



Neuromuscular Ultrasound – New & Happening

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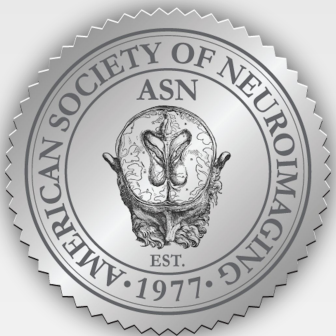
Assistant Professor of PM&R and Neurology

Mayo Clinic

American Society of Neuroimaging
49th Annual Meeting

Disclosures

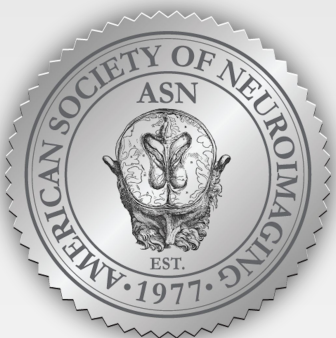
- Nothing to disclose.



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Learning Objectives

- Recognize how neuromuscular ultrasound is a complement to the electrodiagnostic examination
- Identify appropriate clinical situations in which to utilize **nerve** ultrasound examination to augment your diagnostic workup
- Identify appropriate clinical situations in which to utilize **muscle** ultrasound examination to augment your diagnostic workup

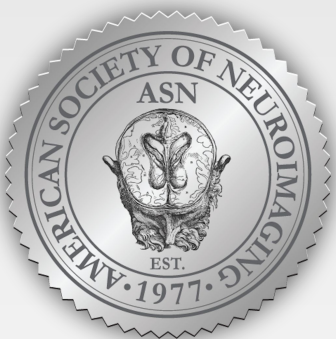




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Neuromuscular Ultrasound (NMUS)

- **Neuromuscular ultrasound (NMUS)** is a diagnostic imaging technique that uses high-resolution ultrasound to visualize and assess the structure and function of nerves and muscles.
- NMUS is an adjunct or complement to the standard electrodiagnostic (EDX) examination, including nerve conduction studies (NCS) and needle electromyography (EMG).



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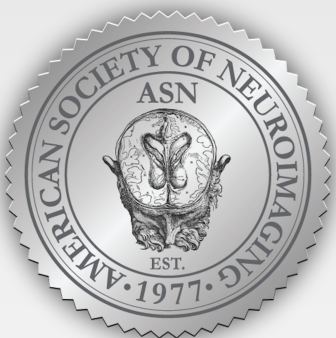
NMUS: US in PMR & Neurology

Musculoskeletal US

- Used for US-guidance for therapeutic injections
- Diagnostic □ MSK conditions
- Pertinent structures:
 - Bones
 - Tendons
 - Ligaments
 - Joints

Neuromuscular US

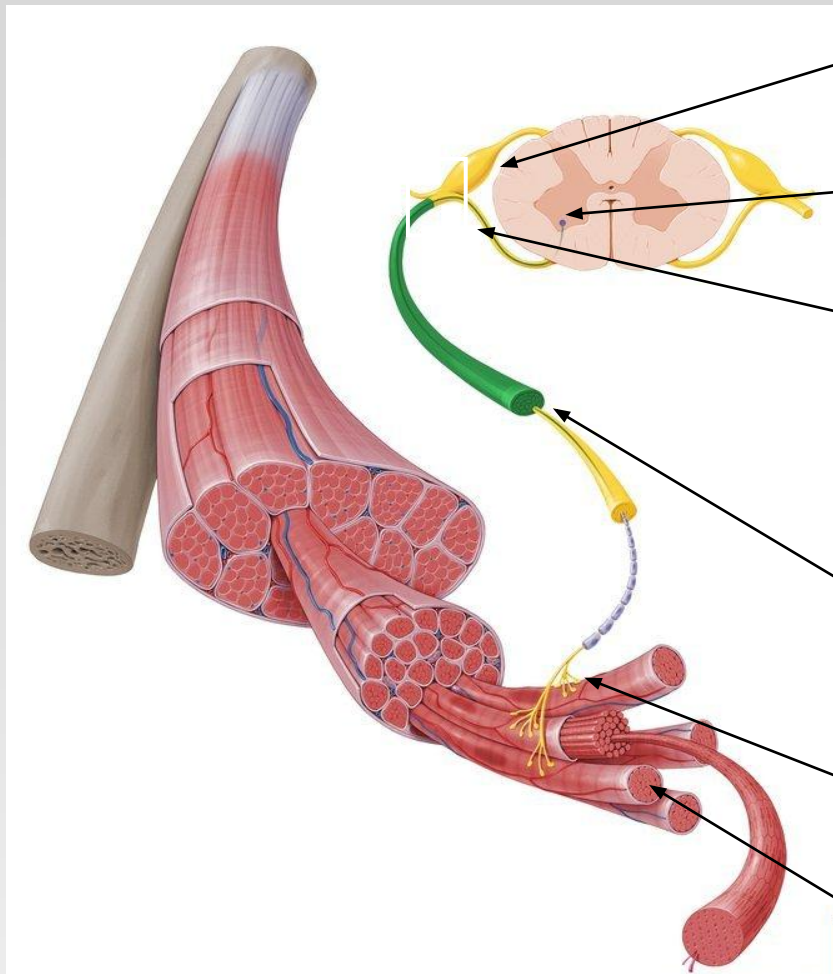
- Used as a complement to EMG
- Diagnostic □ Neuromuscular disorders
- Pertinent structures:
 - Peripheral nerves
 - Muscle



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Meiling JB, Cartwright MS. NMUS Applications in an EDX Laboratory. AANEM Spark. 2024



Dorsal Root Ganglion

Anterior Horn Cell

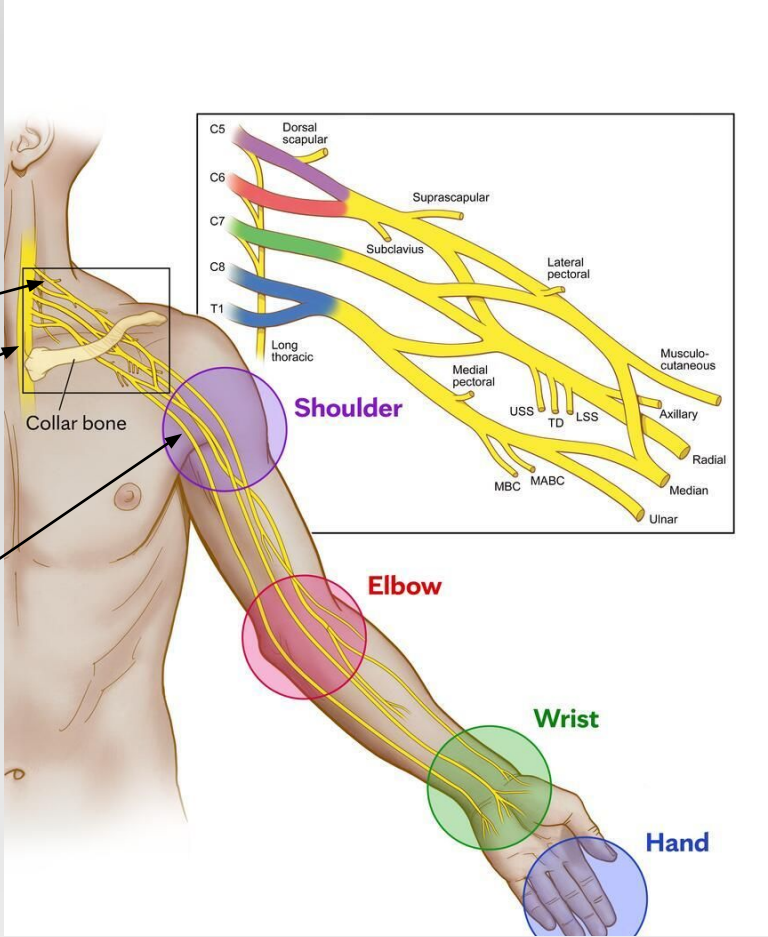
Nerve Root

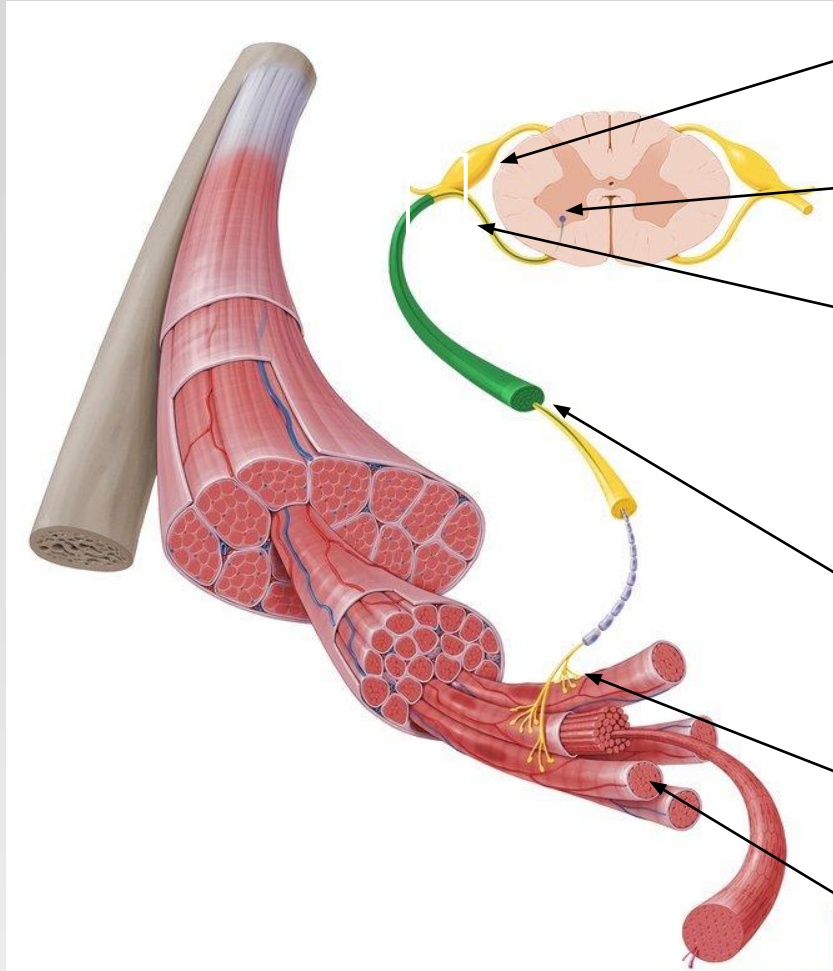
Plexus

Peripheral Nerve

Neuromuscular Junction

Muscle





Dorsal Root Ganglion

Anterior Horn Cell

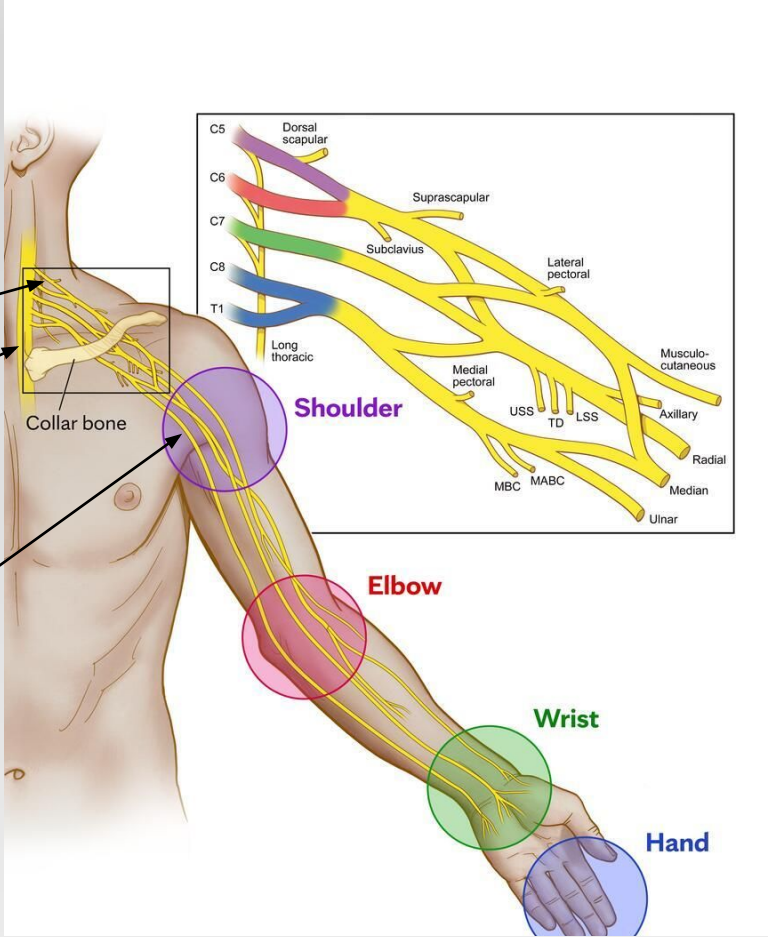
Nerve Root

Plexus

Peripheral Nerve

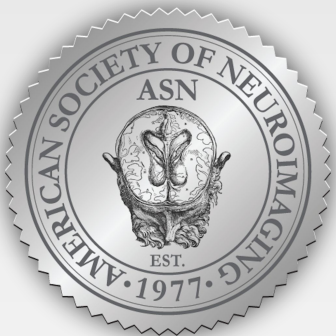
Neuromuscular Junction

Muscle



A close-up photograph showing a hand holding a white ultrasound probe over a patient's arm. The probe is positioned over a vein, and the skin is slightly moist. The background is blurred, showing a blue medical drape.

