. The mean annual crude incidence of CTS is 329 per 100,000 person-years, and more than three-quarters of the cases involve women.\textsuperscript{13} It is a common work-associated condition, and healthcare costs in the United States alone exceed $500 million per year.\textsuperscript{14,15} Median mononeuropathy at the wrist is also the entrapment neuropathy studied most frequently with ultrasound, and the ultrasonographic evaluation of this condition is described below.

**Patient Position.** Arranging the patient in a position that is comfortable for both patient and examiner is important for all ultrasonographic studies (Fig. 5). For the assessment of median mononeuropathy at the wrist, the patient can be either supine or seated with palms upward and resting on the lap or a pillow across the lap. The supine position may be more comfortable for the patient,
particularly for longer examinations, but the seated position allows for more efficient evaluation of both wrists in cases of bilateral median mononeuropathy at the wrist. The seated position also allows patients to observe the study, which some appreciate.

**Transducer Position.** To obtain a sagittal view, the transducer is aligned with the thenar crease (which typically also aligns with the middle finger) and is placed at the wrist (Fig. 6). To obtain a cross-sectional view, the transducer is rotated 90 degrees and aligned with the distal wrist crease. Finally, to obtain a proximal cross-sectional area for comparison, the transducer is started at the wrist and the nerve is traced proximally to the mid-forearm, where it lies deep to the flexor digitorum superficialis muscles and superficial to the flexor digitorum profundus muscles.

**Reference Values.** Many different reference values have been published over the past 10 years for median nerve cross-sectional area at the wrist. Several studies, including a meta-analysis, suggest that a cutoff of greater than 10 mm$^2$ is sensitive for the diagnosis of CTS, whereas others use a more specific cutoff of greater than 12 mm$^2$.9,16 A wrist-to-forearm area ratio of greater than 1.4 is also sensitive and specific for diagnosis of CTS.5 Just as with nerve conduction studies, it is recommended that each lab generate its own reference values for the nerves evaluated commonly.

**Typical Neuromuscular Ultrasound Findings.** Enlargement of the median nerve cross-sectional area at the distal wrist crease is an accurate parameter for diagnosis of CTS, with sensitivity and specificity greater than 85% in several studies.17,18 Not as well characterized is the echotexture change that accompanies CTS. The median nerve at the distal wrist crease often becomes hypoechoic as it enlarges, but the accuracy of this finding is not known.8

**Findings Unique to This Entrapment Syndrome.** Of interest, the median nerve in individuals with CTS has decreased mobility compared with healthy controls, and the decreased movement can be quantified in both lateral and distal–proximal planes.11,19 In our lab, a grading scale is used to assess median nerve movement in those with suspected CTS (Table 1). Another neuromuscular ultrasound finding that has only been studied systematically in CTS is increased nerve vascularity, as detected with Doppler ultrasound. Some studies have reported this to be a very powerful parameter for diagnosis of CTS, with accuracy greater than 95%,10 but machine settings and operator dependence likely result in a lower accuracy during routine clinical use.

Approximately 10–15% of all individuals assessed with neuromuscular ultrasound have bifid median nerves at the wrist, and 5–10% have persistent median arteries running through the carpal tunnel (these conditions sometimes, but not always, occur together) (Fig. 7).20,21 Bifid median nerves and persistent median arteries are not more common in CTS, but they can change the therapeutic approach, especially the presence of a large persistent median artery.20 Other anatomic abnormalities that have been identified with neuromuscular ultrasound as causing or mimicking CTS include traumatic neuromas, Schwannomas, lipomatous hamartomas, ganglion cysts,

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**Table 1. Grading median nerve movement at the wrist.**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Mobility assessment</th>
<th>Description of nerve movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Decreased</td>
<td>The median nerve has minimal movement in all directions.</td>
</tr>
<tr>
<td>1</td>
<td>Slightly decreased</td>
<td>The median nerve moves freely in the transverse plane but does not dive deep.</td>
</tr>
<tr>
<td>2</td>
<td>Normal</td>
<td>The median nerve dives deep and is surrounded on all sides by the flexor tendons.</td>
</tr>
</tbody>
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*The patient is asked to repeatedly flex and extend the fingers and wrist while the ultrasound transducer is held still. The grades described in the table are used to describe the degree of median nerve movement.*
thrombosed persistent median arteries, abscesses, and compressive gouty tophus.\textsuperscript{22–25}

ULNAR NEUROPATHY AT THE ELBOW

The mean crude annual incidence of ulnar neuropathy at the elbow is 24.7 per 100,000 person-years, which is approximately 1/13th as common as median neuropathy at the wrist in the same population.\textsuperscript{13,26} More than two-thirds of cases involve men,\textsuperscript{26} and the neuromuscular ultrasound evaluation of this condition is described below.

