Penn State College of Medicine
Continuing Education

Neurology for the Non-Neurologist

Friday, March 28, 2025

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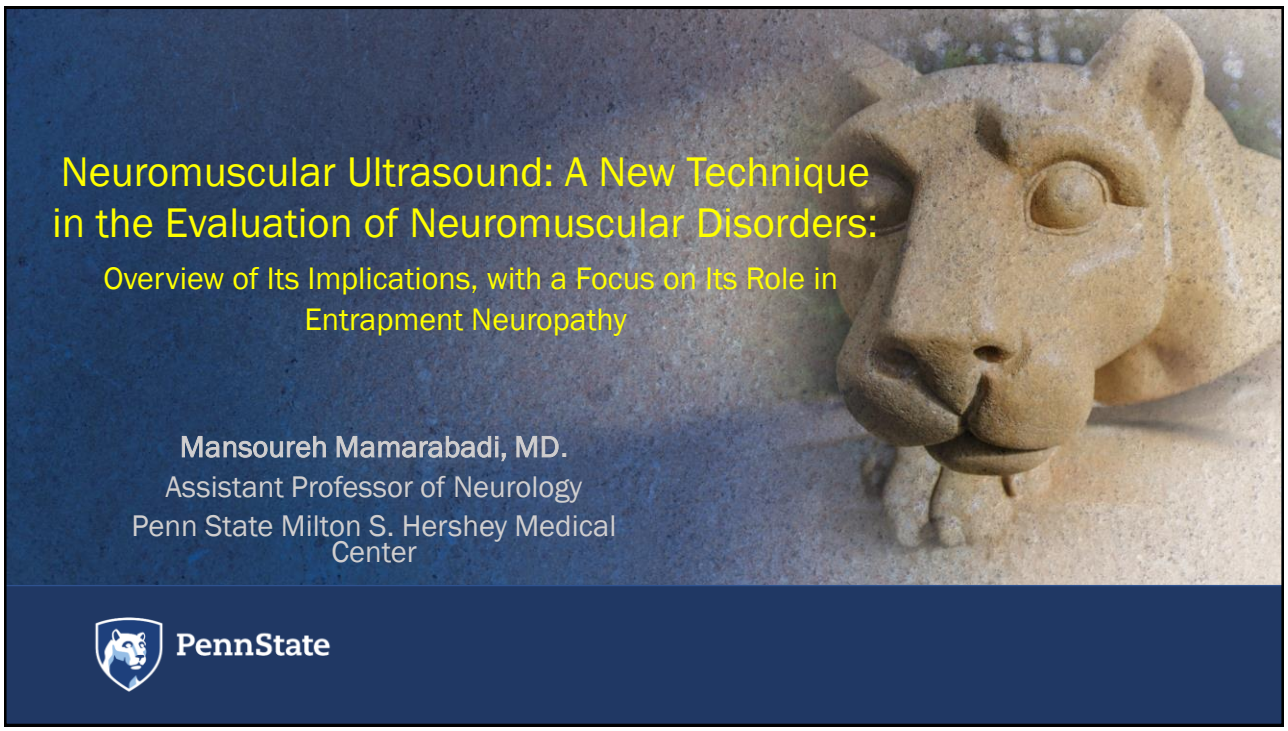

Neuromuscular Ultrasound: A New Technique in the Evaluation of Neuromuscular Disorders:

Overview of Its Implications, with a Focus on Its Role in Entrapment Neuropathy

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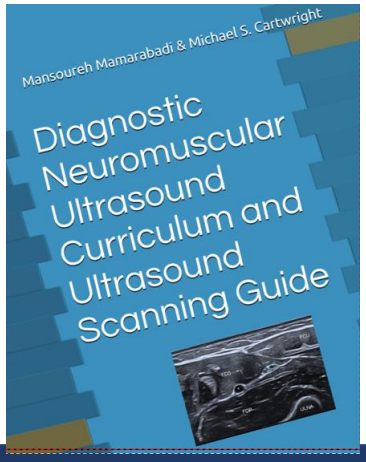
Disclosure

- Royalties from Kindle Direct Publishing



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Learning Objectives

- Become familiar with benefits and limitations of neuromuscular ultrasound (NMUS)
- When to use NMUS in neuromuscular medicine especially in entrapment neuropathies
- Why is NMUS Useful for Non-Neurologists?

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History and overview of NMUS

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History

- 1940s: US was initially developed for medical use
- 1980: first use of NMUS in young boys with Duchenne Muscular Dystrophy in by Heckmatt, and Leeman
- 1988: first ultrasonographic examination of peripheral nerves by Fornage
- 1991: first to assess the accuracy of NMUS for diagnosis of a focal nerve disease, carpal tunnel syndrome (CTS) by Buchberger and colleagues

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Introduction

Musculoskeletal (MSK) US vs NMUS:

- MSKUS is used to assess tendons, ligaments, joints, and bones
- NMUS focuses mainly on peripheral nerves and muscles and their surrounding structures.

