Ultrasound Measurement of the Cross-Sectional Area of the Median Nerve: The Effect of Teaching on Measurement Accuracy

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Jared A. Crasto¹, Michael E. Scott¹, and John R. Fowler¹

Abstract

Background: The purpose of this study was to determine the effect of concise instruction and guidance on the accuracy of measuring the cross-sectional area of the median nerve at the carpal tunnel inlet. **Methods:** Seven orthopedic residents and 5 hand fellows obtained serial measurements of the median nerve at the carpal tunnel inlet using a 15-6 MHz ultrasound (US) probe. After a 5-minute teaching session, all participants repeated measurements. A single cadaveric specimen was used. Measurements were compared with the measurement of a fellowship-trained hand surgeon with extensive experience in US diagnosis of carpal tunnel syndrome. This was considered the reference standard. **Results:** The rate of participants selecting the correct structure to measure on US was 36% before instruction and 97% after. Discarding the measurements of the incorrect structure, the average measurement was 4.8 mm² before instruction and 5.2 mm² after. The standard measurement was 6 mm². The average deviation from the standard measurement -0.2 mm² before instruction and -0.8 mm² after. The percent of measurements (of the correct structure) that fell within 1 mm² of the standard measurement increased from 62% to 74%. Participant self-reported confidence in performing measurements elevated from 2.4/10 before instruction to 6.5/10 after. **Conclusions:** US of the median nerve cross-sectional area can be efficiently taught and results in measurements consistent with that of an experienced operator.

Keywords: ultrasound, carpal tunnel syndrome, point-of-care, teaching, education

Introduction

Ultrasound (US) is an accurate, efficient, and cost-effective tool utilized in the diagnosis of carpal tunnel syndrome (CTS).⁹⁻¹³ US demonstrated 89% sensitivity and 90% specificity in a study of 85 patients using the clinical diagnostic tool Carpal Tunnel Syndrome 6 (CTS-6) as the reference standard.¹³ US can be performed by the same physician who clinically diagnoses patients with CTS, at the same clinic visit. This reduces the number of visits required to confirm a clinical diagnosis and mitigates patient confusion and loss to follow-up.

The basis for using US relies on the consistent finding that when the median nerve is compressed within the carpal tunnel, the nerve swells proximal and distal to the site of compression. Although there are many techniques described for US-based diagnosis of CTS, nerve cross-sectional area (CSA) measured at the level of the pisiform has demonstrated acceptable reliability, with decreasing reliability at other sites.^{1,14} Although there remains debate on the exact

cutoff value, authors agree that an increase in the CSA is diagnostic for CTS.^{1-3,5-8,15,17-20} At the level of the pisiform, 10 mm² appears to be a well-accepted cutoff value, values above which are diagnostic for CTS.^{8,10,18}

A proposed obstacle to the more frequent use of US is the user-dependent nature of the technology, discouraging those unfamiliar with the technique.¹⁹ In addition, there has been an overall moderate interrater and intrarater reliability seen in previous studies,^{1,11,14} which would cause some to question the reproducibility of the results and the conclusions that can be drawn from them.

While many studies call for the adoption of US as a point-of-care (POC) test for the timely, reliable diagnosis of

¹University of Pittsburgh Medical Center, PA, USA

Corresponding Author:

John R. Fowler, Department of Orthopaedics, University of Pittsburgh Medical Center, 3471 Fifth Avenue, Suite 911, Pittsburgh, PA 15213, USA.
Email: fowlerjr@upmc.edu

Figure 1. Measuring median nerve cross-sectional area.

Note. (a) Ultrasound probe positioning for measuring median nerve cross-sectional area. (b) Ultrasound machine ellipse tool function and measurements of the median nerve. (A) Edges of median nerve, measured by ellipse tool. (*) Scaphoid. (**) Pisiform. FCR = flexor carpi radialis tendon; S = flexor digitorum sublimis tendons.

CTS, to the present authors' knowledge, none have examined its learning curve.^{8-13,17,18,20,22} Here, we examined the effects of instruction on the accuracy of US measurements of the median nerve in orthopedic surgeons at various levels of training.

Materials and Methods

The study was performed in a cadaver lab at the authors' institution. Twelve participants consisting of 7 orthopedic surgery residents and 5 hand fellows took part in the study. A single fresh-frozen cadaver arm was obtained for use. Appropriate approval was secured through the Committee for Oversight of Research and Clinical Trials Involving Decedents (CORID) at the institution in which the study was performed. The arm was kept in -20°C freezer until 48 hours prior to the study, when it was placed in a 4°C refrigerator to thaw, and kept at room temperature for 2 hours prior to study.

Preinstruction Survey

Prior to completing the US measurements, the participants completed a survey of the following questions:

1. Please indicate any ultrasound techniques you have performed in the past.
2. How confident are you with using ultrasound to diagnose carpal tunnel syndrome?
3. If valid, would you plan on using ultrasound to diagnose carpal tunnel syndrome in your practice?