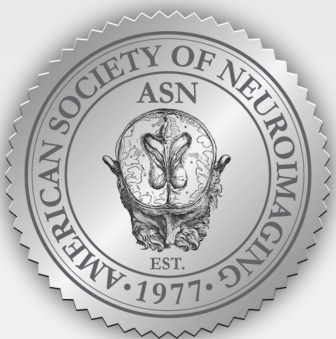
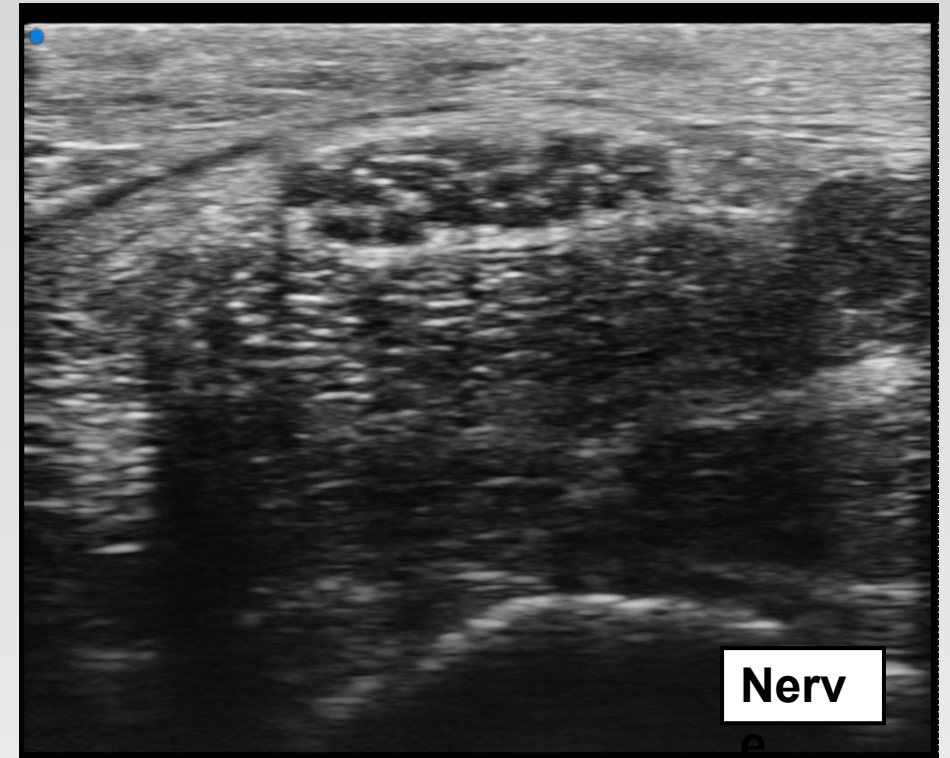
Neuromuscular Ultrasound of Nerve



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NMUS: Normal Appearance of Nerve

- Important to recognize the normal appearance of structures prior to trying to identify pathology
- **Normal Appearance of Peripheral Nerve**
 - Generally hyperechoic (bright) compared to the surrounding tissue
 - “Honeycomb” appearance
 - Hypoechoic (dark) oval-shaped internal structures (fascicles) surrounded by dense hyperechoic rim of epineurium surrounding the nerve
 - Non-compressible
 - No vascular flow with power Doppler



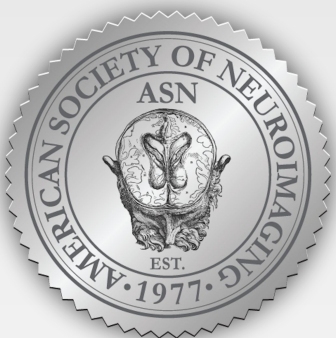
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Lawande AD et al. Role of US in evaluation of peripheral nerves. Indian J Radiol Imaging. 2014.

Images: from personal files of Meiling JB (on file with author)

NMUS: Entrapment Neuropathies

- The most common use of NMUS in the EMG lab
- **Presence of Entrapment**
 - NCS can identify slowing of a nerve response, indicative of entrapment
 - Entrapped peripheral nerves get “pinched” at the site of entrapment and have swelling proximal to this site
 - E.g. Median mononeuropathy at the wrist (carpal tunnel syndrome)



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Aseem F et al. NMUS in patients with CTS and normal NCS. Muscle Nerve. 2017.

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NMUS: Entrapment Neuropathies

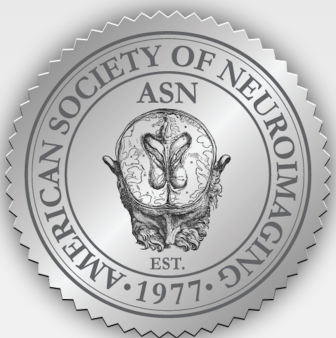
- The most common use of NMUS in the EMG lab
- **Presence of Entrapment**
 - NMUS visualizes the nerve and shows **focal enlargement** just **proximal to the site of entrapment**
 - NMUS visualizes other changes in the entrapped nerve, including **decreased echogenicity** (loss of sonographic brightness) and **loss of normal fascicular architecture**.
- This is particularly helpful in cases of mononeuropathies that are “non-localizable” based on EMG/NCS



Cartwright MS et al. EBM guideline: NMUS for the diagnosis of CTS. Muscle Nerve. 2012.

Alrajeh M, Preston DC. NMUS in electrically non-localizable ulnar neuropathy. Muscle Nerve. 2018.

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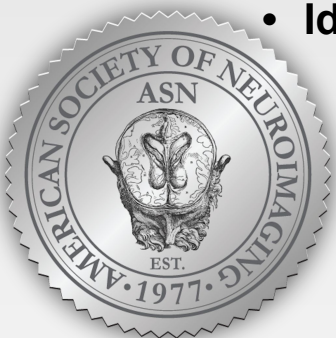
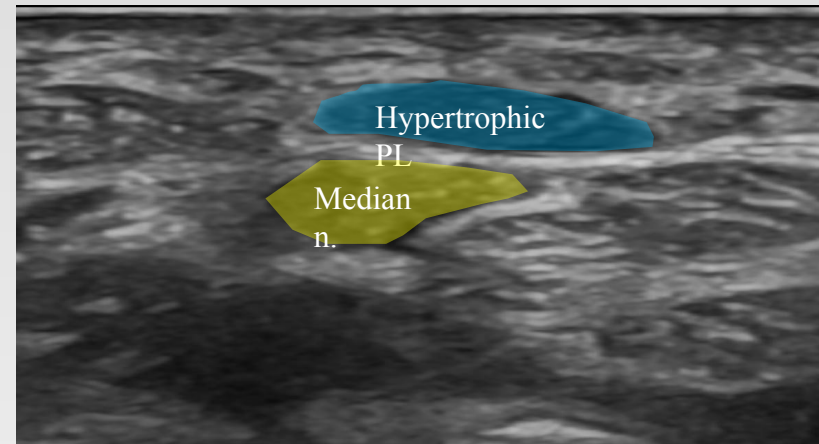
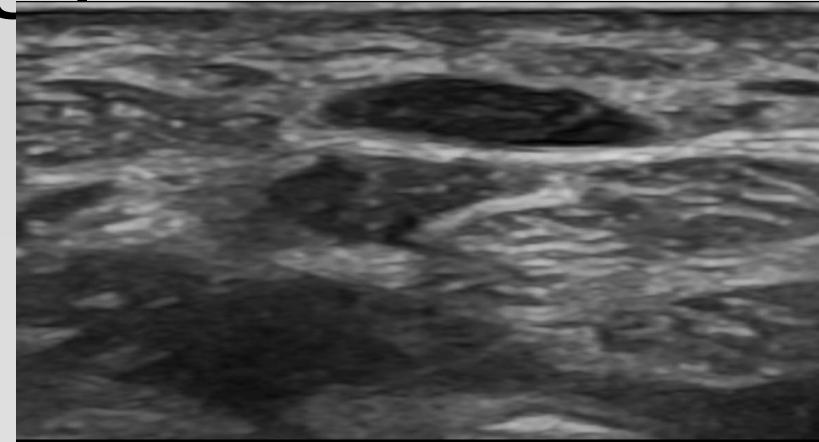


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NMUS: Entrapment Neuropathies

• Etiology of Entrapment

- Peripheral nerves can become entrapped for several reasons.
- Although NCS/EMG can identify the presence of entrapment, they cannot identify the potential cause for entrapment.
- NMUS may identify the etiology for peripheral nerve entrapment:
 - Extraneural ganglion cysts
 - Tenosynovitis
 - AV fistulas
 - Hypertrophic accessory muscles
 - Lipomas
- NMUS can also identify the presence of intraneural ganglion cysts
- **Identifying a potential etiology can help dictate treatment**



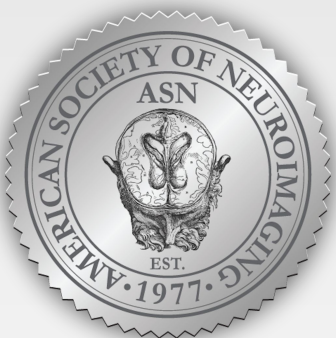
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Cartwright MS et al. EBM guideline: NMUS for the diagnosis of CTS. Muscle Nerve. 2012.

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NMUS: Traumatic Neuropathies

- History with EMG/NCS can diagnosis a likely traumatic mononeuropathy
- **Characterization of Traumatic Mononeuropathy**
 - NMUS visualizes the peripheral nerve and can give an anatomical description of the trauma
 - **Confirm presence of nerve continuity**
 - **Discover post-traumatic neuroma-in-continuity**
 - **Identify post-traumatic stump neuromas**

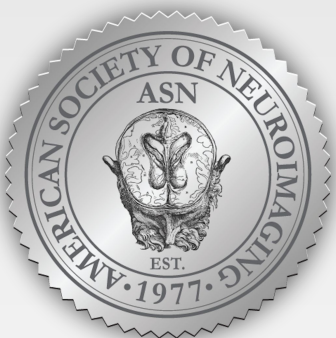
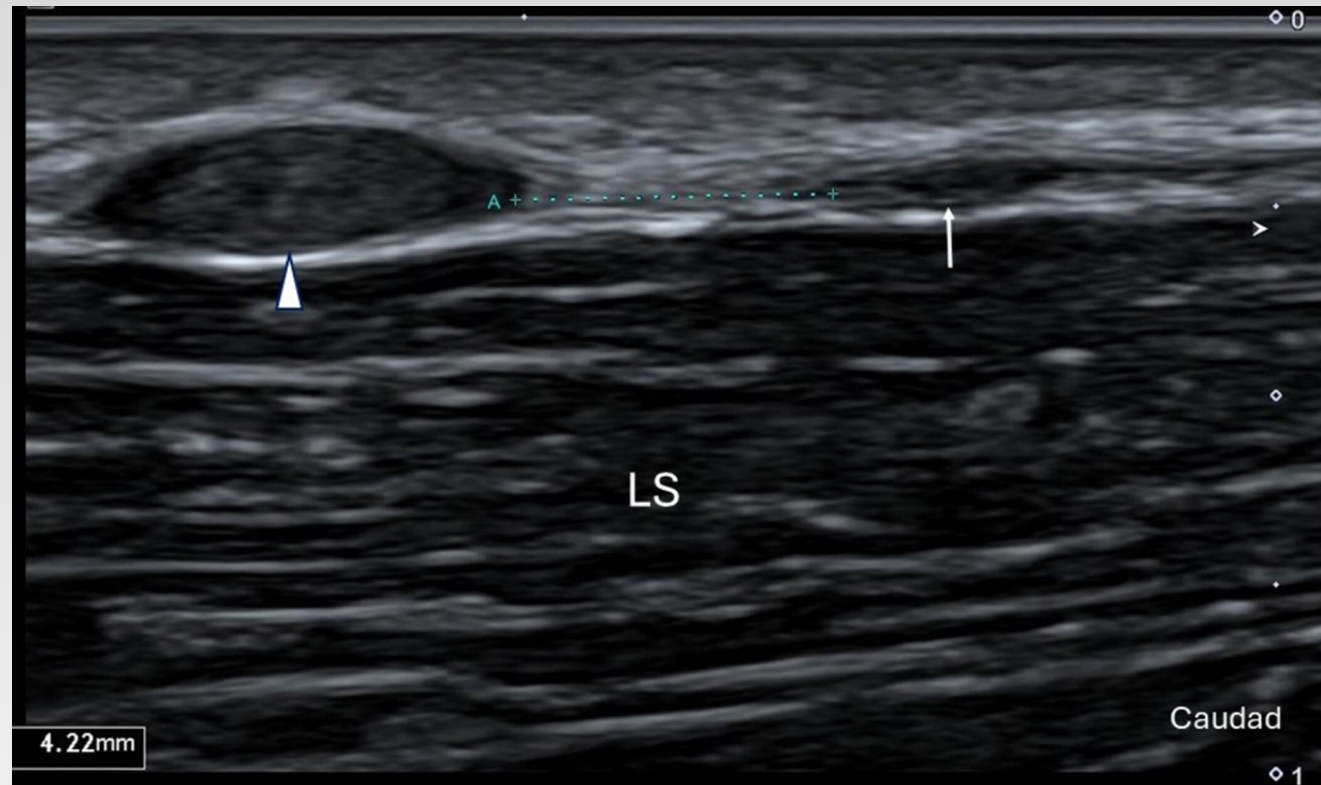


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Elshewi IE et al. Value of US assessment for traumatic nerve injury of the upper limb. J Ultrasound. 2023.