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MRI vs. NMUS

MRI

- Advantage
  - ✓ High resolution images of both deep and superficial soft tissues and structures surrounded by bone
  - ✓ Better appreciation of the large area of the body
  - ✓ Superior at providing tissue contrast and imaging masses
  - ✓ Easier for non-specialist to interpret images
- Disadvantage
  - ✓ Expensive
  - ✓ Time consuming
  - ✓ Static imaging
  - ✓ Not tolerated well in children, during pregnancy, claustrophobic patients
  - ✓ Interference with metallic objects

NMUS

- Advantage
  - ✓ Rapid
  - ✓ Imaging in continuity (without slicing)
  - ✓ Ease of side-to-side comparisons
  - ✓ More dynamic capabilities and interactive patient evaluations
  - ✓ Significantly less cost
  - ✓ No interference with metallic objects or pacemakers
  - ✓ Well tolerated in children, pregnant and claustrophobic patients
  - ✓ No known contraindication to the use of diagnostic ultrasound
- Disadvantage
  - ✓ Resolution is limited for deep structures, structures around the bone and obese body habitus
  - ✓ Operator dependent

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NMUS vs Electro-diagnostic Studies

EDx

- ✓Physiologic assessment
- ✓Sensitive in detecting peripheral neuropathies in every age group
- ✓Invasive
- ✓Less useful in pediatric age group
- ✓Affected by external factors (temperature, patient's effort)

NMUS

- ✓Anatomic assessment
- ✓Confirming accuracy of needle placement in challenging muscles
- ✓Localizing lesions or confirming the localization
- ✓Identifying anatomic variants
- ✓Non-invasive
- ✓Not affected by factors that can complicate NCS/emg (temp or patient's effort)

Clinical Application of NMUS in Neuromuscular Medicine

- Neuropathies
- Motor neuron diseases
- Myopathies (hereditary and acquired)
- Diaphragm paresis

NMUS in Peripheral Nerve Evaluation

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Common clinical applications of nerve ultrasound:

- ✓Screening for entrapment mononeuropathy
  - Distal or proximal median neuropathy
  - Ulnar neuropathy at the wrist or elbow
  - Radial neuropathy
  - Fibular neuropathy at fibular head
  - Tibial neuropathy and tarsal tunnel syndrome
  - Meralgia paresthetica
- ✓Diagnosing polyneuropathies (hereditary and acquired)
- ✓Traumatic neuropathies
  - Transected nerves, fibrosis, pseudoaneurysm, neuroma, bone compression
- ✓Surveying for tumor progression

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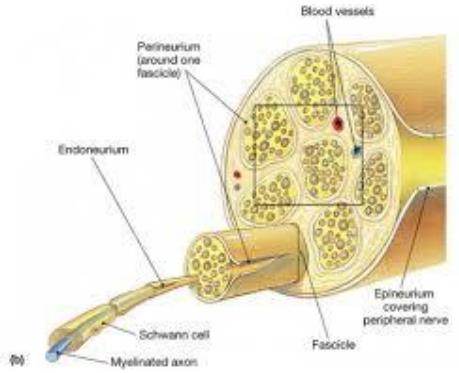
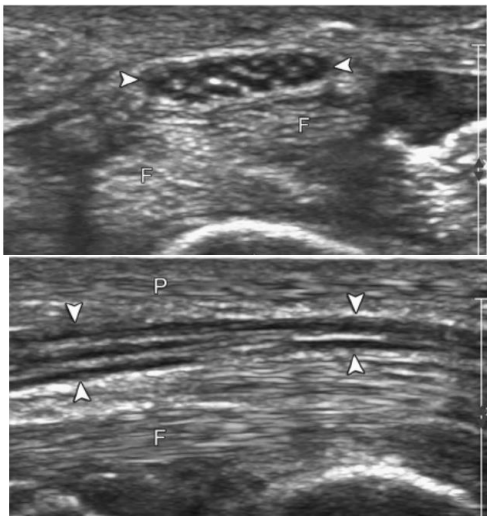
Nerve Ultrasound Imaging





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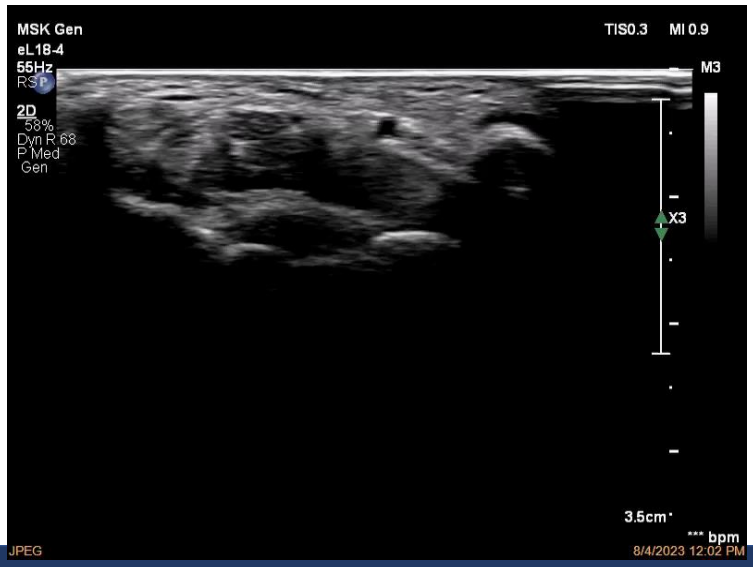
Ultrasound Assessment of the Median Nerve