The answer to question 1 was free form. The answer to question 2 was on a scale of 1 "not at all confident" to 10 "very confident." The answer to question 3 was "yes" or "no."

Preinstruction Measurements

A 15-6 MHz linear array transducer (SonoSite M-Turbo; SonoSite, Bothell, Washington) was used to measure the CSA of the median nerve at the level of the pisiform, using the electronic ellipse function^{11,13,16,18,22} (Figure 1a and 1b). The following instructions were printed on a piece of paper and read by each participant prior to completing the preinstruction measurements.

1. Image the median nerve at the level of the pisiform, in cross-section or "short axis."
2. Take a cross-sectional measurement of the median nerve at the level of the pisiform.
 - a. To measure, first click "Freeze."
 - b. Then click "Caliper" and align the 2 cross-hairs over the radial/ulnar aspects of the nerve using the touchpad, clicking "Select" in between.
 - c. Then click "Ellipse" and again use the touchpad to scale up and down the size of the ellipse to match the contour of the nerve as best you can.
 - d. Click "Select" and use the touchpad as needed to align the cross-hairs of the ellipse and its size.

After the participants were pleased that the ellipse tool represented their desired measurement, the authors (J.A.C. and M.E.S.) recorded the measurement value to the nearest

MUSCULOSKELETAL ULTRASOUND BASICS

- Use lots of gel to transmit ultrasound signal better
- Align leading edge with your (operator's) left
- Tendons are hyperechoic (more white)
- Bones cast shadow below them (black)
- Median nerve appears similar to a "speckled egg"
- Be sure to measure just inside the hyperechoic (white) perineurium of the nerve

Figure 2. Teaching ultrasound basics.

mm² and also recorded if the structure measured by the participant was the median nerve or another structure. The measurement was removed from the US system, and the participants again found and measured the median nerve twice more, for a total of 3 preinstruction measurements. The participants were blinded to each of their measurements so as not to introduce error by participants trying to achieve a consistent measurement value.

Instruction

The participants viewed 3 teaching slides following their preinstruction measurements (Figures 2-4). They were allowed to view each for as long as they would like, and ask questions to the authors (J.A.C. and M.E.S.) about the slides. The US images displayed in the figures were adopted from the European Society of Musculoskeletal Radiology (ESSR) Musculoskeletal Ultrasound Technical Guidelines of the Wrist with expressed permission from the ESSR.⁴

The authors (J.A.C. and M.E.S.) also performed a one-on-one, personalized teaching session with each participant. This was intended to specifically indicate which structure the participant was measuring in their preinstruction measurements—if he or she had not measured the median nerve—and discuss the location and appearance of the median nerve in the image he or she obtained.

Postinstruction Measurements

The participants each completed 3 postinstruction measurements in a similar fashion to that described above for the preinstruction measurements. There was no additional time in-between the preinstruction measurement, teaching, and postinstruction measurements; it took each participant roughly 15 to 20 minutes total to complete.

Postinstruction Survey

After completing the US measurements, the participants completed a survey of the following questions:

4. Do you think the teaching tool was useful in learning how to use ultrasound for the diagnosis of carpal tunnel syndrome?
5. How confident are you with using ultrasound to diagnose carpal tunnel syndrome?
6. If valid, would you plan on using ultrasound to diagnose carpal tunnel syndrome in your practice?

The answer to question 4 was on a scale of 1 "not at all useful" to 10 "very useful." The answer to question 5 was on a scale of 1 "not at all confident" to 10 "very confident." The answer to question 6 was "yes" or "no."

Standard Measurement

Participant measurements were compared with the measurement of a fellowship-trained hand surgeon with extensive experience in US-based diagnosis of CTS (J.R.F.). This was considered the standard measurement.

Power Analysis

A power analysis was conducted to determine the required sample size. Alpha was set at 0.05 and beta at 0.20. If we assumed 25% of measurements would be correct preinstruction, and a significant increase would be indicated by a 55% increase—or 80% correct measurements postinstruction—then our study would need to include 12 participants to achieve adequate power.

Figure 3. Teaching ultrasound anatomy of proximal carpal tunnel.

Source. Reprinted with permission from the European Society of Musculoskeletal Radiology Musculoskeletal Ultrasound Technical Guidelines of the Wrist.

Figure 4. Teaching ultrasound anatomy of distal carpal tunnel.

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Statistical Methods

Descriptive statistics were used to characterize each group. Student's *t* tests were used to compare the averages of any data that were parametric, utilizing a Welch's correction if

the standard deviation was different between the data sets. Mann-Whitney or Wilcoxon matched-pairs signed rank tests were used to compare the averages of any data that were nonparametric. In either case, $P < .05$ was considered significant. A Bland-Altman plot was made comparing the

Figure 5. Bland-Altman plot participant deviation from standard measurement.

participants' measurement deviation from the standard measurement from preinstruction to postinstruction to insure there was no bias.