Patient Position. Two positions can be used (Fig. 8). One is with the patient supine and the arm abducted and flexed at the elbow. This is similar to the position used for ulnar nerve conduction studies, and it allows for evaluation of the nerve from the wrist to the axilla, dynamic evaluation during full flexion and extension of the elbow, and reduced redundancy in the skin or ulnar nerve that may occur when the arm is straight. The other position is with the patient seated, the arm internally rotated, and the palm flat on the examination table. The ultrasonographer sits behind the patient in this arrangement.

Transducer Position. To obtain a sagittal view, the transducer is placed in the ulnar groove (Fig. 9). It can then be rotated 90 degrees to obtain a cross-sectional view at the elbow. The transducer is then advanced distally to the mid-forearm and proximally to the mid-arm, which allows for imaging of the nerve in the cubital tunnel, at the level of the medial epicondyle, and in the supracondylar region, which are the main sites of maximum enlargement in ulnar neuropathy at the elbow.\textsuperscript{27} This also allows for ulnar nerve cross-sectional area measurements at unaffected sites below and above the elbow, which can then be compared with the site of maximum enlargement to generate a ratio.

Reference Values. Different reference values have been published over the past 10 years, with the upper limit of normal for the ulnar nerve at all sites near the elbow typically around 9–10 mm\textsuperscript{2}.\textsuperscript{28–30} A ratio of the site of maximum enlargement compared
with an unaffected site greater than 1.4 also has high diagnostic accuracy.27

**Typical Neuromuscular Ultrasound Findings.**
Enlargement of the ulnar nerve is the most common finding; one of the largest series noted enlargement to be 80% sensitive and 91% specific for the diagnosis.31 A ratio of the site of maximum enlargement compared with an unaffected site greater than 1.4 yielded sensitivity and specificity greater than 95%, but that study was limited by spectrum bias.27

**Findings Unique to This Entrapment Syndrome.**
Hypermobility of the ulnar nerve, which results in the nerve snapping over the medial epicondyle, has long been suspected to increase the risk of ulnar neuropathy at the elbow. Subluxation (when the nerve moves superficial to the medial epicondyle) and luxation or complete dislocation (when the nerve exits the groove and lies anterior to the medial epicondyle) with elbow flexion are easily identified and characterized with ultrasound.32 Several studies have examined this phenomenon with ultrasound to determine if it occurs more often in those with ulnar neuropathy at the elbow than in controls, and the answer remains uncertain, although subluxation does occur frequently in healthy controls.12,33 We use ultrasound to assess for ulnar nerve hypermobility in cases of ulnar neuropathy at the elbow, as information about this condition may affect nerve conduction studies and surgical planning.32

**ULNAR NEUROPATHY AT THE WRIST**
Unfortunately, there are no epidemiologic studies to determine the prevalence or incidence of ulnar neuropathy at the wrist, but it is likely to be much less common than median mononeuropathy at the wrist and ulnar neuropathy at the elbow. In addition, it is thought more often to be secondary to anatomic abnormalities such as trauma, ganglion cysts, and thrombosed ulnar arteries, and it is also more common in those with CTS.7,8 The neuromuscular ultrasound evaluation of this condition is described below.

**Patient Position.** Positioning is the same as for evaluation of suspected CTS, so the patient can be either supine or seated with the elbows flexed and palms upward (Fig. 5).

**Transducer Position.** To obtain a sagittal view the transducer is placed on the wrist over the ulnar artery, and once the artery is identified the transducer is moved just medial (Fig. 10). The sagittal view of the ulnar nerve is challenging. The

`FIGURE 9. A sagittal image of the ulnar nerve at the elbow is demonstrated on the left. The right image shows a cross-sectional view of the ulnar nerve at the elbow. Arrow, ulnar nerve (in both images); ME, medial epicondyle; O, olecranon process.

FIGURE 10. The left image shows the ulnar nerve at the wrist in sagittal view, and the right image demonstrates the cross-sectional view. Arrow, ulnar nerve; curved arrow, ulnar artery; P, pisiform bone; ADM, abductor digit minimi muscle.`
transducer can be rotated 90 degrees, and the ulnar nerve can be identified as a round or oval structure medial to the pulsatile artery. The transducer is then moved proximally and distally 1–2 cm in each direction to identify the site of maximum enlargement.