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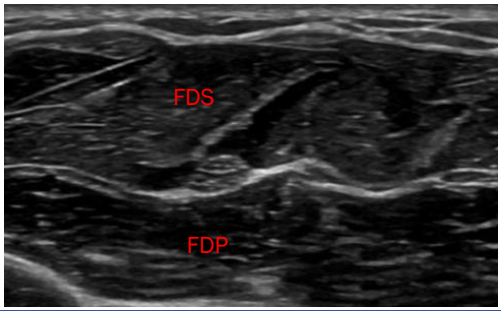
Median Neuropathy at the wrist- What to Evaluate

- Cross-sectional area (mm2)
  - Distal wrist crease (proximal carpal tunnel)
  - Palm (distal carpal tunnel)
  - Forearm (12 cm proximal to the distal wrist crease)

- Wrist-to-forearm ratio:
  - Very sensitive test
  - Useful to determine a superimposed CTS in patients with diffusely enlarged or borderline enlarged nerves at baseline

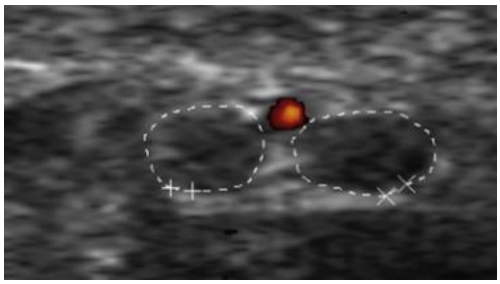


Median Neuropathy at the wrist- What to Evaluate

- Echogenicity
- Mobility
- Vascularity
- Anatomical variants
  - Bifid median nerve
  - Persistent median artery
  - Reversed palmaris longus
- Structural lesions:
  - Ganglion cyst
  - Tumors

Bifid Median Nerve

- The most common anomaly of the median nerve
  - ~ 8 to 15% of individuals
- Knowledge of this can avoid potential complication with injection or surgical injuries
- Post surgical outcome can be worse in these patient as one bundle may not being decompressed



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Walker et al, Muscle nerve, 2013

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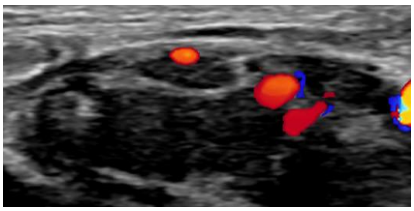
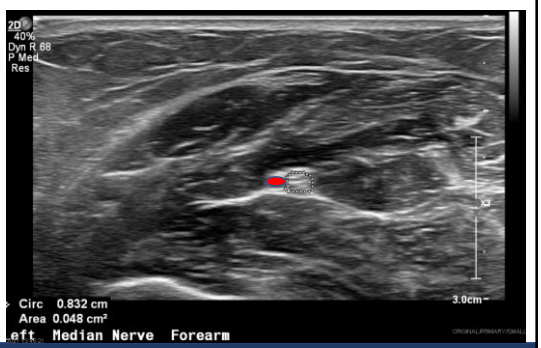
Persistent Median Artery (PMA)

- Most often located between the 2 bundles
  - Sometimes seen adjacent to one side of the median nerve
- ~26% of asymptomatic individuals
- If it is large can contribute to the vascular supply to the hand
- Awareness of its presence is crucial to minimize intraoperative complications such as bleeding or digital ischemia
- An enlarged, thrombosed PMA can contribute to median neuropathy at the wrist
  - Thrombosis of PMA is rare but can be a source of acute CTS





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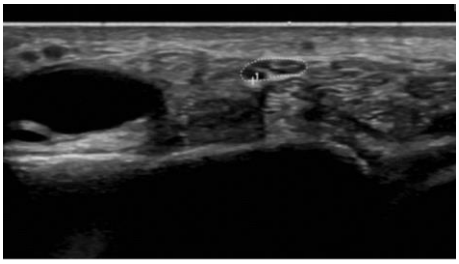
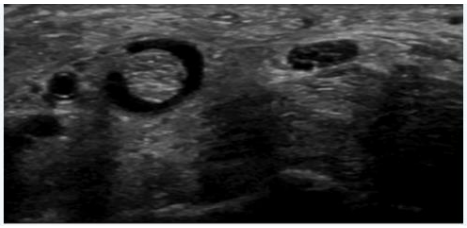
Identifying Structural Abnormalities

