PERIPHERAL NERVE ULTRASOUND AND CARPAL TUNNEL SYNDROME

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OBJECTIVES

• Understand how US can aid in the diagnosis of carpal tunnel syndrome (CTS)

• Review the current evidence for US
  • Diagnosis
  • Post-treatment evaluation
  • Correlation with NCS
  • Other uses

ENTRAPMENT NEUROPATHIES

• Basic principle:
  • Nerves enlarge at or near sites of compression.

  • True for all nerves commonly imaged.

ULTRASOUND IN THE DIAGNOSIS OF CARPAL TUNNEL SYNDROME (CTS)

• Median neuropathy the most common entrapment neuropathy worldwide
  • US prevalence 501,000; incidence 1-3/1,000
  • 500,000 decompression procedures/year in US alone
  • $30,000 lifetime cost per injured worker

  • Sensitivity of EMG/NCS estimated from 80-95%
  • Surgical literature states 16-34% of patients with clinical CTS have normal EDx studies

  • False negatives may occur early in disease course or in mild cases

  • On average, EDx studies 2x as expensive as US

CTS RESEARCH DIFFICULTIES

• Carpal tunnel syndrome is a clinical diagnosis

  • Lack of a true gold standard for research purposes

  • Neurophysiologists consider EDx studies to be the gold standard

  • Many orthopedists, clinicians consider clinical exam findings to be enough

  • Keep this in mind as we discuss research studies...
CTS AND ULTRASOUND

- Median nerve enters hand through carpal tunnel, a fibro-osseous canal.
- Bordered dorsally by the carpal bones and ventrally by the flexor retinaculum.
- Contains the 8 tendons of the flexor digitorum superficialis and profundus, and the flexor pollicis longus.
- The median nerve lies superficial and parallel to the flexor tendons.

THE CARPAL TUNNEL

IMAGING THE MEDIAN NERVE

NORMAL NERVES ON ULTRASOUND

- Normal nerve consists of tubular fascicles (hypoechoic) embedded in a hyperechoic background (epineurium).
- Flexible and change shape with movement.
- Poorly anisotropic.

NORMAL MEDIAN NERVE
WHAT IS AN ABNORMAL MEDIAN NERVE?

- Numerous studies in the last few years
- Signs of compression include:
  - Sudden flattening (notch sign)
  - Nerve swelling at the site of compression
  - An increase in the cross-sectional area
  - The nerve becomes hypoechoic in appearance with loss of fascicular pattern
  - Hypervascularity
  - Loss of mobility with wrist flexion
CTS STUDIES

- Nakamichi 2002
  - 414 patients with CTS by clinical exam
  - 408 asymptomatic controls
  - NCS and ultrasound performed on all
  - Ultrasound results
    - Cross sectional area >12mm² had 76% sensitivity and 90% specificity in diagnosis
    - Distal sensory latency >3.5ms had 67% sensitivity and 97% specificity
    - Combined sensitivity 88%
  - Study results could have been improved by using palmar stimulation techniques.

OTHER ULTRASOUND/CTS STUDIES

- Hammer et al 2005
  - Median nerve area 15.7mm² in patients with EDX positive CTS
  - Median nerve area 8.5mm² in patients with no CTS with rheumatoid arthritis
  - Area 8.0mm² in healthy controls
- Wiesler et al 2006**
  - Median nerve area 9mm² in asymptomatic volunteers
  - 14mm² in those with NCS evidence of CTS