**Reference Values.** The upper limit of normal for the cross-sectional area of the ulnar nerve at the wrist is 8 mm², but the diagnostic utility of this cutoff in the rare entity of idiopathic ulnar neuropathy at the wrist has not been assessed.

**Typical Neuromuscular Ultrasound Findings.** Idiopathic ulnar neuropathy at the wrist is rare, and therefore there are no systematic studies of typical ulnar nerve findings in this condition. However, as with other entrapment syndromes, it is thought that the ulnar nerve enlarges with entrapment at the wrist and may become hypoechoic.

**Findings Unique to this Entrapment Syndrome.** Ulnar neuropathy at the wrist often occurs secondary to an anatomic abnormality. Case reports and series exist describing compressive ganglion cysts and dilated or thrombosed ulnar arteries. In ulnar neuropathy at the wrist, it is important to advance the transducer distally, visualizing the pisiform bone and the ulnar nerve just distal to the pisiform bone, as pathology can arise from this site.

**FIBULAR NEUROPATHY AT THE KNEE**

As with ulnar neuropathy at the wrist, no comprehensive epidemiologic studies exist regarding the prevalence of fibular neuropathy at the knee, but it is thought to be the most common entrapment syndrome of the lower extremity. Conditions such as habitual leg crossing and squatting, dramatic weight loss, casting, and immobility increase the risk of fibular neuropathy at the knee. The neuromuscular ultrasound evaluation of this condition is described below.

**Patient Position.** The fibular nerve can be evaluated with the patient prone or supine, but the lateral decubitus position allows for the most comprehensive evaluation of the nerve, from the separation from the sciatic nerve to the point of crossing over the fibular head (Fig. 11).

**Transducer Position.** Imaging can begin at either the level of the distal sciatic nerve or over the fibular head (Fig. 12). Obtaining a sagittal view of the fibular nerve as it travels near the fibular head is challenging, as the nerve runs at an angle. In the cross-sectional view, the fibular nerve should be imaged from the sciatic nerve to at least the fibular head, and possibly distal to that point, where it splits into the superficial and deep fibular nerves.

**Reference Values.** A few studies have provided reference values for the cross-sectional area of the fibular nerve, and in general the upper limit of normal for this nerve in the popliteal fossa and at the fibular head is approximately 20 mm². The cross-sectional area of the fibular nerve is typically one-third that of the sciatic nerve and half that of the tibial nerve in the popliteal fossa.

**Typical Neuromuscular Ultrasound Findings.** Enlargement of the fibular nerve near the fibular head has not been studied systematically in cases of idiopathic mononeuropathy at this site, although decreased echogenicity has been described in a small cohort of patients with fibular mononeuropathy at the knee associated with weight loss. Potential abnormalities in mobility and vascularity have not been explored.

**Findings Unique to this Entrapment Syndrome.** Some individuals with foot drop secondary to fibular neuropathy at the knee have intraneural ganglion cysts, which are crucial to identify, as they change...
medical management (Fig. 13). This finding is relatively common; it has been reported to occur in 18% of individuals with electrodiagnostically confirmed fibular neuropathy at the knee.\(^{40}\) Intraarticular ganglion cysts should be suspected in patients without habitual leg crossing, squatting, standing, or immobility.\(^{41}\) Secondary to acute or chronic trauma to the proximal tibiofibular joint and ligation of the intra-articular nerve branch prevents re-accumulation of the cyst.\(^{42}\)

It has been proposed that some cases of idiopathic fibular neuropathy at the knee may be secondary to compression of the nerve between the tendon of the biceps femoris and the lateral head of the gastrocnemius.\(^{43}\) Therefore, a dynamic evaluation of the fibular nerve at this site, with flexion and extension of the knee, can assist in diagnosing the specific anatomic site of compression, although this theory has not been studied systematically.

**CONCLUSIONS**

Neuromuscular ultrasound of common entrapment neuropathies provides diagnostic information that complements the history, physical examination, and electrodiagnostic studies. Neuromuscular ultrasound has also advanced our understanding of entrapment neuropathies and improved treatment strategies, by demonstrating relatively common conditions such as intraneural ganglion cysts in the fibular nerve. Intensive study of neuromuscular ultrasound has only occurred over the past decade, so as more experience is gained, techniques are refined, and ultrasound technology advances, it is likely the technique will continue to gain importance in evaluation of entrapment neuropathies as well as a wide variety of other neuromuscular diseases.

**REFERENCES**
