ULTRASOUND EVALUATION FOR CARPAL TUNNEL SYNDROME

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Objective

1. Background
2. Literature appraisal
3. US vs EMG
4. Ultrasound protocol
5. Summary
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Disclosure

- Yin-Ting Chen has no conflicting interests to disclose
- Joseph Scholz has no conflicting interests to disclose
- Dallin Thomas has no conflicting interests to disclose
- View points presented are those of the authors and do not represent the Department of Defense, United States Army or the United States Government.
Background

- CTS is the most common compressive neuropathy
  - Accounts for 90% of all compressive neuropathies
  - 3.8% of all general population (Ibrahim 2012)
  - 9.2% in women and 6% in men (Atroshi 1999)
- Electrodiagnostic examination (EDX) considered gold standard
- Most common referral to EDX laboratory for evaluation
Advantages of US for CTS

- Patient comfort
- Non-invasive
- Timely evaluation
- Real time, office-based exam
- Less time-consuming
- Dynamic exam
- Relatively inexpensive
- High resolution anatomical evaluation (mass lesions, bifid median nerve, tenosynovitis, lipoma, ganglion cyst, lumbrical incursion... etc)
Disadvantages of US for CTS

- Learning curve
- Operator dependent
- Not yet universally recognized

…..To be overcome with training, training, training
CTS Sonographic Characteristics

- Increased *cross sectional area* (CSA) within the carpal tunnel due to swelling
- Flexor retinaculum bowing
- Increased flattening ratio of the median nerve
- Median nerve notching
- Hypervascularity of the median nerve
- Increased Delta CSA
  - (as compared to forearm segments)
Conclusion