MEDIAN NERVE AREA IN CTS VS. ASYMPTOMATIC CONTROLS

<table>
<thead>
<tr>
<th>Study</th>
<th>Median Nerve CSA (mm²)</th>
<th>Diagnostic of CTS</th>
<th>Asymptomatic Mean / Range</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>Symptomatic Mean / Range</td>
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</tr>
<tr>
<td>Hammer et al.</td>
<td>NA</td>
<td>14.7 (11.1-21.8)</td>
<td>8.2 (5.0-12.2)</td>
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<tr>
<td>Ruedner et al.</td>
<td>NA</td>
<td>14.6±4.9 (11-20)</td>
<td>8.6±2.9 (5-15)</td>
</tr>
<tr>
<td>Kaysercoglu et al.</td>
<td>&gt;10.5</td>
<td>14.3±3.1 (10-21)</td>
<td>8.6±1.4 (5-15)</td>
</tr>
<tr>
<td>Kuver et al.</td>
<td>&gt;10.7</td>
<td>12.3±2.2 (NA)</td>
<td>10.2±3.8 (NA)</td>
</tr>
<tr>
<td>Nakamichi et al.</td>
<td>&gt;12.0</td>
<td>14.6±4.7 (NA)</td>
<td>9.4±1.9 (NA)</td>
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<tr>
<td>Pivetta et al.</td>
<td>&gt;9.5</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sennik et al.</td>
<td>&gt;10.0</td>
<td>15.1±2.3 (NA)</td>
<td>9.5±1.6 (NA)</td>
</tr>
<tr>
<td>Umeda et al.</td>
<td>&gt;10.0</td>
<td>15.0 (NA)</td>
<td>9.0 (NA) (7.0-14.0)</td>
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<td>Wiesler et al.</td>
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NORMAL MEDIAN NERVE SIZE - MRI

- Yao et al 2009
  - MRI imaging of 23 wrists in 17 healthy volunteers
  - Median CSA at the carpal tunnel 10.0mm²
  - 90% upper confidence interval of 14.4mm²
  - Larger than reported in most US studies
ARE THERE OTHER WAYS TO DIAGNOSE CTS WITH ULTRASOUND?

- Median nerve areas vary between individuals
- Published data (Cartwright et al 2006) show the normal median nerve has a constant area between the wrist and axilla
- If focal enlargement occurs near a site of entrapment, the nerve should return to its “normal” size more proximally
- A wrist: forearm ratio of median nerve area may be more useful
- Allows the patient to serve as their own internal control

THE WRIST: FOREARM RATIO IN CTS

- Hobson-Webb et al 2008
- Asymptomatic volunteers
- Patients with electrodiagnostic evidence of CTS
- Median nerve imaged at wrist and 12cm proximally
- Area at wrist/Area at forearm (WFR)

RESULTS

- Mean wrist-to-forearm ratio in volunteers: 1.0 ± 0.1
- Mean WFR in patients with CTS: 2.5 ± 0.7
- P<0.0001
- WFR > 1.5 diagnostic of CTS in our series
- Klauser et al 2009 published similar approach (termed ΔCSA) and found it helpful in patients with “borderline” CSA measurements at the wrist.
- Other recent publications (Hobson-Webb & Padua 2009, Kim 2012) further support this concept

HOW DOES US COMPARE TO EMG?

- Two different types of information, but...
- Visser 2008 compared the diagnostic accuracy of ultrasound to nerve conduction studies for CTS
- 207 patients, 107 controls
- Control median nerve area at wrist: 8mm² (7-10mm²)
- Patients CSA at wrist: 13mm² (11-15mm²)

ULTRASOUND VS. EMG CONTINUED...

- Sensitivity of sonography 78%, specificity 91%
- Sensitivity of median-ulnar digit IV difference >0.4msec was 82%, specificity 97%
- Sensitivity of the distal sensory latency, distal motor latency lower than sonography (54% and 74%)

US VS NCS PART 2

- Pastare et al 2009
- CTS defined clinically by presence of 2 or more symptoms consistent with the diagnosis
- CTS defined on NCS by one or more of the following:
  - Second lumbrical/interosseous distal motor latency difference >0.3ms
  - Abnormal 3rd digit sensory peak latency
  - Abnormal distal motor latency to APB
US VS. NCS PART 2
- Abnormal median nerve area ≥9mm²
- 66 hands with CTS imaged in the study
  - 82% had abnormal NCS
  - 62% with median nerve enlargement on US
  - NCS superior to US
- More work needed to address this topic
  - Kwon et al 2008 found NCS superior as well

META-ANALYSIS
- Fowler et al, 2010
  - 19 studies regarding the use of US for diagnosis of CTS
    - All used different criteria for what constituted CTS
    - Different CSA cut-offs for each study
  - Pooled sensitivity of US 77.8%, specificity 88.8%
  - EDx sensitivity 89.2%, specificity 78.7%
  - “Compares favorably with EDx”