NMUS: Traumatic Neuropathies

- **Confirm presence of nerve continuity**
 - E.g. Spinal accessory transection



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Kopacz KS... Meiling JB. Diagnostic NMUS of
SAN... J Clin Ultrasound. 2025.

NMUS: Traumatic Neuropathies

- **Discover post-traumatic neuroma-in-continuity**
 - E.g. Iatrogenic sural neuroma after foot surgery

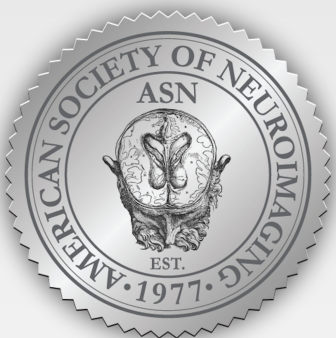
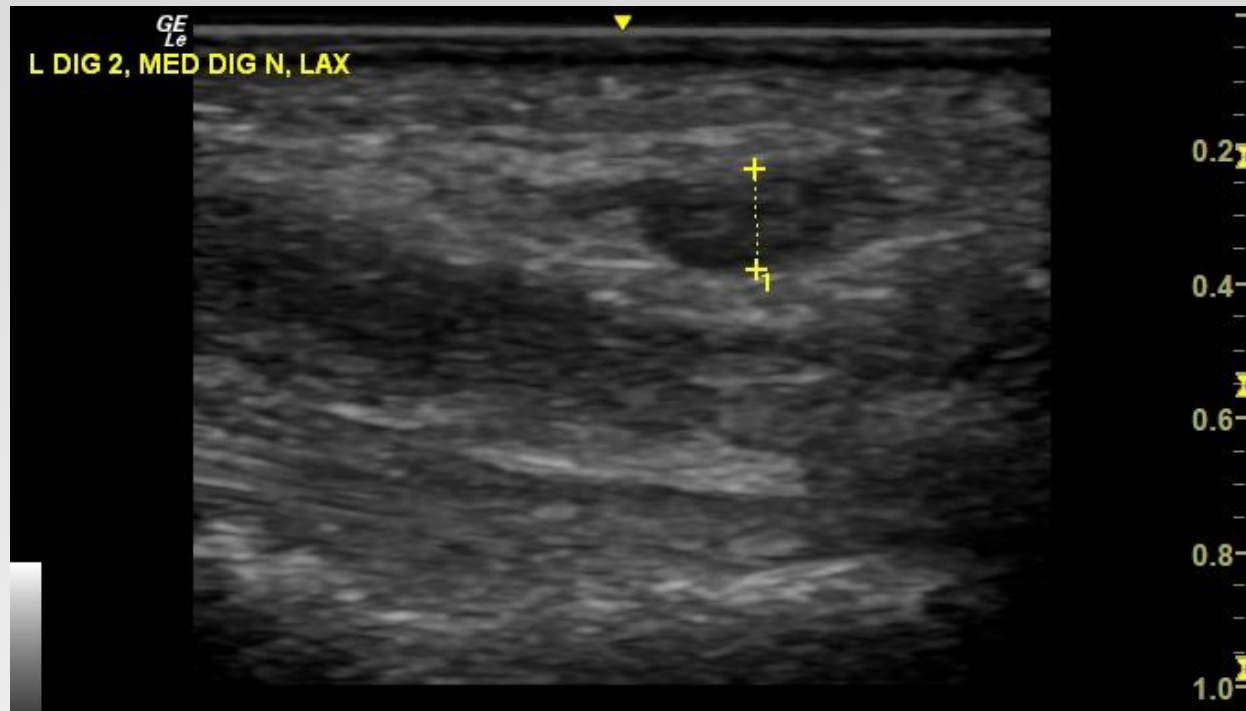


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NMUS: Traumatic Neuropathies

- **Identify post-traumatic stump neuromas**
 - E.g. Digital neuroma after traumatic finger amputation

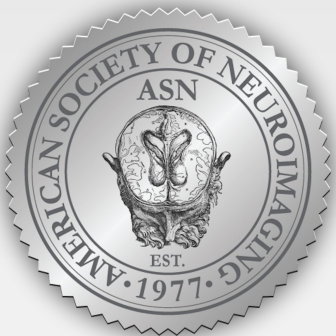
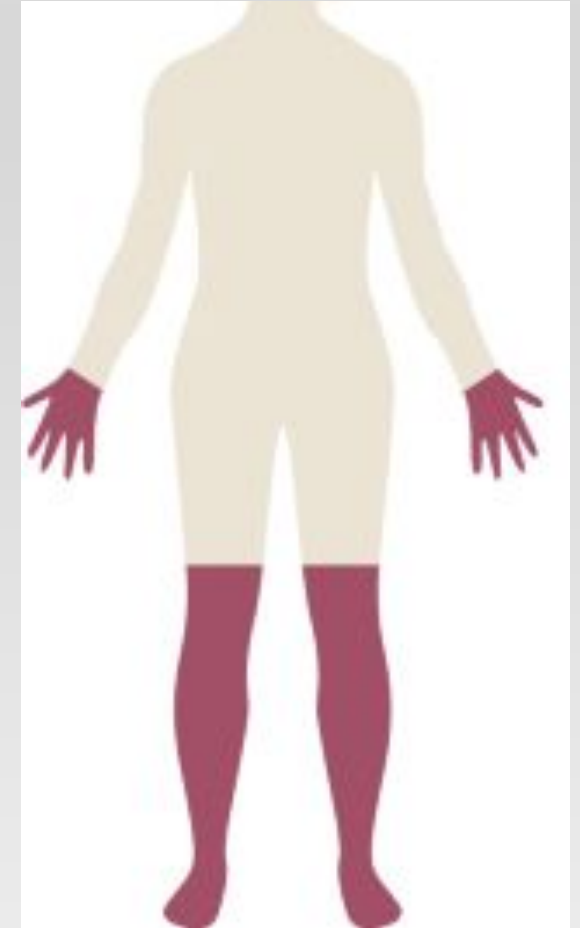


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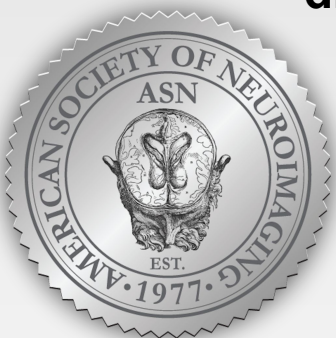
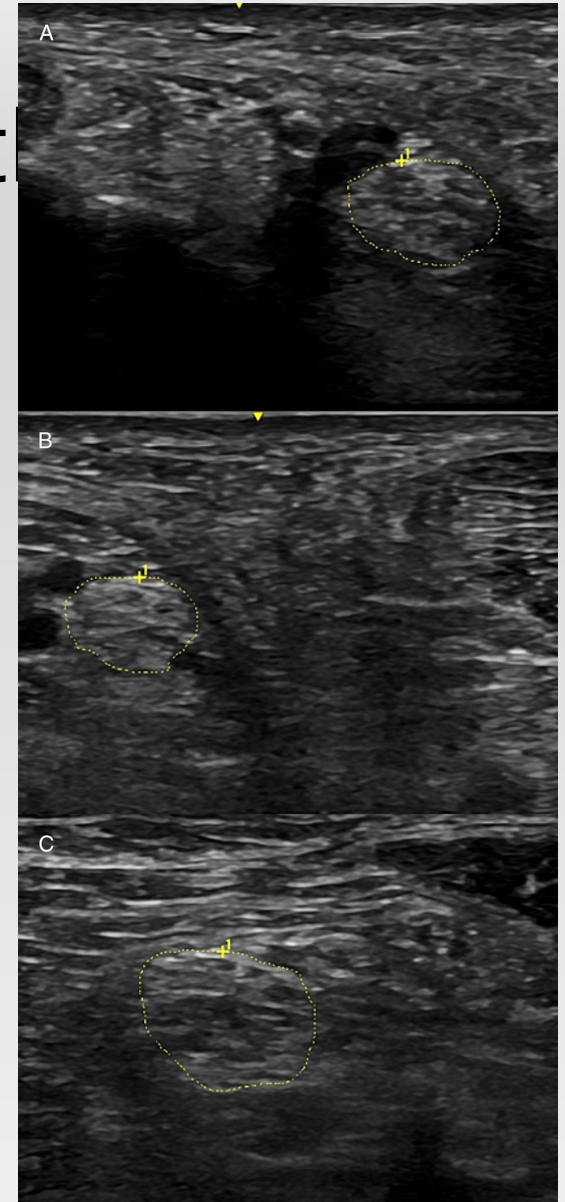
NMUS: Polyneuropathy

- EMG/NCS can identify the presence of a polyneuropathy and can usually discern whether it is axonal or demyelinating in nature
- NMUS has not yet proven useful in axonal-predominant polyneuropathies.
 - Such as diabetic or chemotherapy-induced



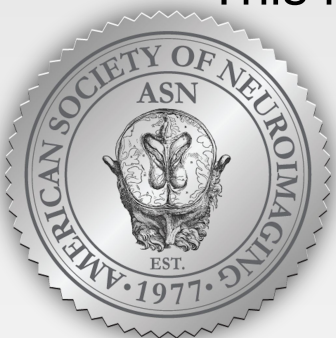
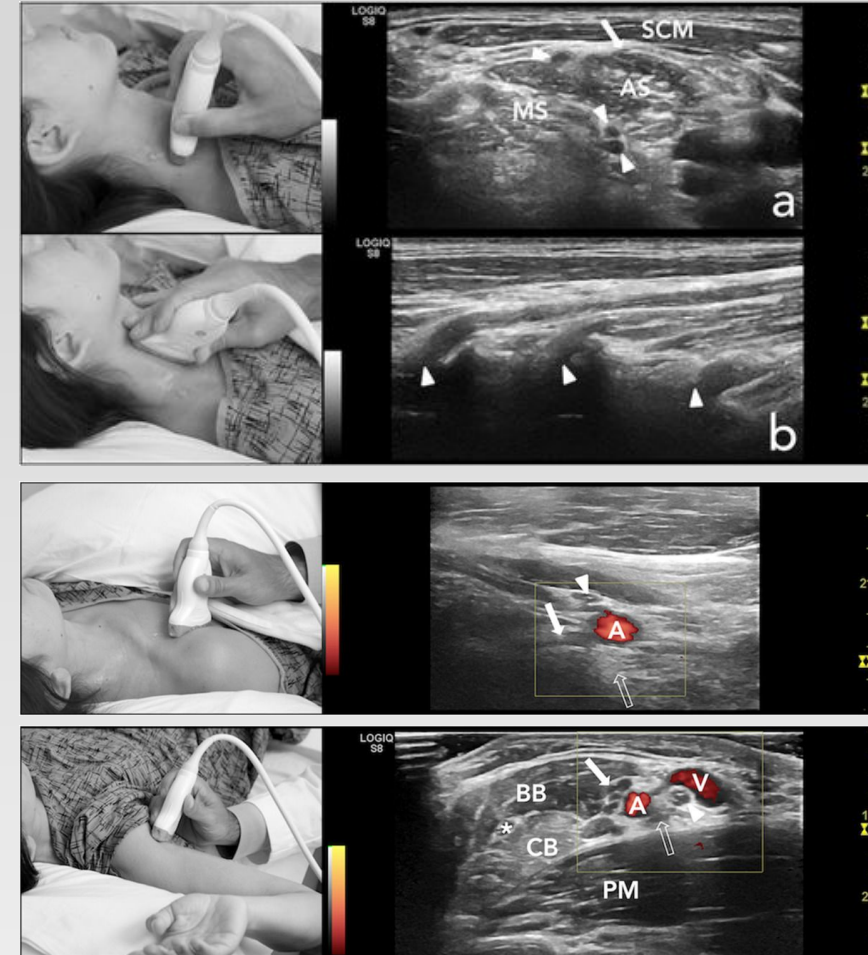
NMUS: Demyelinating Polyneuropathy