- CSA is mostly studied and validated measurement for CTS
Objective

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<th>Author, Year</th>
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<th>Sensitivity (%)</th>
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<th>Accuracy (%)</th>
<th>CSA (mm²)</th>
<th>Comment</th>
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<tr>
<td>Buchberger, 1992</td>
<td>Clinical symptoms + NCS abnormalities (undefined), MRI</td>
<td>DRUJ, pisiform, hamate; flattening ratio, swelling ratio, retinaculum bowing</td>
<td>14.5 (pisiform), 10.5 (hamate)</td>
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<td>Duncan, 1999</td>
<td>Median/ulnar SNC, MNC (not specified)</td>
<td>Inlet</td>
<td>82</td>
<td>97</td>
<td>NA</td>
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<td>Keberle, 2000</td>
<td>Median SNC, MNC (&lt; 5 mV CMAP, DML &lt; 4.6 msec, SNAP digit II &gt; 0.01 mV, SNAP CV &lt; 42 m/s)</td>
<td>Wrist, inlet, outlet, flattening ratio</td>
<td>100</td>
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<td>NA</td>
<td>Swelling ratio 1.3</td>
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<td>Sarria, 2000</td>
<td>Clinical + median SNC, MNC (SNAP CV &lt; 50 m/s or a DML &gt; 4.2 ms.)</td>
<td>Wrist, inlet, outlet, flattening ratio, bowing</td>
<td>81.3 (bowing) 73.4 (wrist) 73.4 (inlet) 75 (outlet) 53.1 (all signs) 95.3 (one of signs)</td>
<td>64.3 (bowing) 57.1 (wrist) 57.1 (inlet) 57.1 (outlet) 78.5 (all signs) 40.4 (one of signs)</td>
<td>NA</td>
<td>11 (all levels) 2.5 (bowing)</td>
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<td>Swen, 2001</td>
<td>(1) The median nerve DSL &gt; 3.6 msec. (2) Ring-diff &gt; 0.4 msec, (3) DML-1 over the thenar &gt; 4.3 msec. (4) The median MNC CV &lt; 49 m/s. (5) The median sensory CV &lt; 49 m/s. (6) The ulnar motor and sensory nerve CV Measurements 4, 5, and 6 were performed for the forearm.</td>
<td>Inlet</td>
<td>70</td>
<td>63</td>
<td>68</td>
<td>10</td>
<td>US PPV 85, NPV 42</td>
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<td>Nakamichi, 2002</td>
<td>Median ulnar SNC, MNC Forearm NAP (not specified)</td>
<td>Wrist, inlet, outlet, distal 1/3 forearm</td>
<td>67.0</td>
<td>96.4</td>
<td>93.9</td>
<td>12 (mean area without forearm)</td>
<td>NCS coefficient of variation &lt; 5%, US &lt; 10% Mean CSA at wrist, inlet, and outlet provides improved sensitivity without reducing specificity</td>
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<td>Author, Year</td>
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<td>US measurement</td>
<td>Sensitivity (%)</td>
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<td>CSA (mm²)</td>
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<td><strong>Leonard, 2003</strong></td>
<td>Clinical (characteristic history of paresthesia in the median nerve distribution with a positive Phalen’s test and no other co-existent neurological disease)</td>
<td>Inlet, outlet, flattening ratio</td>
<td>72</td>
<td>90</td>
<td>NA</td>
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<td><strong>Altinok, 2004</strong></td>
<td>Median SNC, MNC Median-ulnar midpalm-wrist DL dif &gt; 0.4ms</td>
<td>Wrist, inlet outlet</td>
<td>65.0</td>
<td>92.5</td>
<td>78.9</td>
<td>9 (inlet) Swelling ratio &gt; 1.3</td>
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<td><strong>Kotevoglu, 2004</strong></td>
<td>Median SNC, MNC (not specified)</td>
<td>Wrist, inlet, outlet out, flattening ratio, flex ret bowing</td>
<td>89</td>
<td>100</td>
<td>NA</td>
<td>NA</td>
<td>Abnormal US finding is correlated with clinical exam (Phalen, Tinnel)</td>
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<td><strong>El Miedany, 2004</strong></td>
<td>(1) Median nerve distal sensory latency, upper limit of normal 3.6ms. (2) Difference between the median and ulnar nerve distal sensory latencies, upper limit of normal 0.4 ms. (3) Distal motor latency over the thenar, upper limit of normal 4.3 ms. (4) Median motor nerve conduction velocity, lower limit of normal 49m/s.</td>
<td>Inlet, outlet</td>
<td>97.9</td>
<td>100</td>
<td>NA</td>
<td>10</td>
<td>Algorithm for CTS evaluation suggested CTS severity by US: Mild: CSA 10-13 Mod: CSA 13-15 Severe: &gt; 15</td>