1. Ganglion cyst
   - Common at the wrist but most often affected dorsal side
   - In volar side, arises from radiocarpal or one of the carpal-carpal joints and can cause CTS
   - US: hypoechoic structures with prominent posterior acoustic enhancement
2. Tenosynovitis
   - Results in increased fluid within the tendon sheaths and thickening of the sheaths
   - Predisposing factor to median neuropathy at the wrist





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Images: courtesy to Dr. Preston

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Identifying Structural Abnormalities

3. Tumors
   - Schwannoma or Neurofibroma
   - Neural fibrolipoma or fibrolipomatous hamartoma:
     - Most commonly affects the median nerve at the wrist
     - Macrodactyly is present in about two thirds of patients
     - US: an enlarged nerve (often dramatically enlarged) with hypoechoic fascicles with additional tissue between the fascicles

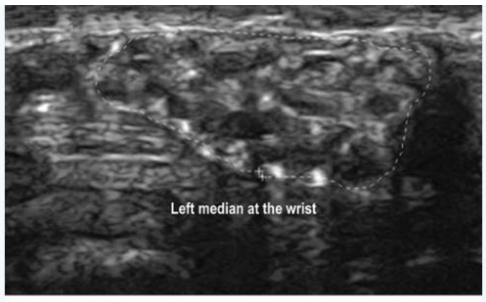

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Image: courtesy to Dr. Preston

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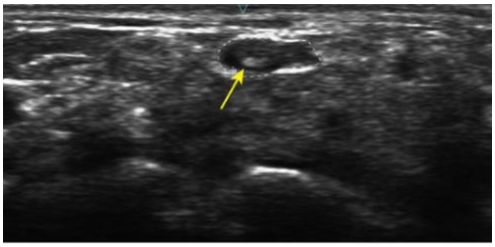
Identifying Structural Abnormalities

4. Thickened epineurium and intraneural scar
   - Scar tissue is usually hyperechoic and can either surround the nerve and/or form inside the nerve.

5. Traumatic neuromas



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Role of NMUS in Some Other Clinical Situations

- Non-localizing Median Neuropathy
- Clinical suspicion of CTS but with normal EDX studies
  - Prevalence: 5%

Neuromuscular ultrasound in patients with carpal tunnel syndrome and normal nerve conduction studies

Fazila Aseem MPH, Jessica W. Williams MD, Francis O. Walker MD, Michael S. Cartwright MD, MS

  - From 22 wrists with normal EDX studies and a high clinical suspicion of CTS:
    - 92.3% enlarged median CSA at the wrist
    - 82.4% decreased median nerve echogenicity
    - 100% had an increased wrist to forearm ratio
- CTS in the Non-dominant Hand

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NMUS Role Following Carpal Tunnel Release

- Clinical situations following CTS release:
  1. Immediate worsening of symptoms after the surgery
     - Suggests surgical complication (hematoma, vascular complication or direct neve injury)
  2. A period of improvement followed by subsequent chronic worsening
     - Suggests scar tissue or new pathology
       - Clue suggesting the scarring is compressive: " notch sign" in relationship to the scar
  3. No period of improvement occurs after surgery
     - Suggests incorrect initial diagnosis, previously unidentified causes or incomplete release

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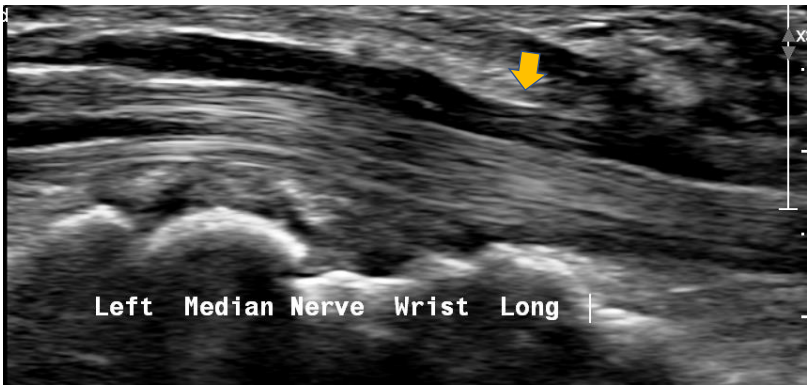

Case 1: Patient with hx of CTS s/p release x3

- Notch sign: characteristic for ongoing compression

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AANEM Evidence - Based Guidelines for CTS:

- If available, NMUS measurement of median nerve CSA at the wrist may be offered as an accurate ***diagnostic test*** for CTS (Level A).
- If available, neuromuscular ultrasound should be considered to screen for ***structural abnormalities*** at the wrist in those with CTS (Level B).