- **Characterization of a Demyelinating Polyneuropathy**
 - **Acquired (Inflammatory)**
 - Single or multiple focal patchy areas of nerve enlargement throughout the course of multiple nerves, commonly at non-entrapment sites, particularly proximal portions of nerve and in brachial plexus (CIDP, MMN, DADS, POEMS)
 - **Hereditary**
 - Uniform enlargement throughout the entire course of the nerve including the brachial plexus (CMT)
 - Focal areas of nerve enlargement at common entrapment sites (HNPP)
- In some cases of clinically suspected demyelinating polyneuropathy with indeterminate NCS, **NMUS can confirm the diagnosis with evident enlargement of the peripheral nerves**



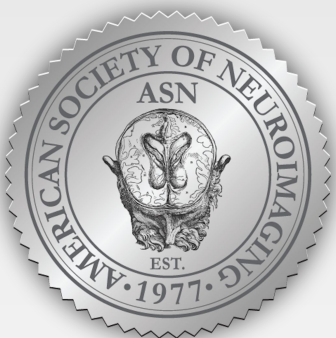
NMUS: Brachial Plexus

- NMUS can be used to view several portions of the brachial plexus to describe pathologies and injuries to the plexus
 - **Supraclavicular view:** Roots (C5-8), Trunks (Upper/Middle), Divisions
 - Other nerves: phrenic, vagus, spinal accessory, dorsal scapular, suprascapular
 - T1 nerve root and lower trunk are not readily seen.
 - **Infraclavicular view:** Cords (Lateral, Posterior, Medial)
 - **Axillary view:** Terminal nerves (Median, Ulnar, Radial, Musculocutaneous, and MAC)
 - Axillary nerve not readily seen
- This is an advanced technique.



NMUS: Brachial Plexopathy

- NMUS may illuminate enlargement of the brachial plexus in other acquired, traumatic, or hereditary conditions
 - **Hereditary:** CMT (diffusely enlarged plexus)
 - **Acquired:** CIDP (patchy portions of enlarged plexus)
 - **Traumatic:** Involved portions that are not discontinuous may be focally enlarged

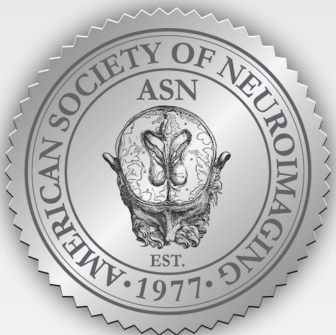
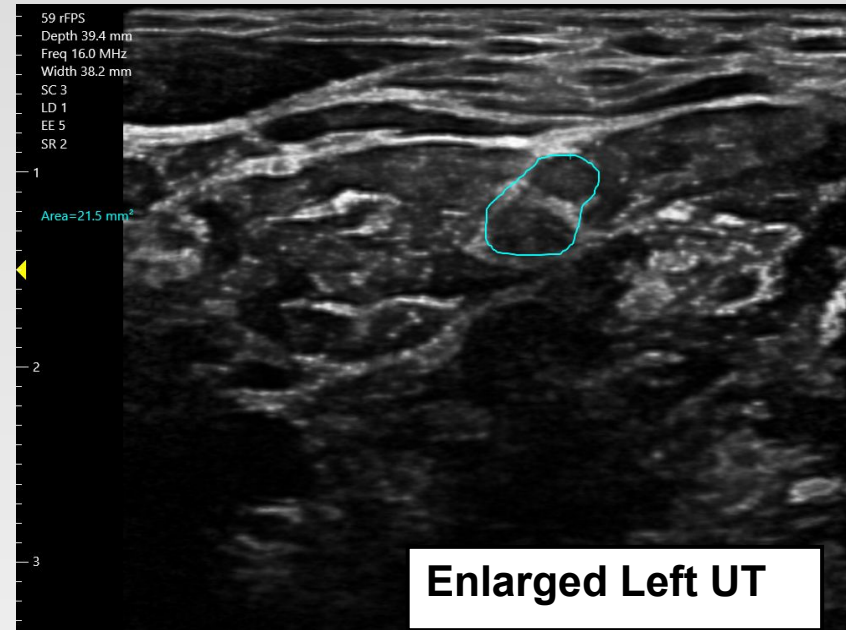
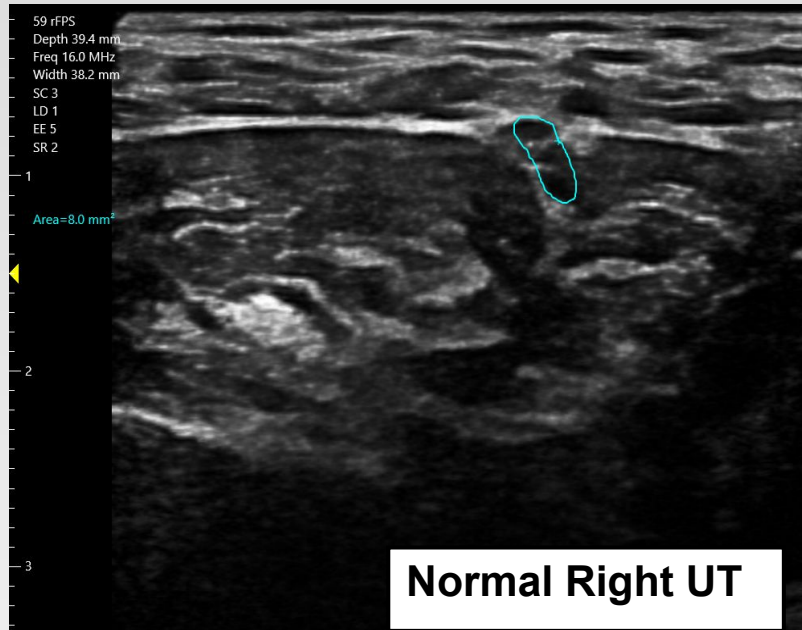


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Baute V et al. NMUS of the brachial plexus: A standardized approach. Muscle Nerve. 2018.

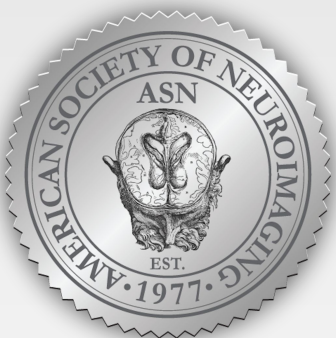
NMUS: Inflammatory Brachial Plexopathy

- Similar to inflammatory polyneuropathies, **inflammatory brachial plexopathies may show enlargement of portions of the brachial plexus with NMUS**
 - E.g. A patient with neuralgic amyotrophy and an enlarged left upper trunk



NMUS: Traumatic Brachial Plexopathy

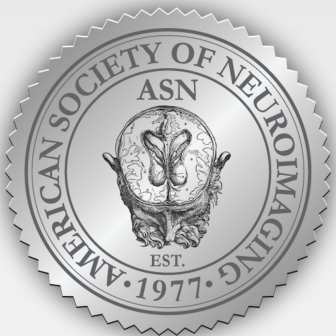
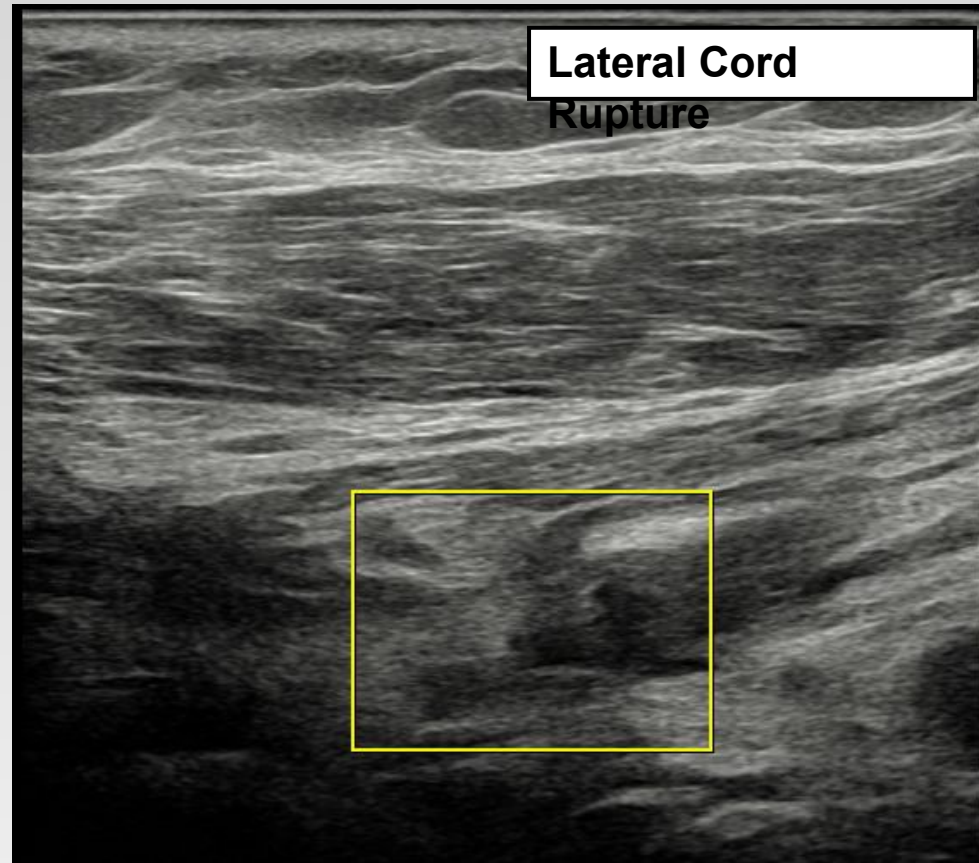
- EMG/NCS is the gold standard to evaluate for traumatic brachial plexopathies
- **Characterization of Traumatic Brachial Plexopathies**
 - Like in traumatic mononeuropathies, NMUS visualizes the plexus trauma and can give an anatomical description of the trauma
 - Confirm presence of nerve continuity
 - Discover post-traumatic neuroma-in-continuity
 - Localize the two separated nerve ends in cases of transection