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<td><strong>Wong, 2004</strong></td>
<td>Median/ulnar SNC, MNC (8-cm transcarpal orthodromic median and ulnar SNAP peak latencies, median forearm CV, 8-cm median CMAP, and distal motor latencies)</td>
<td>Wrist, inlet, tunnel, outlet</td>
<td>94 (Combine: 86)</td>
<td>92.5</td>
<td>74</td>
<td>Wrist 8.8, inlet 9.8, outlet 85</td>
<td>Inter-rater reliability coefficient 0.87.</td>
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<td><strong>Keles, 2005</strong></td>
<td>1. Median SNAP CV of digits I, II, and III of palm-to-wrist segments 2. Median nerve DML prolonged. 3. Ulnar SNC, MNC</td>
<td>Tunnel CSA, flex ret bowing, flattening of median nerve</td>
<td>80 (CSA) 71.4 (Flex ret bowing)</td>
<td>77.5 (CSA) 55 (Flex ret bowing)</td>
<td>NA</td>
<td>9.3 (Tunnel CSA), 8.5 (inlet), 9.5 (outlet)</td>
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<td><strong>Lee, 2005</strong></td>
<td>Median SNC, MNC (not specified)</td>
<td>Wrist, inlet, outlet</td>
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<td>CSA inlet best correlates with EDX finding and questionnaires</td>
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<td>Ziswiler, 2005</td>
<td>Median/ulnar SNC, MNC (SNAP CV &gt; 41–53 m/s, DML &gt; 3.9–4.1 msec, and CMAP &gt; 5 mV)</td>
<td>Wrist, inlet</td>
<td>86 (9 mm²), 82 (10 mm²), 54 (11 mm²)</td>
<td>70 (9 mm²), 87 (10 mm²), 96 (11 mm²)</td>
<td>83.4</td>
<td>10 tunnel</td>
<td>CSA &lt; 8 mm to rule out CTS, &gt; 12 mm to rule in CTS</td>
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<td>Wiesler, 2006</td>
<td>Median SNC, MNC (DSL &gt; 3.5 ms, or DML latency &gt; 4.5 ms)</td>
<td>Inlet, tunnel, outlet</td>
<td>91</td>
<td>84</td>
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<td>11 at inlet</td>
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<td>Hammer, 2006</td>
<td>Clinical + median NCS (palm-to-wrist median SNAP onset latency &gt;2.0 msec at 7 cm, or absence of SNAP, and median DML &gt;4.9 msec)</td>
<td>Inlet</td>
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<td>Mallouhi, 2006</td>
<td>Clinical + NCS (median DSL&gt; 6.2 msec and DML &gt; 3.9 msec)</td>
<td>Wrist, inlet, outlet, Flex ret bowing, color Doppler</td>
<td>91 (CSA)</td>
<td>47 (CSA)</td>
<td>91 (CSA)</td>
<td>11</td>
<td>Hypervascularization detected by color Doppler useful for CTS evaluation</td>
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<td>Bayrak, 2007</td>
<td>Median/ulnar SNC, MNC (median–ulnar sensory latency difference &gt;0.5 ms and a median–ulnar DML difference &gt;1.2 ms); MUNE APB</td>
<td>Wrist, inlet, outlet</td>
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<td>Visser, 2008</td>
<td>Median DSL digit IV &gt; 3.2 msec, Median ulnar ring-diff &gt; 0.4 msec, median DML &gt; 3.8 msec,</td>
<td>Distal 2/3 forearm, inlet</td>
<td>78</td>
<td>91</td>
<td>10 (inlet)</td>
<td>US CSA of 10 at inlet has equivalent sensitivity and specificity of ring-diff</td>
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<td>Kaymak, 2008</td>
<td>Median SNC, MNC (cut off unspecified)</td>
<td>Wrist, inlet</td>
<td>88 (Wrist)</td>
<td>66 (wrist)</td>
<td>11.2 (wrist), 11.9 (inlet)</td>
<td>Median DSL most predictive of severity; DML most predictive of functional status</td>
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<tr>
<td>Klauser, 2008</td>
<td>Clinical + NCS (not specified)</td>
<td>Wrist, inlet, tunnel, outlet, proximal third of PQ</td>
<td>99</td>
<td>100</td>
<td>Delta 2 mm</td>
<td>Delta CSA useful in both mild and severe CTS</td>
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<td>Hoboson-Webb, 2008</td>
<td>NCS (Motor DML ≥ 4.4 at 6.5 cm, mixed latency ≥ 2.2, or &gt; 0.3 ms compared to ulnar)</td>
<td>Wrist-forearm ratio ≥ 1.4</td>
<td>100</td>
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<td>10 inlet</td>
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<td>Mhoon, 2012</td>
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<td>99 (CSA 9)</td>
<td>97 (WFR 1.4)</td>
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<td>El Miedany, 2004</td>
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Literature Appraisal