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Cartwright et al, Muscle nerve, 2012

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Ulnar Neuropathy at the Elbow (UNE)

- UNE is the second most common entrapment neuropathy
- Causes:
  - Chronic mechanical compression or stretch
    - Tardy ulnar palsy or leaning on the elbow
  - Rare cause:
    - ganglia, tumors, fibrous bands, or accessory muscles

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Ultrasound Assessment of the Ulnar Nerve

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Ultrasound Assessments of the Ulnar Nerve- What to Evaluate

- Cross-sectional area
  - Distal wrist adjacent to the pisiform bone (Guyon's canal)
  - Mid-forearm (where the ulnar nerve and artery separate)
  - Cubital tunnel
  - Cubital groove
  - Retrocondylar
  - Mid-arm
- Swelling ratio
  - Elbow /mid-forearm
  - Elbow/mid-arm
- Echogenicity

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Mamarabadi et al, Muscle Nerve 2021
Hobson web et al
Carwright

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Ultrasound Assessments of the Ulnar Nerve- What to Evaluate

- Vascularity
- Anomalies
  - Accessory epitrochlearis muscle at the groove
  - Accessory ADM muscle at the wrist
- Structural lesions
  - Ganglion cyst at the elbow
  - Bone spurs at the elbow
  - Intraneural and extraneural scar
  - Tumor
    - Schwannoma, neurofibroma, fibrolipoma

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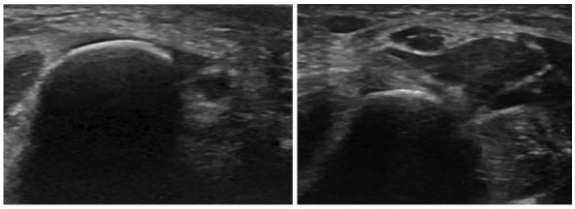
Subluxation and dislocation of the Ulnar nerve at the elbow

- Mobility
  - Subluxation:
    - Ulnar nerve leaves the groove during elbow flexion and ascends toward the tip of the medial epicondyle
  - Dislocation:
    - Nerve rolls anteriorly over the tip of the medial epicondyle



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NMUS Role in Non-Localizing UNE

- Several studies showed that EDX were non-localizing in ~20-25% of patients with ulnar neuropathy
  - Ultrasound was successful in identifying the site of pathology in ~80-100% of these cases
- Adding NMUS to EDx testing, would increase sensitivity of diagnosis UNE from 78% to 98%.

CLINICAL, ELECTRODIAGNOSTIC, AND SONOGRAPHIC STUDIES IN ULNAR NEUROPATHY AT THE ELBOW

ROY BEEKMAN, MD,[1,2] JEROEN P. L. VAN DER PLAS, MD,[3] BERNARD M. J. UITDEHAAG, MD, PhD,[4] RONALD L. L. A. SCHELLENS, MD,[1] and LEO H. VISSER, MD, PhD[1]

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Ulnar neuropathy with abnormal non-localizing electrophysiology: Clinical, electrophysiological and ultrasound findings

Luciana Pelosi [a,*], Dominic Ming Yin Tse [b], Eoin Mulroy [d], Andrew M. Chancellor [a], Michael R. Boland [c]

NEUROMUSCULAR ULTRASOUND IN ELECTRICALLY NON-LOCALIZABLE ULNAR NEUROPATHY

MOHAMMAD ALRAJEH, MD, and DAVID C. PRESTON, MD

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Fibular Neuropathy at the Fibular Head

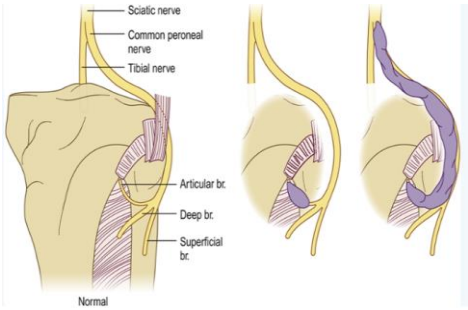
- The most common mono-neuropathy in the lower extremities
- Common causes:
  - Weight loss
  - Prolonged immobility
  - Frequent crossing of the legs
- Other causes:
  - Intra-neural ganglia
  - Lipoma
  - Neurofibroma, schwannoma

NMUS Role in Fibular Neuropathy at the fibular head

- Particularly helpful in three situations:
  - EDX studies demonstrate a non-localizing fibular neuropathy
    - Occurs in approximately a third of patients with fibular neuropathy
  - Fibular neuropathy without any obvious cause
    - Specifically assess for an intraneural ganglion cyst
  - Fibular Neuropathy following trauma (especially knee dislocation)

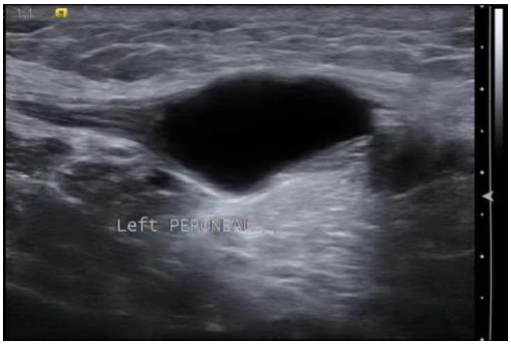
Intra-neural ganglion cysts

- More common in the fibular nerve
- Reported in 18% of patients with fibular neuropathy with foot drop without RF for fibular neuropathy
- Why is more common in fibular nerve?