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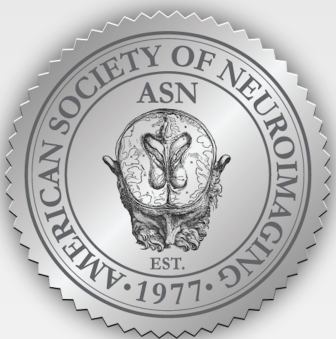
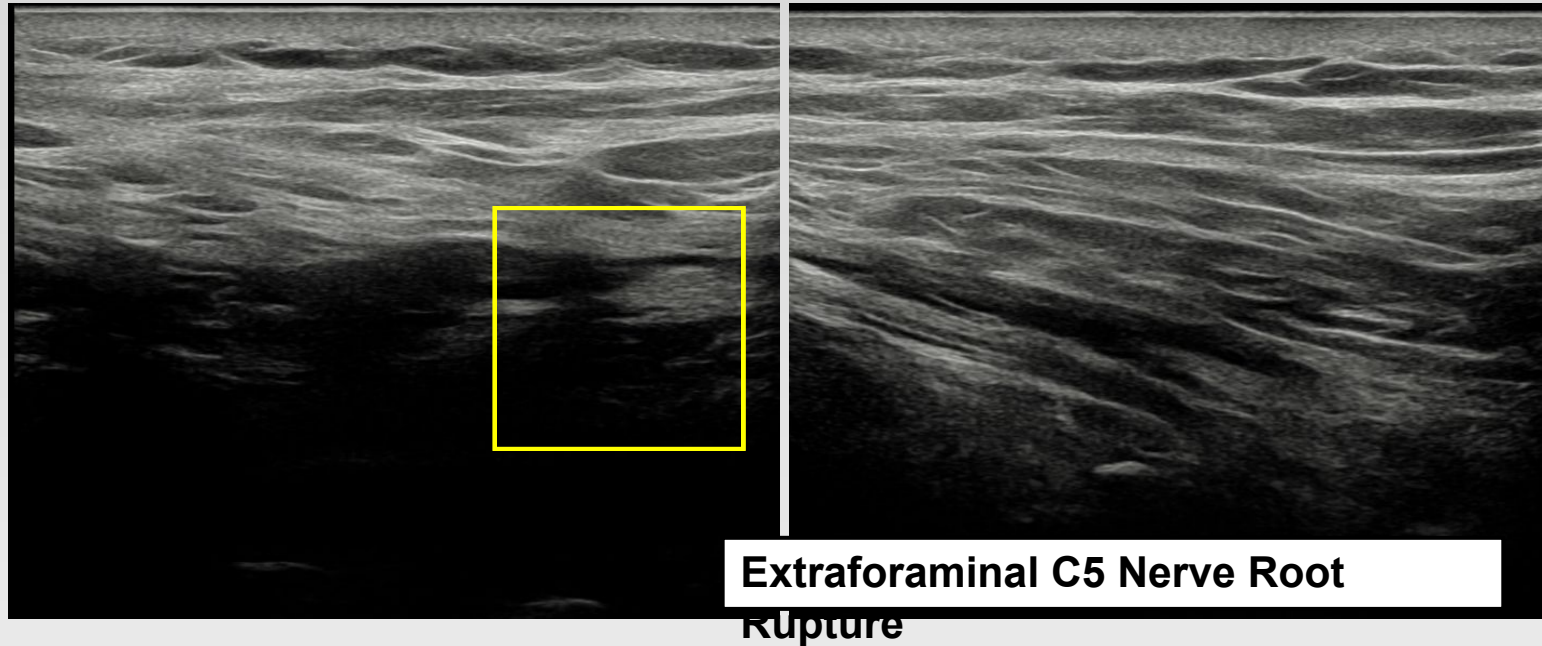
NMUS: Traumatic Brachial Plexopathy



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NMUS: Traumatic Brachial Plexopathy

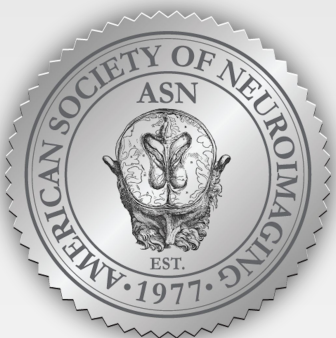


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NMUS: HFUS vs. UHFUS

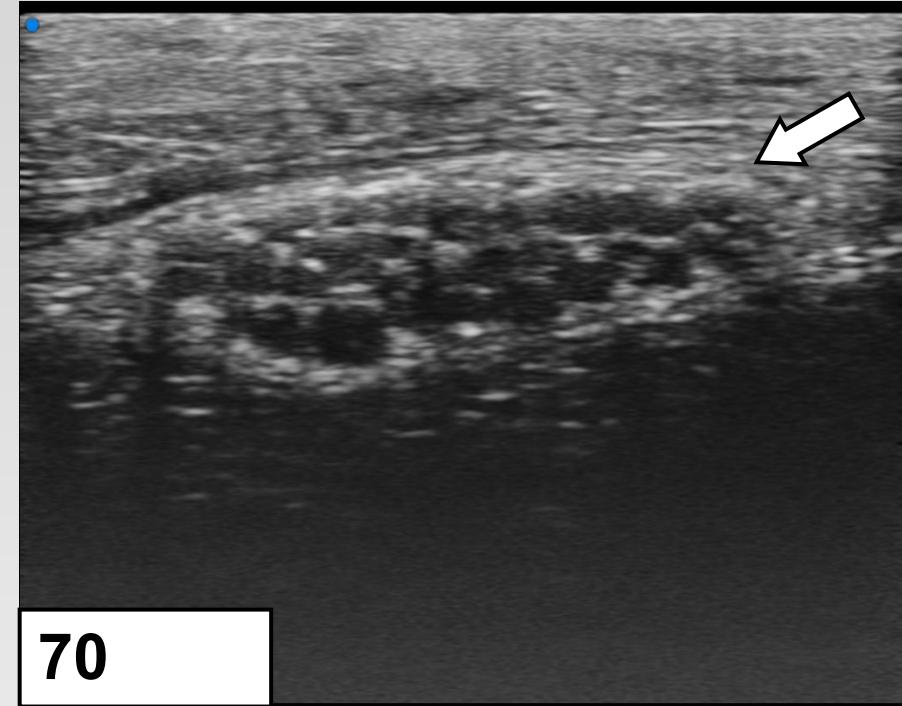
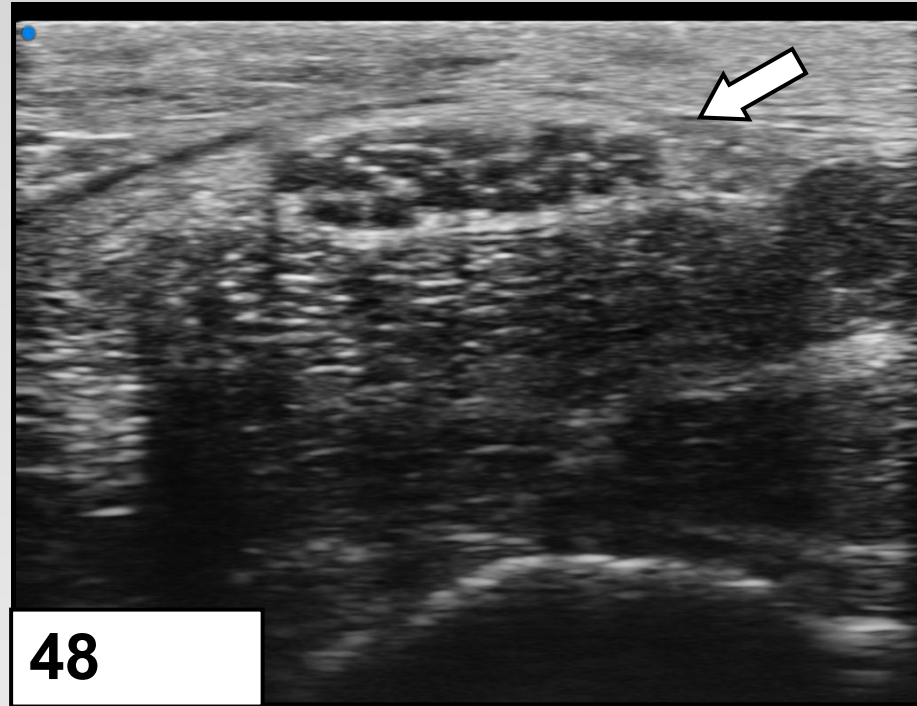
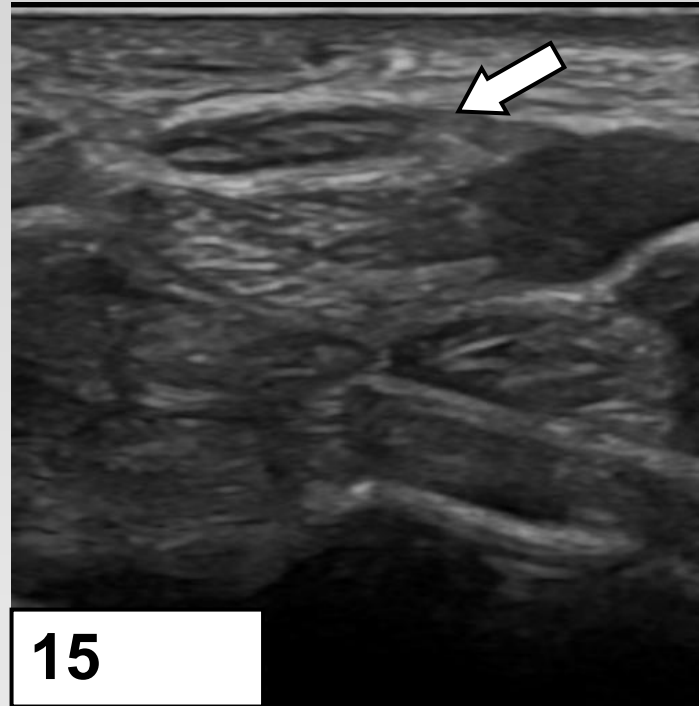
- Ultrasound frequency determines the depth of penetration
 - Lower frequency = longer sound waves = deeper penetration
 - Higher frequency = shorter sound waves = more superficial penetration
- Historically, NMUS performed with 12–18 MHz linear transducer – high-frequency ultrasound (HFUS)
- Recent advancements featuring 30- to 100-MHz transducers – ultras-high-frequency ultrasound (UHFUS) – enable:
 - Enhanced visualization of superficial peripheral nerves
 - Facilitate the quantification of nerve fascicles and their density



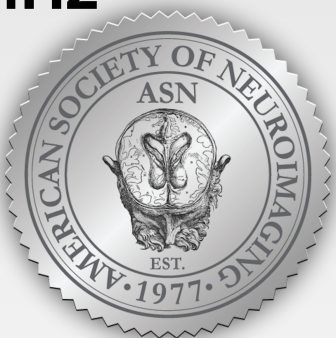
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Meiling JB, et al. UHFUS of fascicles in the common fibular, superficial fibular, and sural nerves. Muscle Nerve. 2024.

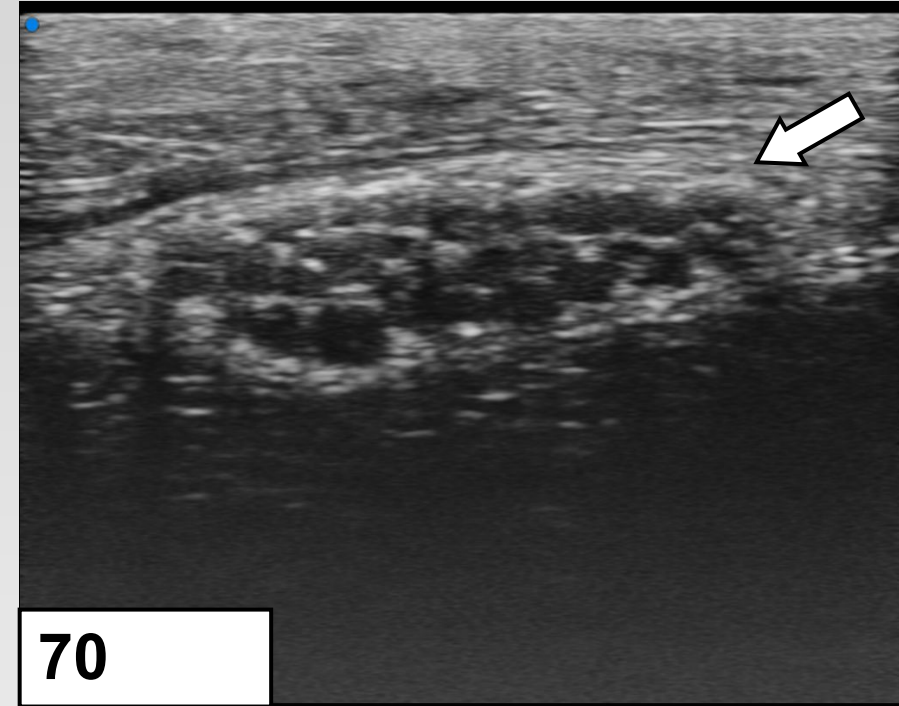
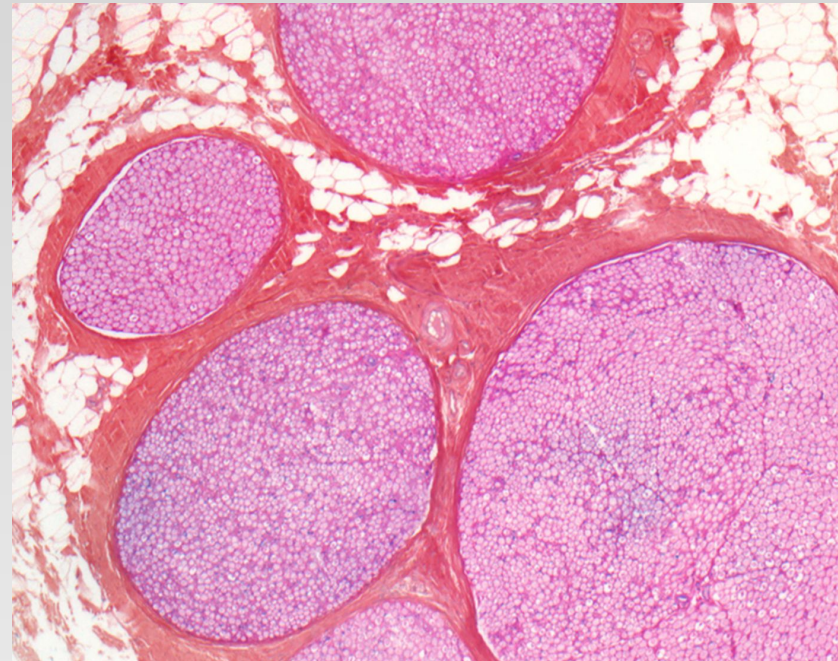
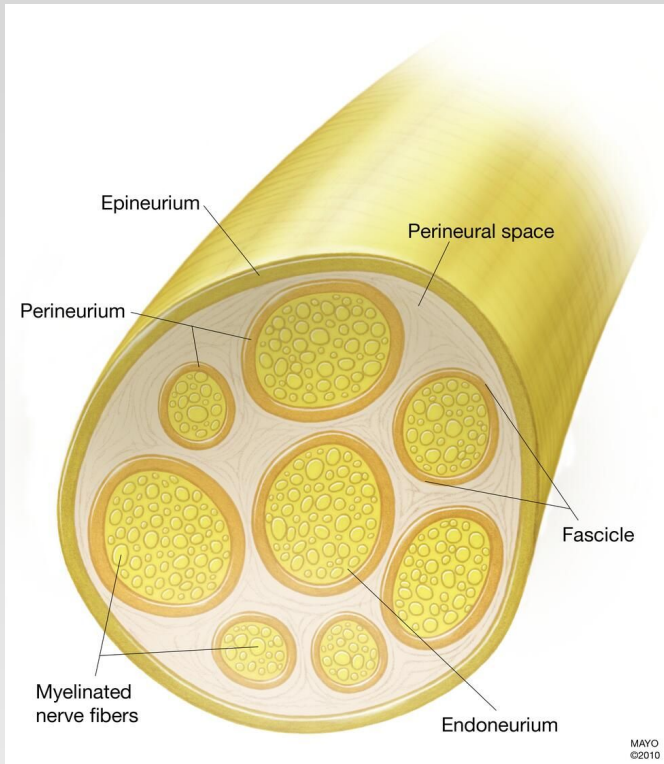
NMUS: Fascicles