- Diagnostic value uncertain
  - CSA 6.5 mm² to 13 mm² (Pinilla, 2008; Bayrak, 2007)
  - Sensitivity 60% - 100% (Moran, 2009; Keberle, 2000)
  - Specificity 22% - 100% (Mhoon, 2012; El Miedany, 2004)
  - Accuracy 68% - 97.2% (Swen, 2001; Klauser, 2011)

- EMG
  - Various EDX protocols used, differ across studies
  - Combined sensory index (CSI) not used in any studies

- US
  - Various protocols (measurement method, location, study design, tracing algorithm... etc)
  - Technique and technician dependent
Literature Review

- “…it is not evident how it compares to electrodiagnostic studies” (Beekman 2003)

- “Determining the diagnostic utility of sonography has been confounded by a lack of standardization among research methodologies/designs and variability in evaluation and measurement protocols.” (Roll, 2011)
Systematic Review

Fowler et al 2011
- Reviewed 323 papers; 19 entered analysis
- Heterogenous set of reference standards
- Pooled US sensitivity/specificity using different reference standards
  - Clinical 77.3 (62.1–84.6) 92.8 (81.3–100)
  - EDX 80.2 (71.3–89.0) 78.7 (66.4–91.1)
  - Composite 77.6 (71.6–83.6) 86.8 (78.9–94.8)
- Compares favorably against EDX (69, 97%)
- Limitation:
  - Variable reference methodologies
  - No clear cut-off value for CSA
  - Consider as first-line screening tool when there is high pre-test probability
AANEM Evidence-Based Guideline, 2012 (Cartwright et al 2012)

- 121 manuscripts reviewed
  - Class I: 4 (prospective cohort, blinded, appropriate reference, include measures of diagnostic accuracy)
  - Class II: 6 (retrospective, blinded, free of spectrum bias, include measures of diagnostic accuracy)
  - Class II with added value: (draw from a statistical and non-referral clinic-based sample of patients, evaluate all CTS patients prior to surgery, and conduct neuromuscular ultrasound on all study participants)
AANEM Guideline, cont

- Class I finding:
  - 8.5 to 10 mm²
  - Sensitivity 65% - 97%, specificity 72.7% - 98%, accuracy 79% - 97%

- Class II finding:
  - Sensitivity 67 - 83%, specificity 50 - 97%, accuracy 71 - 87% at CSA 12 mm²
  - Delta CSA ≥ 4 mm² shows sensitivity 92%, specificity 96%, accuracy 94%
AANEM Guideline, cont

- Class I/II Recommendation:
  - “If available, neuromuscular ultrasound measurement of median nerve cross-sectional area at the wrist may be offered as an accurate diagnostic test for CTS (Level A).”
Delta CSA, WFR, Swelling Ratio

- Comparison of forearm (PQ or proximal) to tunnel, inlet
- Indicative of swelling
  - Delta CSA ≥ 2 mm² (99% sensitivity, 100% specificity) (Klauser 2008)
  - Delta CSA ≥ 4 mm² for bifid median nerve (92.5% sensitivity, 94.6% specificity) (Klauser 2011)
  - WFR > 1.4 (sensitivity 97-99%) (Hobson-Webb 2008, Mhoon 2012)
AANEM Guideline, cont.

- Class II with added value:
  - Significant anatomical abnormalities noted
  - 25% occult ganglion cyst (Nakamichi 1993)
  - 2 - 25% bifid median nerve (Iannicelli 2000)
  - 6 - 9% persistent median artery (Bayrak 2007, Padua 2012)
  - 9% tenosynovitis (Padua 2012)
  - 3% accessory muscles (Padua 2012)
AANEM Guideline, cont.

- Class II with added value
  Recommendations:
  - “If available, neuromuscular ultrasound should be considered to screen for structural abnormalities at the wrist in those with CTS (Level B)”
Pisiform is the most commonly measured location

No studies definitively demonstrates correlation to severity

US has definitive value to CTS evaluation, and may be helpful in diagnosing atypical CTS

CSA > 14 mm$^2$ rules-in CTS

CSA < 8 mm$^2$ rules-out CTS

Δ CSA

- Non-bifid median nerve: $\geq 2$ mm$^2$
- Bifid median nerve: $\geq 4$ mm$^2$

WFR ratio > 1.4 as screening test

WFR < 1.4 and CSA < 9 mm$^2$ has 99% sensitivity in predicting normal EDX (Mondelli 2008)
US should be considered as first line screening tool in patients with high pre-test probability; EDX may not be needed.