Intra-neural ganglion cysts

- Important to be recognized as they are amenable to surgical decompression and potentially full recovery
- US:
  - Hypoechoic on ultrasound
  - Nerve is bulbous with a scalloped appearance
  - Posterior acoustic enhancement
  - Negative doppler



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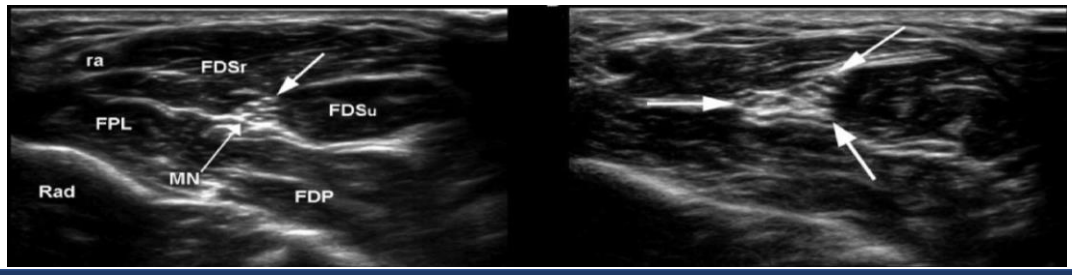
NMUS Role in Hereditary Neuropathies

- CMT1:
  - Diffuse nerve enlargement (>x2 of healthy controls) with prominent dark fascicles
  - Useful tool in children who may not tolerate Edx
  - Screening family members before proceeding with more expensive testing
- Diagnostic ultrasound models created to discriminate between demyelinating and axonal forms of CMT which reported high sensitivity (84%-100%) and specificity (86%-100%) with US especially for the axonal CMT subtypes



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Ziadman et al, J Neurol 2013 Cartwright et al, Muscle Nerve, 2009
Loewenbruck et al, J Neurol 2016

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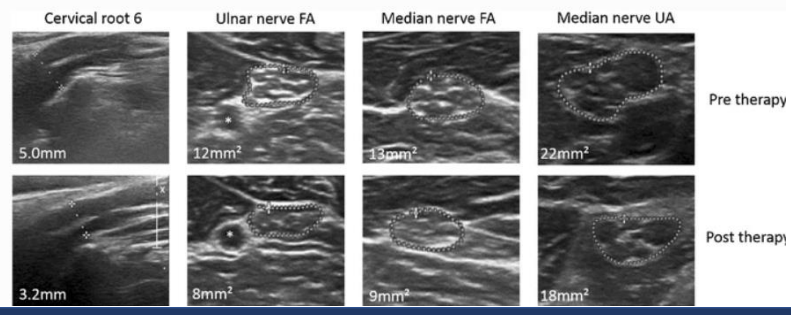
NMUS in Immune-mediated Neuropathies

- AIDP:
  - US role in diagnosis of GBS is still unknown
  - Increased CSA of the nerves
    - The degree of enlargement of CSA is less than CMT1 and CIDP and patchier
  - Enlarged vagus nerve CSA has been identified in patients with autonomic dysfunction in both demyelinating and axonal forms of GBS
- MMN (Multifocal Motor Neuropathy):
  - Moderate, segmental nerve enlargement primarily in proximal nerves, and at sites with and without neurophysiological evidence of conduction block
  - Helps with differentiating MMN from ALS

Gallardo et al, Clin Neurophysiol 2015
Grimm et al, Clin Neurophysiol 2015

NMUS and CIDP

- Multifocal enlargements of CSA in proximal and distal segments of the nerves with hypervascularity
- US to help with diagnosis, classify disease state, predict and evaluate treatment response
- Particularly useful:
  - Patients with multiple diseases such as CIDP and diabetic polyneuropathy
  - Patients with severe neuropathy, difficult to differentiate demyelinating or axonal neuropathy based on EDx.



Carroll SA, World J Radiol, 2020
Härtigal F., Ross , Neurotherapeutics , 2018

CIDP NMUS Diagnostic Guidelines

- European Academy of Neurology/Peripheral Nerve Society guideline on diagnosis and treatment of CIDP
  - ✓Recommended to use ultrasound in adult patients to diagnose CIDP in patients fulfilling diagnostic criteria for possible CIDP but not for definite CIDP
  - ✓The diagnosis of CIDP is more likely if there is:
    - Nerve enlargement of at least two sites in proximal median nerve segments and/or the brachial plexus
    - CSA median nerve >10 mm2 at forearm, >13 upper arm, >9 interscalene (trunks) or >12 for nerve roots.