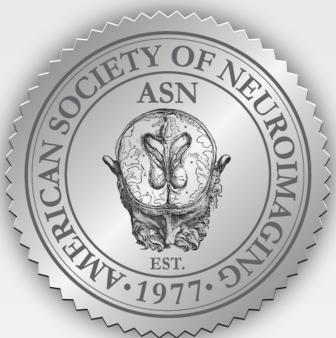
- With higher frequency transducers, the sonographic beam narrows, resulting in good lateral resolution and cleaner differentiation of nerve fascicles.



NMUS: Fascicles



- Ultra-high-frequency NMUS has improved some much that we can actually identify and quantify the number of visible fascicles within peripheral nerves.



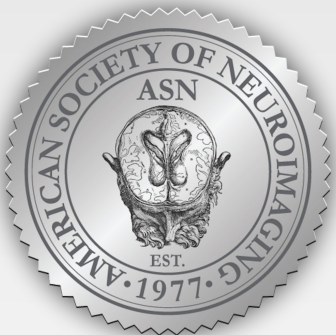
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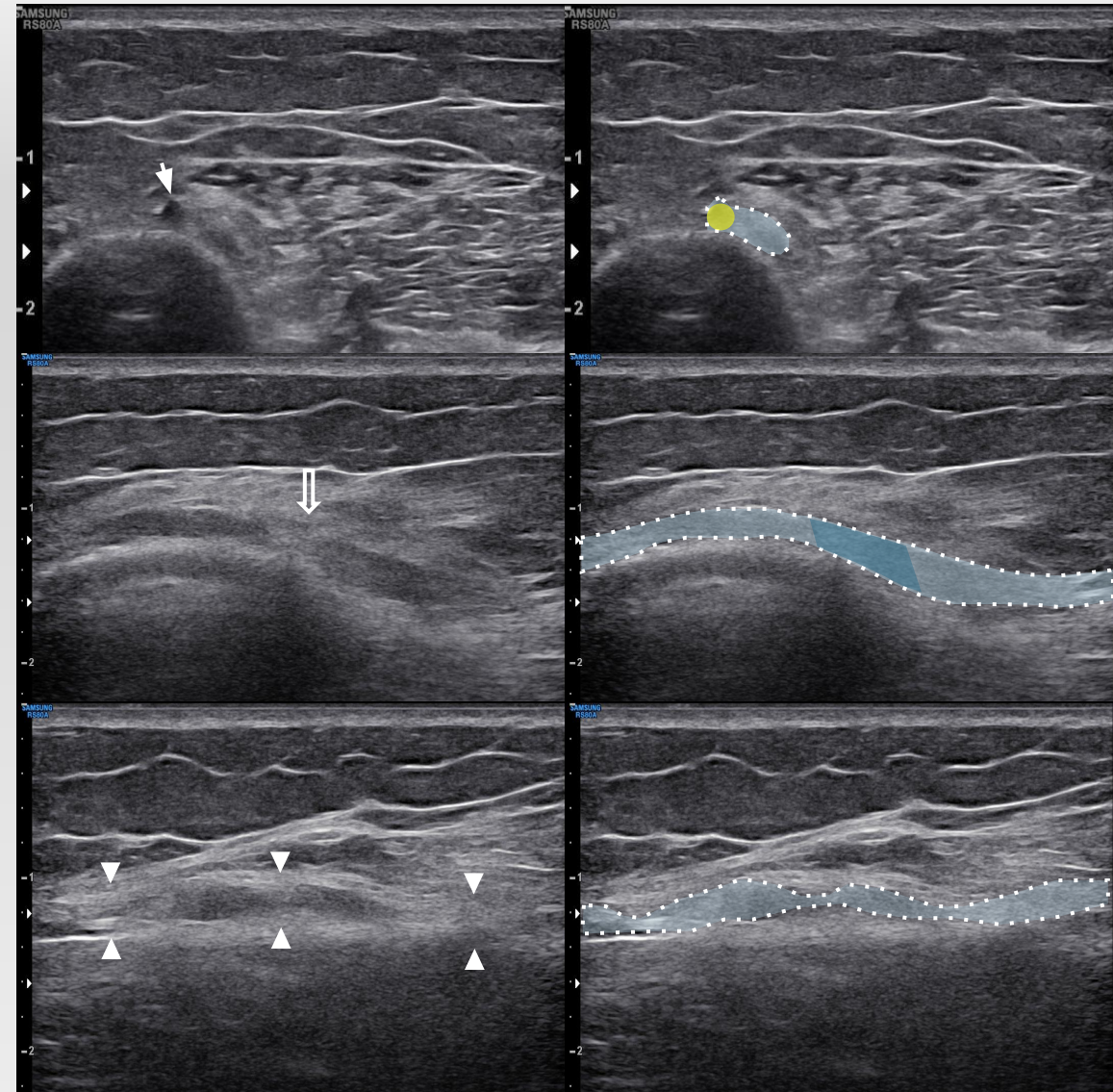
Meiling JB et al. UHFUS of fascicles in the ulnar and radial nerves. Muscle Nerve. 2024.

NMUS: Fasciculopathy

- Fasciculopathy refers to **1+ injured fascicles within the nerve**; neuropathy refers to nerve
- In Parsonage-Turner syndrome, lesions are not from external compression or trauma, rather, from **intrinsic fascicular changes secondary to autoimmune-mediated nerve injury**.
- Parsonage-Turner syndrome has pathognomonic US findings:
 - Fascicular enlargement
 - Fascicular entwinement
 - Neural torsion
 - Hourglass constrictions



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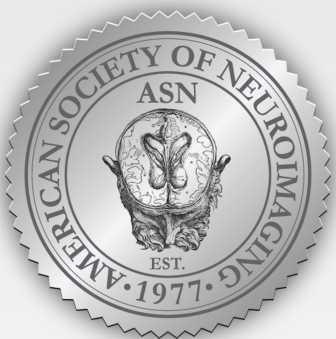


Arányi Z, et al. US identification of nerve pathology in neuralgic amyotrophy. *Muscle Nerve*. 2015.

Images: from personal files of Meiling JB (on file with author)

A close-up photograph showing a hand holding a white ultrasound probe against a patient's arm. The probe is in contact with the skin, which has some gel applied. The background is blurred, showing a blue medical drape.

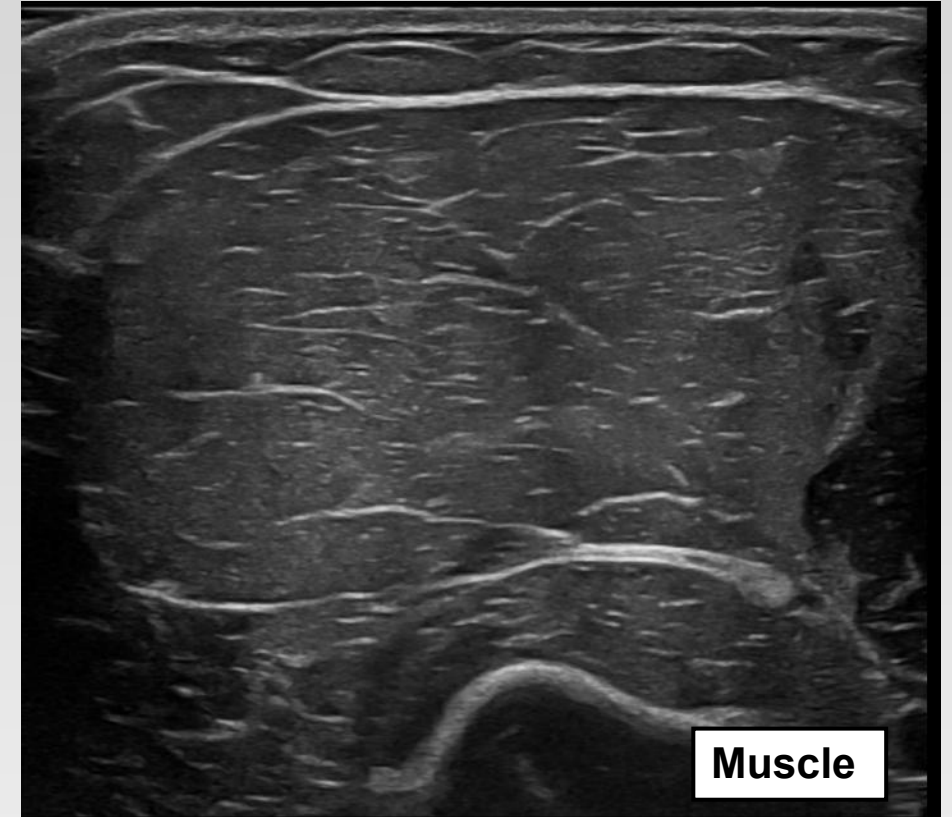
Neuromuscular Ultrasound of **Muscle**



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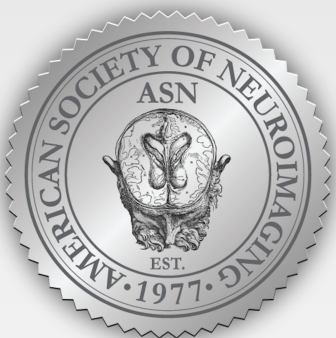
NMUS: Normal Appearance of Muscle

- Important to recognize the normal appearance of structures prior to trying to identify pathology
- **Normal Appearance of Muscle**
 - “Starry night” appearance
 - Hypoechoic (dark) muscle fibers interspersed with hyperechoic (bright) streaks or speckles of connective tissue throughout the muscle



Wijntjes J, van Alfen N. Muscle US: Present state and future opportunities. Muscle Nerve. 2021.