US AND CTS SEVERITY
- Padua et al 2008
  - 54 consecutive patients with clinical evidence of CTS
  - Mean CSA 12.4mm² (range 5.3-34mm²)
    - 70% with abnormal US (>10mm²)
    - NCS abnormal in 94%
  - Strong correlation between median nerve CSA and neurophysiologic class (r=0.80)

MORE ON US AND CTS SEVERITY
- Karadağ et al 2009
  - 99 wrists of 54 patients with symptoms of CTS
    - NCS and US performed in all patients
    - High correlation found between CSA of median nerve and NCS abnormality (r²=0.831)
    - Patients with normal NCS had CSA of 8.52mm²
    - Those with severe NCS (absence of sensory response and prolonged DML) had CSA of 16.34mm²

COUNTERPOINT
- Moran et al 2009
  - 72 hands in 46 patients
  - NCS studies performed by AANEM standards
  - NCS abnormal in 50 hands of 70 hands, 2 hands excluded because of variant anatomy
  - 12.3mm² recommended as the cut-off for diagnosing CTS
  - CSA did not correlate with degree of abnormality on NCS

CTS AND EDX SEVERITY
- Mohammadi et al, 2010
  - 164 wrists in 82 patients
    - All patients with CTS confirmed by nerve conduction studies
      - Underwent US measurement of median nerve area at the wrist
    - Mean area at wrist 11.4mm² ± 1.7mm²
    - Normal wrists 5.78mm² ± 0.7mm²
    - Any correlation between nerve size and EDx severity?
MOHAMMADI ET AL, 2010

- Patients classified as mild, moderate or severe
- Based on nerve conduction velocity
  - Not a validated classification system
  - Methods not well described
- Mild – 10.8 ± 1.9mm²
- Moderate – 11.4 ± 1.8mm²
- Severe 12.0 ± 1.5mm²
- Differences did not reach significance (p=0.2)

IS THE TRUTH SOMEWHERE IN BETWEEN?

- Results of recent study at Duke University
- All patients presenting to EMG lab for evaluation of CTS over 4 months
- 192 patient wrists examined; 50 patient control wrists
- EDx severity graded on Duke 3-point scale and internationally validated 5 point scale
- Clinical severity graded on validated Hi-Ob-Db scale

US AND EDX SEVERITY

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US AND CLINICAL SEVERITY

| A | B |

CORRELATIONS

- No clinically significant correlation between CSA/WFR and EDx or clinical severity scales
- Clinically significant defined as r>0.70
- In summary, a nerve area measure of x is not equal to a severity of y
- Other contributing factors? age, duration of entrapment, body habitus
  - Miwa et al 2011: Age>90 years associated with lower CSA

NORMAL NCS, ABNORMAL EXAM
CTS WITH NORMAL EDX

- US may have a role in patients with clinical evidence of CTS, but normal NCS
- May occur in early or very mild cases
- Rahmani et al, 2011 addressed this question
- 34 patients and 41 healthy controls

RESULTS

- Wrist CSA
  - Patients 9.24mm², Controls 8.32mm²
- WFR
  - Patients 1.58, Controls 1.35
- Patient group with hypervascularity and hypoechogenicity had larger CSA at wrist (10.25-10.67mm²)
- Probability of having clinical CTS with either increased wrist CSA and hypervascularity or hypoechogenicity was approx. 70%

FINALLY...THE POST-SURGICAL CARPAL TUNNEL

- Smidt & Visser 2008
- 79 patients imaged before and 6 months after surgical release
- Pre-surgery CSA: 14mm²
- Post-release CSA: 11.5mm²
- Still above normal values for their laboratory
- US findings did not correlate with outcome
  - Only a few patients had a poor surgical outcome

POST-SURGICAL CTS

- Kim et al, 2012
- 24 patients followed pre- and post-surgery with ultrasound
- Decreased median nerve CSA and CSA ratio seen at 3 week follow-up
- Baseline median CSA at wrist 14.5mm², dropping to 11.5mm² at 3 months
- US ratio (WFR) 2.73 at baseline and 2.11 at 3 months
- US ratio suggested as post-surgical follow-up tool

WORSENING SYMPTOMS AFTER CTS RELEASE
US AS PREDICTOR OF SURGICAL OUTCOME?