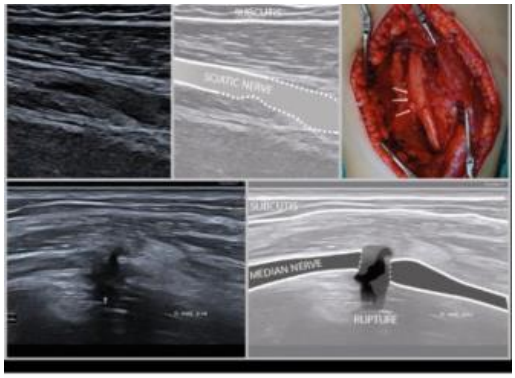
Van den Bergh et al, J Peripher Nerv Syst. 2021

NMUS in Diabetes

- There is very mild CSA enlargement of the sural nerve
- Enlargement is not significant enough to make it an effective diagnostic test
- US help to identify focal mononeuropathies superimposed on severe polyneuropathy

NMUS and Traumatic nerve injury

- In the first few weeks of trauma, EMG/NCS provides inconclusive results and may be difficult to distinguish between axonotmesis and neurotmesis → delayed surgical repair and poor outcomes
- NMUS can identify transected nerves, fibrosis, pseudoaneurysm, neuroma and other anatomic changes→ expedite appropriate care



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Wijntjes J, et al, Diagnostics 2021
Pillen et al, Muscle Nerve, 2015
Smith et al. Muscle Nerve, 2016

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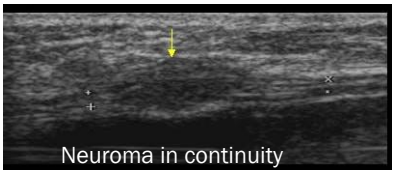
Traumatic nerve injury - Neuroma

35 yo man with history of ulnar nerve trauma (falling on glass table) with partial nerve laceration s/p nerve repair referred for constant pain in forearm.



44 yo man with hx of varicose vein and venous insufficiency presented with persistent right leg pain over the medial side of the leg following ablation of veins and microphelebectomy

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NMUS in ALS

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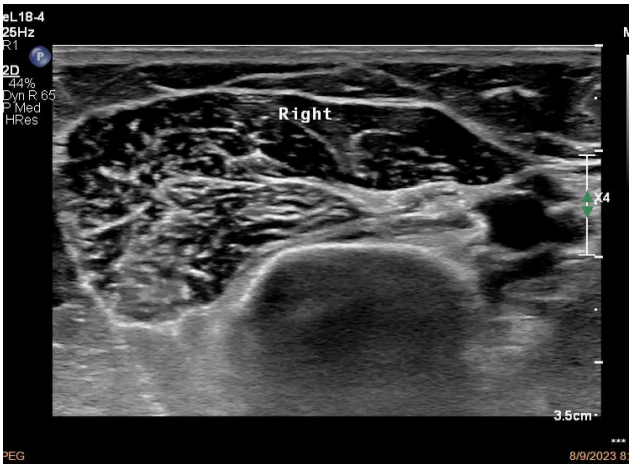
- ALS:
  - Reduced cervical root and peripheral nerve CSA reflective of motor axon loss
  - Hyperechogenicity and decreased muscle thickness consistent with atrophy
  - Muscle ultrasound is more sensitive than EMG in detecting fasciculations, particularly in the tongue.
    - US detected fasciculation in 10% to 30% of muscles that may be subclinically involved or negative on EMG→ improved the diagnostic certainty for patients with motor neuron diseases
  - Diaphragm muscle changes



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Arts et al, clinical neurophysio 2011
Reimers et al, J Neurol 1996
Cartwright et al, Muscle Nerve, 2011
Johanson et al, clinical neurophysio ,2017
Misawa et al. Neurology, 2011

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NMUS in Myopathy

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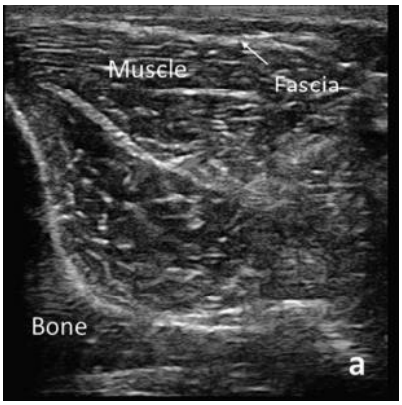
- Starry night appearance in healthy muscles
- Evaluate echogenicity and muscle thickness, dynamic images, and fasciculation
- US is better tolerated compared to EMG in pediatric group



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Gonzales N, Hobson-Webb L, Clinical Neurophysiol 2019

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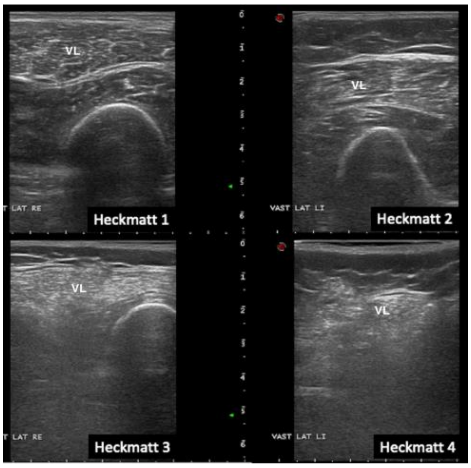
- NMUS is 70% sensitive for myopathy detection