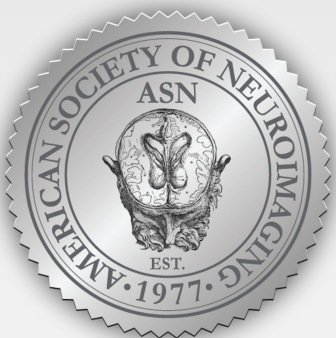
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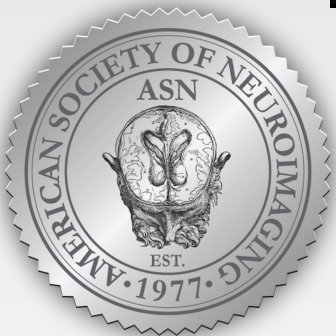
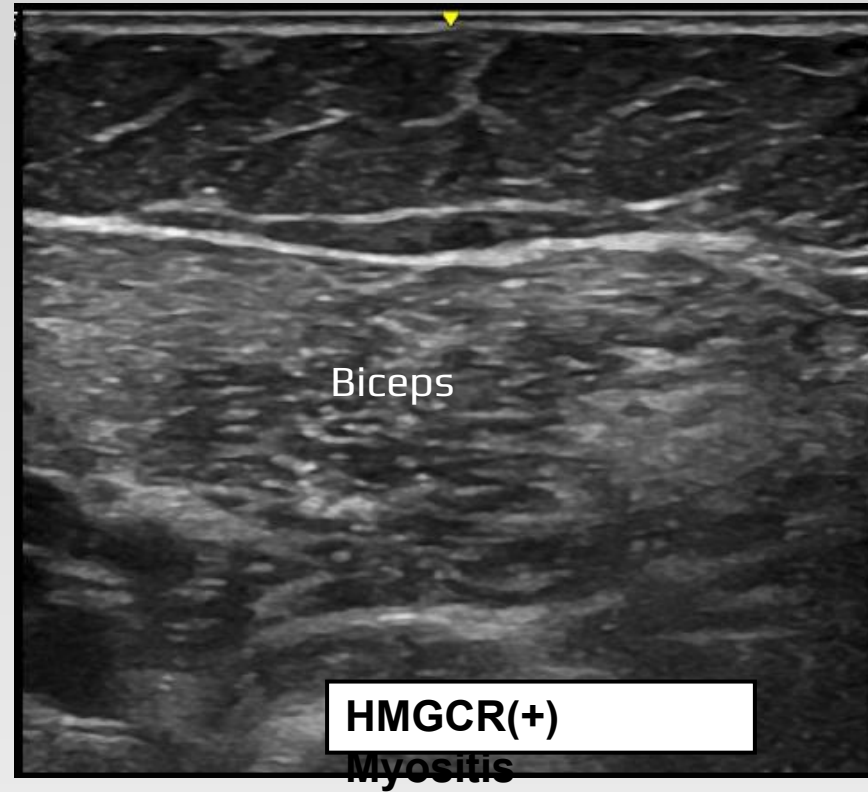
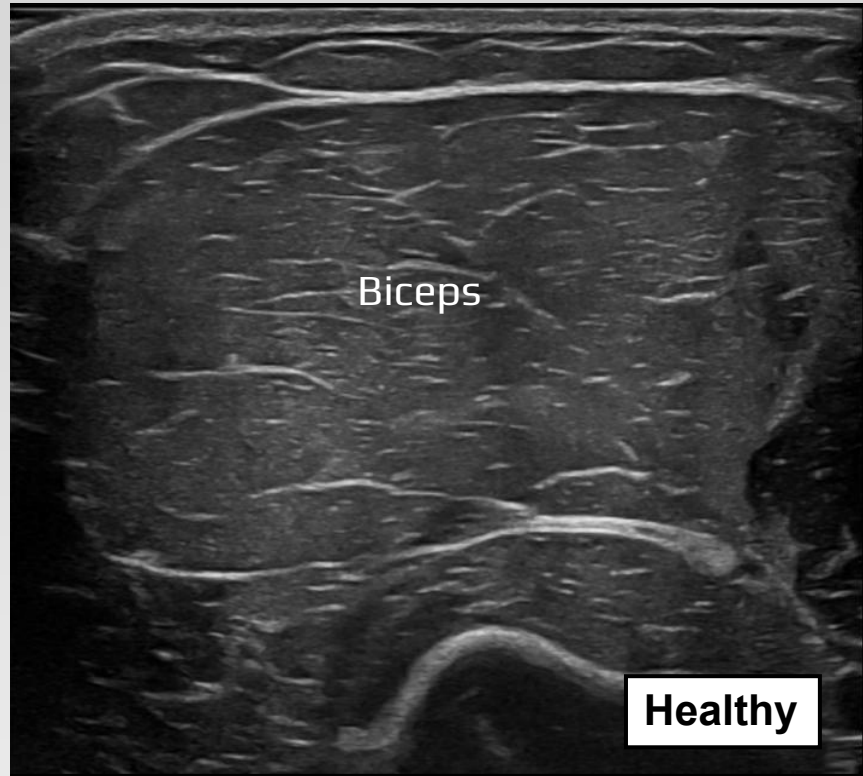
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NMUS: Muscle Disease

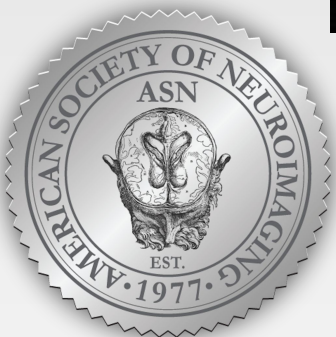
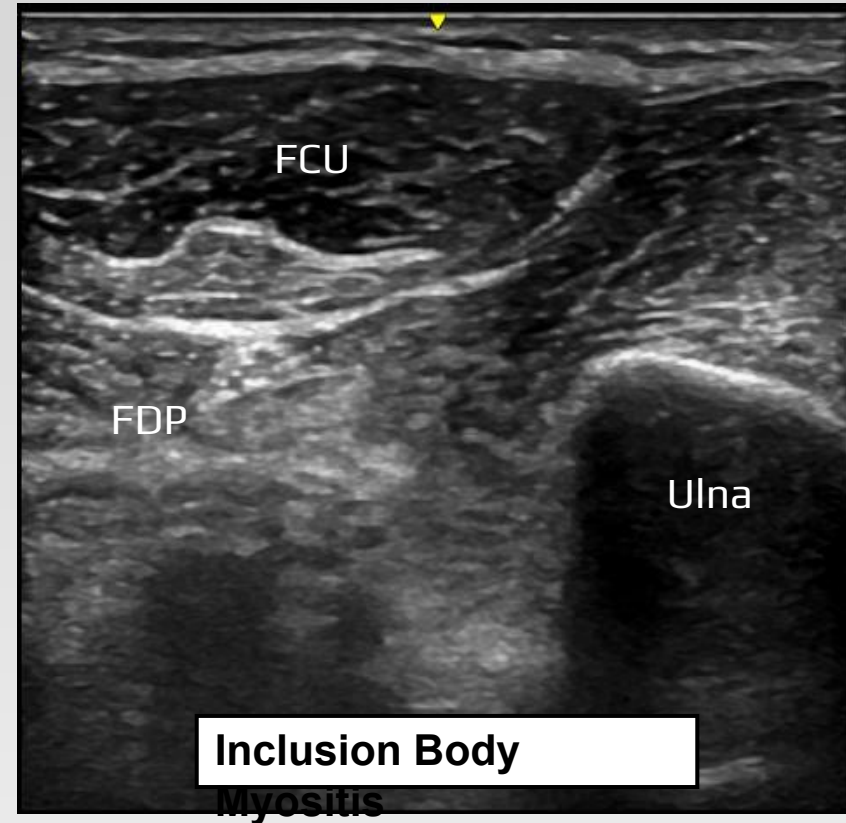
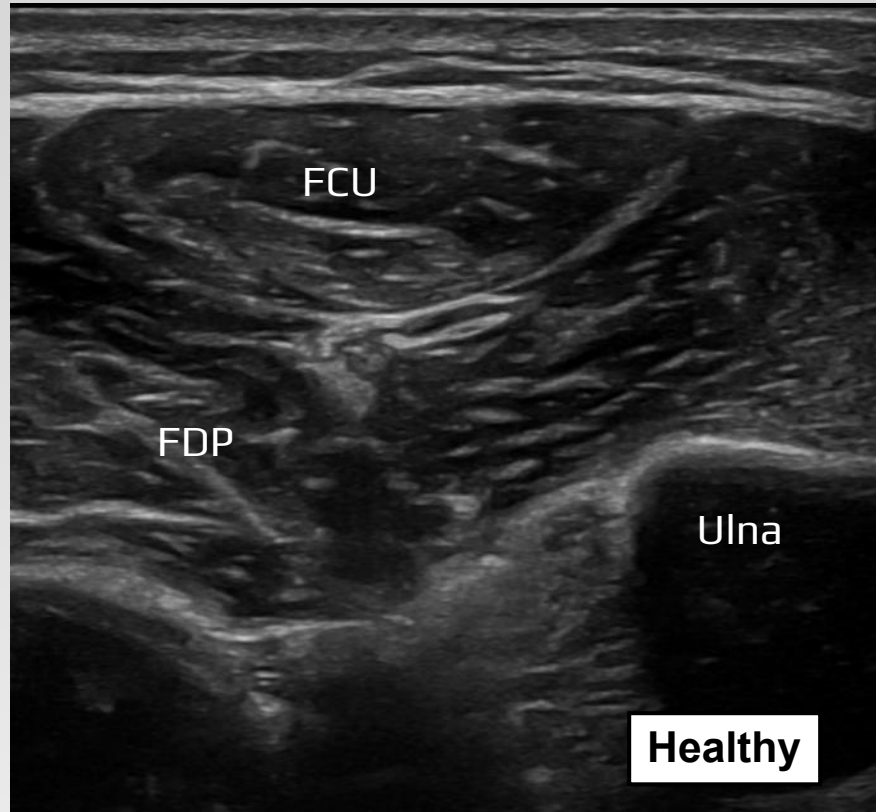
- Muscle disease includes muscular dystrophies, inflammatory myopathies, and non-inflammatory myopathies
- **Presence of Muscle Disease**
 - Correlation with needle EMG (Rapid R of small MUP; +/- fibs)
 - NMUS visualizes hyperechoic (bright areas) throughout the near-entirety of the muscle, fibrosis/fatty infiltration, and atrophy of muscles
- **Pattern of Involvement**
 - Muscle diseases generally follow patterns of muscle involvement
 - Needle EMG shows involvement by affected muscles with myogenic changes
 - NMUS visualizes pattern involvement to complement EMG



NMUS: Muscle Disease



NMUS: Muscle Disease

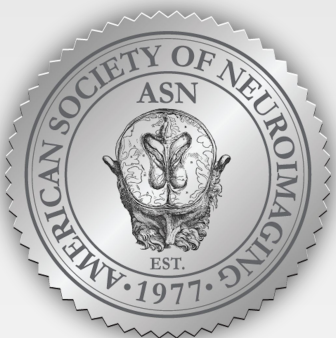
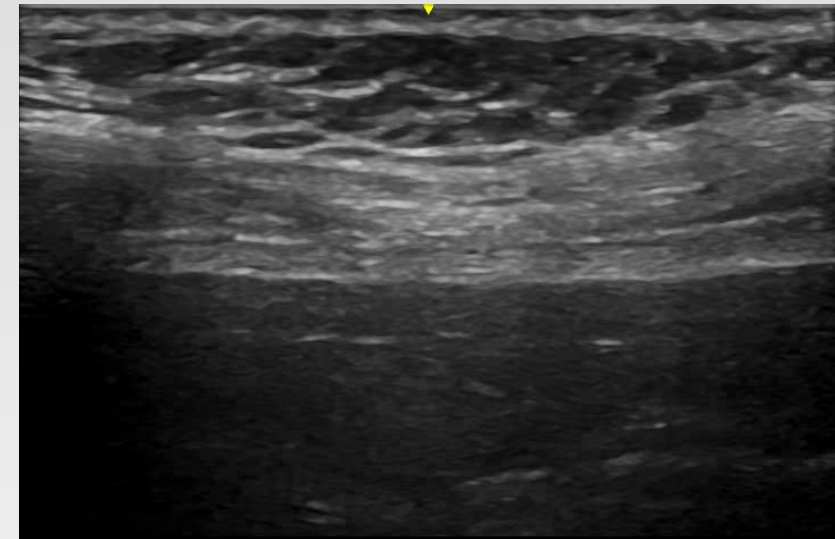


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Images: from personal files of Meiling JB (on file with author)

NMUS: Diaphragm

- **Assessment of Hemidiaphragm Muscle:**
 - Thickness
 - Echogenicity
 - Movement
 - Thickness ratio
- **NMUS can visualize changes in the hemidiaphragm muscle and movement in many conditions involving respiratory muscles**



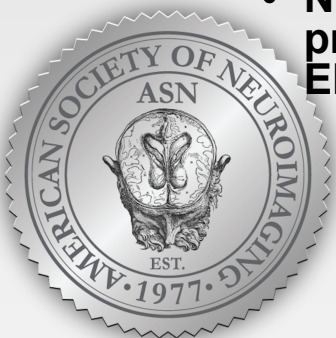
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Boon AJ et al. US in assessment of respiration. J Clin Neurophysiol. 2016.