US should be considered in atypical CTS (unilateral, sudden onset, in setting of trauma, no occupational history or risk factors) due to high prevalence of structural abnormalities.
Objective

1. Background
2. Literature appraisal
3. US vs EMG
4. Ultrasound protocol
5. Summary
Comparing US and EMG

- EMG and clinical examination both considered as competing “gold standards” for CTS diagnosis
  - Debated amongst different specialties
  - PE vs EMG: study shows no difference in outcome
- EMG, however, offers objective data (El Miendany 2004)
  - Severity
  - Prognosis
  - Rule out co-existing conditions
- EMG mostly used as validating standard in US CTS studies
Literature Overview

- Literature correlating severity
  - El Mietany 2004
  - Pauda 2008
  - Karadag 2009

- Literature not correlating severity
  - Kaymak 2008
  - Mondelli 2009
  - Mhoon 2012
  - Visser 2008
El Miedany et al, 2004

- Cross-sectional, age-group-matched case–control study
- n=78, control n=78
- Boston Carpal Tunnel Questionnaire (BCTQ)
- US: flattening ratio, CSA (inlet, mid-tunnel)
- EMG severity scale

- Negative: normal findings on all tests.
- Minimal: abnormal segmental or comparative tests only.
- Mild: abnormal digit/wrist sensory nerve conduction velocity and normal distal motor latency.
- Moderate: abnormal digit/wrist sensory nerve conduction velocity and abnormal distal motor latency.
- Severe: absence of sensory response and abnormal distal motor latency.
El Miedany et al, 2004

- **Result**
  - Diagnostic CSA 10.03 mm², flattening ratio 0.3
  - Mild: 10 - 13 mm²
  - Moderate: 13 - 15 mm²
  - Severe: > 15 mm²
  - Highly positive correlation between EMG and CSA, as well as both symptom and functional severity scales

  “…In addition to being of high diagnostic accuracy it is able to define the cause of nerve compression and aids treatment planning; US also provides a reliable method for following the response to therapy.”
Pauda et al, 2008

- Prospective study examining correlation between CSA, clinical, neurophysiological, BCTQ, EMG findings, and clinical findings (n=54)
- CSA at inlet (10 mm²)
- EMG
- Clinical exam

Conclusion

- Statistically significant linear correlation between CSA and clinical scales
- “…when neurophysiological tests are negative – US may be useful because it may show abnormal findings that are not revealed even using sophisticated neurophysiological tests.”
Karadag et al, 2009

-Prospective study examining correlation between CSA, **BCTQ**, EMG, and clinical findings

- BCTQ assigned severity scale
  - Mild: 1.1 – 2
  - Moderate: 2.1 – 3
  - Severe: 3.1 – 4
  - Extreme: 4.1 – 5

- US CTS severity score based on El Miedany
  - Mild: 10 - 13 mm²
  - Moderate: 13 - 15 mm²
  - Severe: > 15 mm²

- EMG CTS severity based on Pauda
Result:
- Substantial agreement for CTS severity (Cohen’s $k$ coefficient $= 0.619$) between CSA and NCS
- Based on US CTS severity classification, groups were significantly different in VAS ($P = 0.017$) and BCTQ ($P = 0.021$)

Conclusion: “CSA reflects in itself the degree of nerve damage as expressed by the clinical picture”
EMG vs US as predictor of symptom severity (n=34, control=38)

Symptoms: measured by BCTQ

US: median nerve at level of DRUJ vs pisiform
  - CSA and flattening ratio

EMG: standard studies

Result:
  - Symptom BCTQ significantly correlated w/sens peak latency
  - Function BCTQ significantly correlated w/motor distal latency

**No US significant correlation with BCTQ**
  - BUT, US can still help in the yes/no diagnosis of CTS
Prospective, blinded study comparing CSA and WFR to EDX and clinical symptoms (n=100, n=25 control)

EDX: standard studies

US: Inlet, 12 cm proximal to inlet

- WFR > 1.4 considered positive

Result:

- CSA 9 mm² sens 99%, WRF 1.4 sens 97%
- **US parameters not related to CTS severity**
  - Consider EMG if CSA ≤8 mm²
Visser et al, 2008

- n= 168 CTS, 137 control
- NCS: Median DSL digit IV > 3.2 msec, Median ulnar ring-diff > 0.4 msec, median DML > 3.8 msec
- US: distal forearm vs. inlet
- Patient survey on preference (EMG vs. US)
- Result (vs. clinical symptom severity):
  - US: sens 78 (70–84), spec 91 (86–95)
  - EMG: 82 (75–88) 88 (78–95)
  - CSA inlet differed significantly between control and subject (P < 0.00001)
  - Patient survey indicates preference for US
Mondelli et al, 2008