- Heckmatt grading
  - 1: normal muscle
  - 2: increase in muscle echogenicity with normal bone echo
  - 3: moderate increase in muscle echogenicity with decreased bone echo
  - 4: severe increase in muscle echogenicity with shadowing obscuring the underlying bone echo



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Pillen et al, Muscle Nerve 2008
Heckmatt et al, J child Neurol, 1989

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NMUS in Inherited Myopathies

- Can characterize the pattern of involvement of affected muscles to suggest or confirm a diagnosis and aid in guiding genetic studies ordered
  - Duchenne and Becker muscular dystrophy (BMD) as well as limb girdle muscular dystrophies→ ground-glass appearance
  - Bethlem myopathy→ central shadow sign
- Preferential involvement of certain muscles can also suggest a specific diagnosis
  - late-onset Pompe disease→ sparing of triceps and rectus femoris with preserved bone echogenicity

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Bonnemann et al, 2003
Zaidman et al, 2011

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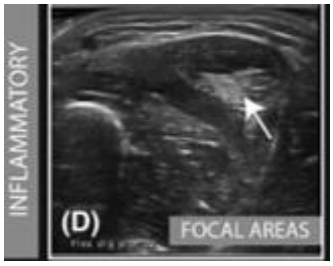
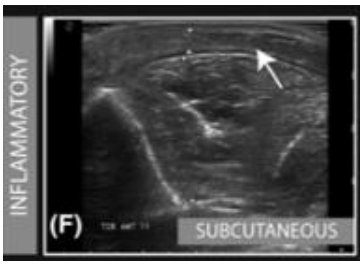
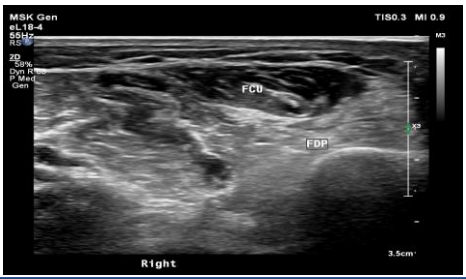
NMUS in Inflammatory Myopathies

- Dermatomyositis:
  - Increased echogenicity due to inflammation and edema
  - Increased subcutaneous layer
- IBM:
  - Hyperechogenicity in the FDP with sparing of the adjacent flexor carpi ulnaris







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Wijntjes J and Nens AV. Muscle Nerve 2021
Pillen S et al. Muscle Nerve, 2008

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NMUS and Diaphragm Muscle Evaluation

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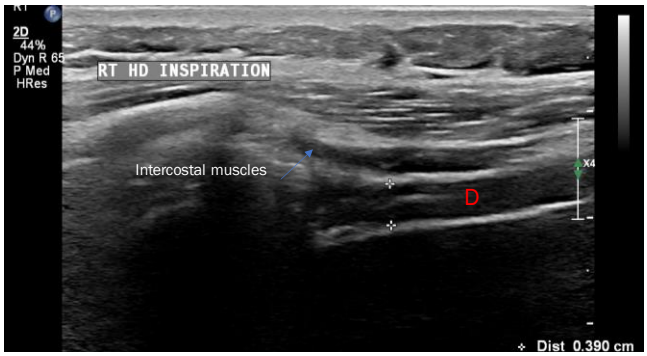

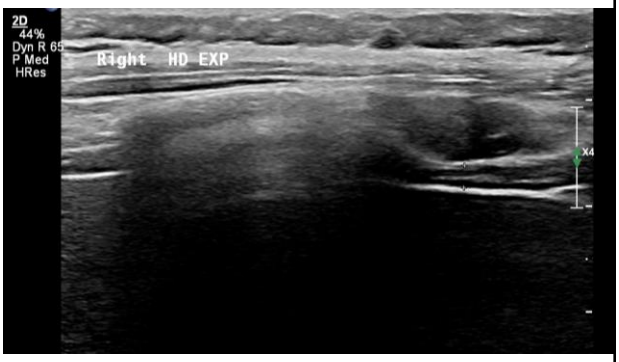

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- Study on patients with unexplained dyspnea showed diaphragmatic ultrasound was 93% sensitive and 100% specific for the diagnosis of neuromuscular diaphragmatic dysfunction
- Valuable in patients with absent phrenic nerve responses on EDx, particularly when body habitus makes the study difficult
- Guide needle insertion during electromyography

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Boon AJ, et al. Neurology. 2014

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Take Home Messages

- Helps primary care physicians, orthopedists, rheumatologists, and other specialists evaluate nerve and muscle disorders.
- EMG/NCS, MRI and NMUS are complementary technologies
- Safety, ease of accessibility, and dynamic nature of ultrasound has led to its increasing use, and knowledge of this growing field
- NMUS is especially helpful in:
  - Localization of a non-localizing lesion on EMG/NCS
  - Identifying unexpected pathology causing entrapment neuropathies
  - Identifying benign anatomic variants
  - Identifying pathology and associated etiologies
  - Guiding additional testing
  - Screening children with suspected neuromuscular conditions