- Mondelli et al 2008
- N=67 with NCS/US prior to release and at 1 and 6 months post release
- CSA reduced at 1 month
  - 15.6mm² pre-op
  - 13.8mm² at 1 month post-op
  - 13.6mm² at 6 months
- Reduction in area correlated with NCS and clinical improvement
- Smaller pre-op CSA correlated with improvement

OTHER USES OF US IN CTS

- Identification of conditions that mimic CTS on electrodiagnostic studies
- Information on variant anatomy
- Follow-up after failed surgical repair
- Screening for EDx abnormality*
- Monitoring response to treatment*

MONITORING RESPONSE TO THERAPY

- Cartwright et al 2011
- 19 patients, 29 wrists with CTS
- Ultrasound and EDx studies at baseline, 1 week, 1 month and 6 months following steroid injection
- Median nerve CSA at wrist decreased from nearly 16mm² at baseline to 12.5mm² at 6 months
- CSA had moderate correlations with symptom score, motor latency and motor amplitude

SCREENING FOR EDX ABNORMALITY

- Previously mentioned Duke study
- Median nerve CSA <9mm² and WFR <1.4 – no EDx changes consistent with CTS
  - ≥99% sensitivity
- Could US be used to screen patients presenting for evaluation of CTS?
- If normal, patients might go to needle EMG for cervical radiculopathy.
  - Cost and time efficient.
- Follow-up study at Duke and with other centers needed
- Adequate clinical history and examination needed in each patient

MEDIAN NERVE IN CTS

...BUT WHAT ELSE WAS PRESENT?
Another View...

What is the structure?

Neuroma of the Median Nerve (Cross-Sectional View)

Sagittal View of Neuroma

Another Neuroma

Bifid Median Nerve
MEDIAN NERVE CHANGES

At rest

With finger extension, sublimis appears

MUSCLE IN THE TUNNEL AT REST

PERSISTENT MEDIAN ARTERY

VALUE OF ULTRASOUND IN CTS

• Aids diagnosis in patients with borderline or normal EDx studies
• May be useful in predicting surgical outcomes
• In patients with clear CTS by EDx, can add structural information
  • Bifid median nerves
  • Persistent median arteries
  • Cysts
  • Neuromas

FUTURE DIRECTIONS

• Assessing nerve vascularity to diagnose of CTS
  • Already featured in some studies
  • Frequently used at Wake Forest University
• Quantification of nerve signal
  • Nerve density measures (Martiroli et al, 2010)
• Ultrasound Contrast Agents (DeMarchi 2011)
• 3D Ultrasoundography

INTRANEURAL BLOOD FLOW IN CTS

Patient

Control
NERVE VASCULARITY

- Studies by Gharsemi-Esfe and Joy highlight potential use of color Doppler in the diagnosis of CTS
- Gharsemi-Esfe has noted reduced pulsatility of the radialis indicis artery in CTS
- Both groups have reported increased intra-neural blood flow in CTS
- Need standardized means of measuring vascularity

FUTURE DIRECTIONS - 3D ULTRASOUND

- Pyun et al., 2011
- 50 patients with EDx confirmed CTS and 37 control patients
- 3D ultrasound performed at bilateral wrists
- 8-15MHz mechanical 3D volume transducer
- Time per wrist scan – 56 seconds (excluding 5.7 minutes of image analysis
- All areas well imaged except the distal carpal tunnel
- Patient CSA 16.7mm²; Control CSA 8.3mm²

HOW IT WORKS....

EXEMPLARY OF 2D VS. 3D TRANSDUCERS


ADVANTAGES OF 3D US APPROACH

- Far less operator dependent than traditional 2D ultrasound
  - Not an issue with experienced operators
- Image reconstruction in any plane
- Reduced scanning time
  - Counterbalanced by lower image analysis time for 2D US

CONCLUSIONS

- Median nerve US is a helpful adjunct in the assessment of CTS
  - Possible stand-alone diagnostic tool in select cases
- Potential as a screening tool for EDx abnormalities
- Potential to predict outcomes