- Prospective study of US vs NCS (n=85)
- Ability to correlate with abnormal BCTQ
- NCS (AAEM standard)
  - Median SNAP, Ulnar SNAP, Median CMAP, median-ulnar transpalmar
- US: CSA at inlet, outlet, mid-tunnel using manual tracing method

Result:
- NCS (57/85): 67%
- US (55/85): 64.7%
- **NCS + US: 76.5%**
  - *NCS & US alone miss more cases than when combined*
US vs EDX Conclusion

- US has similar diagnostic value as NCS
- Conflicting data on correlating CTS severity
- Can consider US as the first diagnostic procedure in patients with typical CTS
- EMG remains essential to detect other confounding diagnoses
Objective

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Don’t worry about:

Ultrasound terminology

-- We will teach it in the small groups

Getting your hands dirty,

-- We all do in the beginning

Just don’t drop the probe!
Key Views

1. Distal forearm transverse axis, for baseline CSA
2. Wrist inlet, transverse axis, CSA
   1. Delta CSA = inlet – baseline
   2. WFR = inlet / baseline
3. Tunnel to outlet, transverse axis, for mass lesions
4. Across carpal tunnel, long axis view
   1. Baseline diameter
   2. Notching
   3. Tethering
5. Dynamic tests
   1. FDS intrusion test
   2. Lumbrical intrusion test
   3. Thenar digital flexion stress test, LAX and SAX
6. Accessory structures
   1. PCB MN
Ultrasound Protocol

- Patient comfortably seated across from examiner
- Wrist on table at comfortable height, in slight extension (10-20 degrees)
- Generous gel, throughout distal arm to wrist
- Staying perpendicular to structure by examining the anisotropy
- Video
- Maintaining proper echotexture
- Areas examined
  - Distal forearm (pronator quadratus)
  - Carpal tunnel (inlet, tunnel, outlet)
Distal Forearm
Inlet

- Sc: scaphoid
- Ps: pisiform
- S: FDS
- P: FDP
- PL: palmaris longus
- •: flexor retinaculum
- ▼: median nerve
- △: ulnar nerve
- U a/v: ulnar a/v
Palmar Cutaneous Branch

FCR

FPL

Med
Outlet
Longitudinal View
Dynamic Testing

- FDS intrusion
Dynamic Testing

- Lumbrical intrusion test (Sucher 2014)
Dynamic Testing

- Thenar digital flexion stress test, LAX (Sucher 2014)
  - Detect intracanal, where most compression occurs
  - Improves visualization of notching, at 3rd CMC
Dynamic Testing

- Thenar digital flexion stress test, SAX
  “open mouth view”
  (Sucher 2014)
Key Views

1. Distal forearm transverse axis, for baseline CSA
2. Wrist inlet, transverse axis, CSA
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Future Research Direction

- Large, population-based prospective study
- Assess prevalence of structural abnormalities to define the expected benefit for delineating anatomical detail
- Standardized research protocol, with defined measuring method, location
- Evaluate efficacy outcome compared between EDX, US or clinically defined CTS
- Utilize improved reference standard (CSI)
Summary

- Limitation of literature; interpret results with caution

  - No conclusive diagnostic CSA
    - Rule in > 14 mm², rule out < 8 mm²
    - Delta CSA 2 mm², 4 mm² (bifid), WFR ratio > 1.4

- Conflicting literature on correlating to severity; data support correlation to subjective symptom and function.
Summary, cont…

- Complementary to EDX

- Consider for atypical cases for dynamic lesions, first-line for classic CTS, combine with EDX for improved sensitivity and specificity

- CTS examination can be performed quickly, and well-preferred by patients

- Prospective research with standardized protocol
Questions?
Thank You!
• El Miedany YM, Aty SA, Ashour S. Ultrasonography versus nerve conduction study in patients with carpal tunnel syndrome: substantive or complementary tests? Rheumatology (Oxford) 2004;43:887–95
References, Cont