Video and Image: from personal files of Meiling JB (on file with author)

NMUS: Motor Neuron Disease

- ALS is a progressive NMD classically affecting the UMN and LMN
- **Presence of Denervation**
 - Correlation with needle EMG (fibrillation potentials and RR of large MUP)
 - NMUS visualizes patchy denervation (bright areas) and atrophy of muscles
- **Fasciculation Detection**
 - LMN involvement = fasciculations (random muscle twitching)
 - When diagnosing ALS with EDX, there are (2) main criteria followed:
 - El Escorial Criteria (more specific)
 - Awaji Criteria (more sensitive – allows inclusion of fasciculations)
 - Needle EMG is used to detect fasciculations in muscles (even the tongue)
 - Limited by which small areas of the muscle are sampled
 - **NMUS visualizes the entire muscle, more easily detects the presence of fasciculations, and detects fasciculations early than EMG**



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Misawa S et al. US detection of fasciculations markedly increases diagnostic sensitivity of ALS. Neurology. 2011.

Video: from personal files of Meiling JB (on file with author)

NMUS: Pediatric NMD

- **Advantages of NMUS in Pediatrics:**

1. **Painless**

- Better tolerated than EMG or NCS (often needs sedation)

2. **Distribution of muscle involvement**

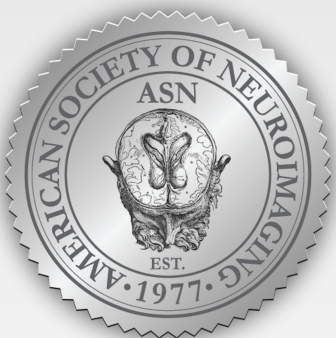
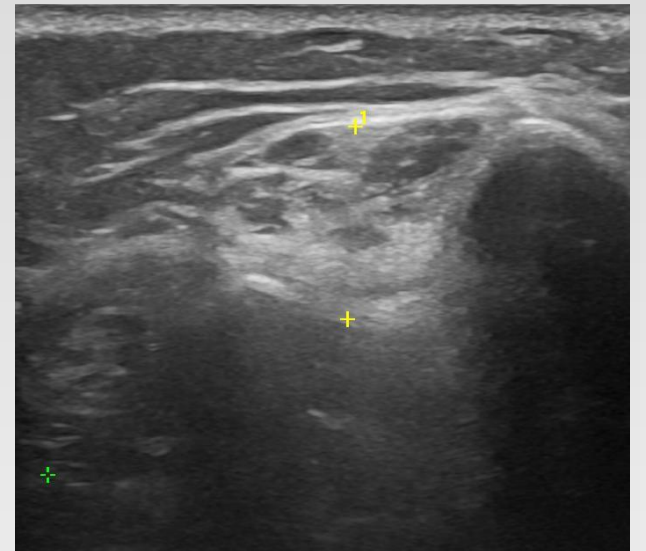
- Single or multiple muscles?
- Pattern of involvement?
- Diffuse or patchy involvement in single muscle?

3. **Quick & Flexible** with squirmy kids

4. **Follow changes over time**

5. Like NCS, **Easy to Use with Sedation**

- Does not require movement like EMG



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VanHorn TA, Cartwright MS. NMUS in the Pediatric Population. Diagnostics (Basel). 2020.

Image: from personal files of Meiling JB (on file with author)

NMUS: US-Guided EMG

- Typical EMG needle placement is based off:
 - Anatomical knowledge
 - Practical application of that knowledge (e.g. palpation of structures)
- Incorrect needle placement may lead to:
 - Incorrect diagnosis
 - Hazardous adverse events (e.g. needle into nerve, vessel, or organ)
- **NMUS can be used to guide the EMG needle into any skeletal muscle**



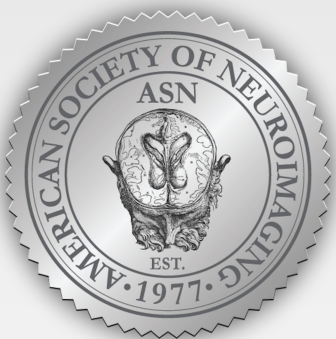
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Boon AJ et al. Accuracy of EMG needle placement in cadavers: Non-guided vs. US guided. Muscle Nerve. 2011

NMUS: US-Guided EMG

- Why US-guided needle EMG?
 1. **Unfamiliar muscles**
 2. **Adjacent muscles with (1) similar activation pattern but (2) different innervation**
 - E.g. Infraspinatus (suprascapular n.) and teres minor (axillary n.)
 3. **Non-adjacent muscles with (1) similar activation pattern but (2) different innervation**
 - E.g. Pronator teres (median n.) and pronator quadratus (AIN)
 4. **Unable to activate muscle**
 - E.g. AMS, sedated, plegia
 5. **Important nearby structures**
 - E.g. Diaphragm, lung, spleen, liver, etc.



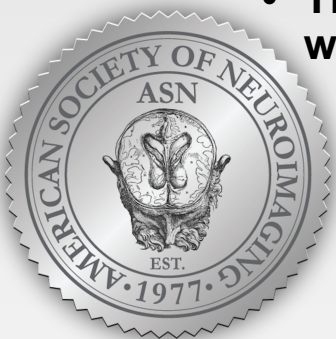
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NMUS: US-Guided EMG

- Why US-guided needle EMG?
 - Cervical spinal cord injuries are devastating and life changing
 - When incomplete injuries, there may be options for function improving reconstructive surgeries (ex. Tendon transfers)
 - For tendon transfers to work, you need to be absolutely sure you are in the muscles (or portions of muscle) you think you are in.
- **ECRL vs. ECRB**
 - If both work:
 - ECRB untouched wrist extension
 - ECRL-to-FDP tendon transfer assist with grasp
 - If only one works:
 - Leave functioning muscle for wrist extension
 - **There was no way to know which ECR (B vs. L) you are in without US**



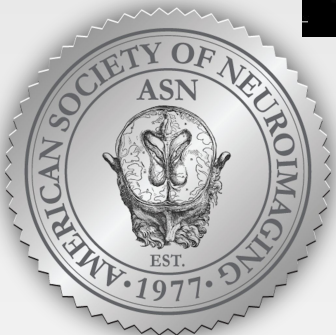
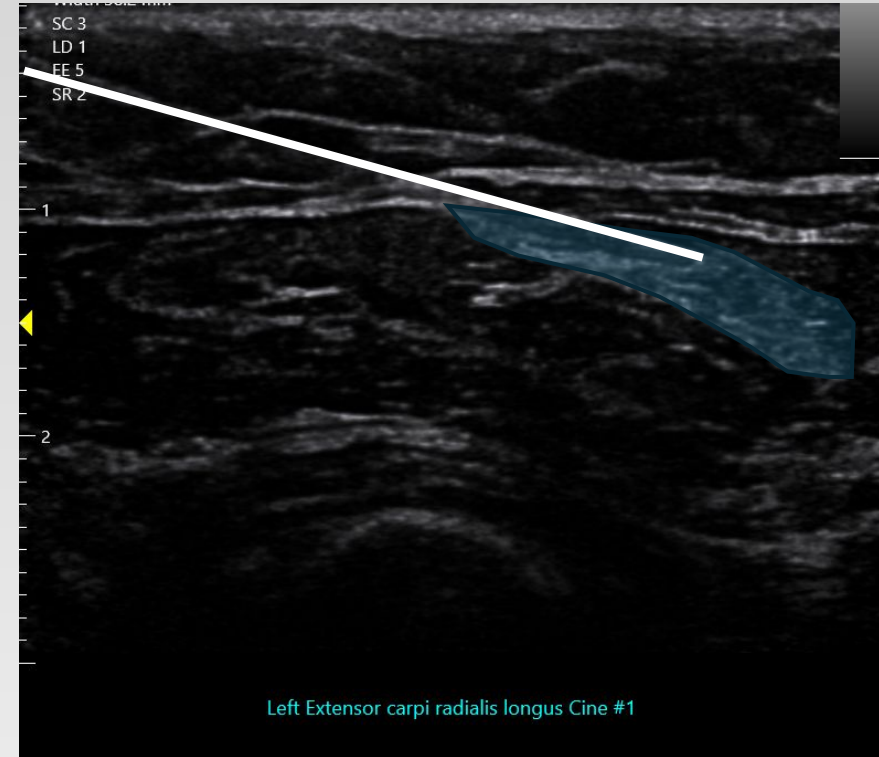
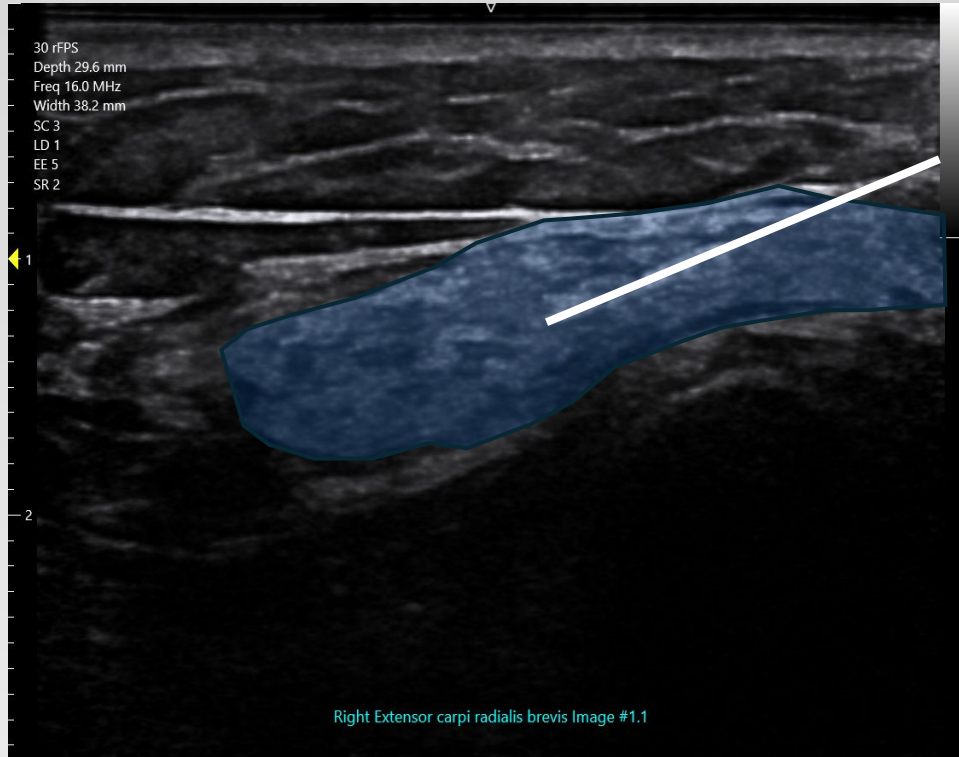
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Meiling JB, et al. Ultrasound-guided needle electromyography of the ECRL and ECRB... AM J Phys Med Rehabil. 2025.

NMUS: US-Guided EMG

Trace from 2nd dorsal compartment at wrist □ ECRB 1st □ ECRL 2nd



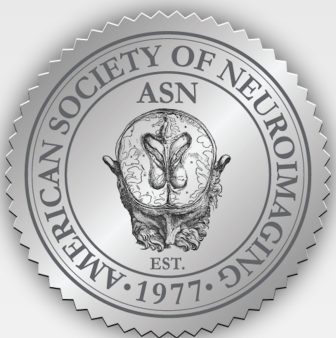
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Summary

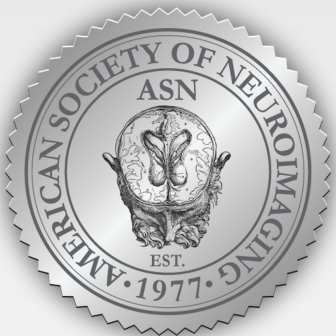
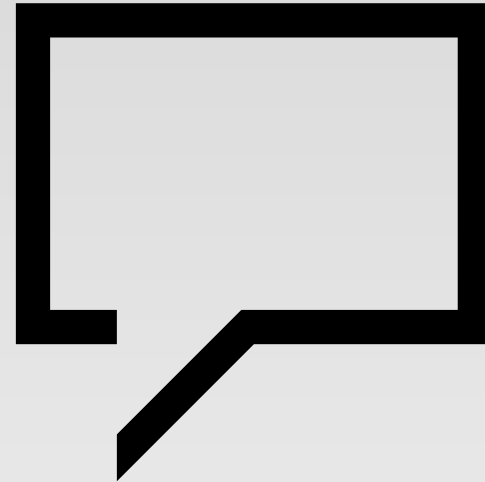
- NMUS is an adjunct or complement to the standard electrodiagnostic (EDX) examination, including nerve conduction studies (NCS) and needle electromyography.
- NMUS can be used to aid in the diagnosis of any of the following conditions:
 - Mononeuropathies
 - Demyelinating polyneuropathies
 - Brachial plexopathies
 - Motor neuron disease
 - Myopathies/Muscular Dystrophies
 - Hemidiaphragm paralysis
- NMUS is a non-invasive, painless imaging modality that is well-tolerated by children.
- NMUS can be used to provide EMG needle guidance for difficult to needle muscles.



Neuromuscular Ultrasound – New & Happening

Questions & Answers

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