Results

Correct Measurements

In all, 13 of 36 (36%) of preinstruction measurements correctly identified the median nerve, and this increased to 35 of 36 (97%) for postinstruction measurements ($P = .004$): for residents, 8 of 21 (38%) versus 21 of 21 (100%) ($P = .063$), and for fellows, 5 of 15 (33%) versus 14 of 15 (93%) ($P = 0.125$). Of the 24 incorrect measurements, 15 of 24 (62%) were ulnar to the median nerve and usually identified a flexor digitorum sublimis tendon. Nine of 24 (38%) were radial to the median nerve and usually identified the flexor carpi radialis tendon. Notably, each participant who imaged the incorrect structure would continue to err on the same side. Only 1 participant identified a structure radial and in a subsequent measurement identified a structure ulnar to the nerve.

Measurement Values

Measurements that were taken of the incorrect structure were discarded for this and all subsequent statistics. In all participants, the average preinstruction measurement was 4.8 mm² (95% confidence interval [CI]: 4.2-5.3 mm²), which changed to an average postinstruction measurement of 5.2 mm² (4.8-5.6 mm²) ($P = .187$): for residents, 5.1 mm²

(4.6-5.7 mm²) versus 5.1 mm² (4.5-5.7 mm²) ($P = .961$), and for fellows, 4.2 mm² (2.8-5.6 mm²) versus 5.3 mm² (4.9-5.7 mm²) ($P = .091$).

Deviation From Standard Measurement

In all participants, the average preinstruction measurement deviation from the standard measurement was -1.2 mm² (95% CI: -1.8 to -0.7 mm²), which changed to an average postinstruction measurement deviation of -0.8 mm² (-1.2 to -0.4 mm²; $P = .187$; Figure 5): for residents, -0.9 mm² (-1.4 to -0.3) versus -0.9 mm² (-1.5 to -0.3) ($P = .961$), and for fellows, -1.8 mm² (-3.2 to -0.4) versus -0.7 mm² (-1.1 to -0.3) ($P = .091$).

Measurements Within 1 mm² of Standard Measurement

In all, 8 of 13 (62%) of preinstruction measurements (of the correct structure) correctly identified the median nerve and were within 1 mm² of the standard measurement, increasing to 26 of 35 (74%) of postinstruction measurements ($P = .481$): for residents, 7 of 8 (88%) versus 14 of 21 (67%) ($P = .381$), and for fellows, 1 of 5 (20%) versus 12 of 14 (86%) ($P = .017$).

Preinstruction and Postinstruction Surveys

Survey questions 2 and 5 asked each participant to rate on a scale of 1 to 10 how confident they were with using US to

diagnose CTS both before and after the study, respectively. In all participants, the average rating was 2.4 before the study (95% CI: 1.4-3.5) and increased to 6.5 after (5.4-7.6) ($P < .0001$): for residents, 1.9 (0.4-3.3) versus 7.1 (5.9-8.4) ($P = .0001$), and for fellows, 3.2 (1.2-5.2) versus 5.6 (3.0-8.2) ($P = .024$). Interestingly, the single participant to measure the incorrect structure post instruction rated his or her confidence at a 2 of 10 before instruction and a 6 of 10 after instruction. Survey questions 3 and 6 asked each participant whether or not if valid, they would plan to use US to diagnose CTS in their practice. All participants answered yes, both before and after the study. Survey question 4 asked each participant to rate on a scale of 1 to 10 whether the teaching tool was useful in learning how to use US for the diagnosis of CTS. In all participants, the average rating was 8.6 (95% CI: 7.5-9.6): for residents, 8.9 (8.0-9.7), and for fellows, 8.2 (5.1-11.3).

Discussion

This study indicates that without teaching, about 2 in 3 measurements were of the incorrect structure, which validates the concerns of many who feel that operator error or inexperience is of paramount importance to prevent the deleterious effects of invalid measurements.¹⁸ Subjects unfamiliar with the characteristic appearance of the nerve on US tend to measure a tendinous structure instead of the nerve—the flexor carpi radialis radially and a flexor digitorum sublimis tendon ulnarly. However, with appropriate teaching, orthopedic residents and fellows quickly learned to correctly identify the median nerve. At the conclusion of the instruction, only 1 out of 36 measurements was of the incorrect structure. Furthermore, participants' confidence in performing US to diagnose CTS elevated from an average of 2.4 before the instruction to 6.5 after on a 10-point scale. While the overall increase in confidence and that pertaining to the residents was significant, there was not a significant increase in confidence in the fellows group. This may be due to the smaller sample size of participants in this group, or could demonstrate that for some reason the fellows initially reported higher confidence, but potentially after learning they imaged the incorrect structure felt less confident, even after imaging the correct structure subsequently. In addition, all participants indicated that if valid, they would use US in their practice. Despite a low rate of identifying the incorrect structure (3%) after teaching, the question remains as to what is an acceptable rate of identifying the wrong structure. If surgical decisions are being made on this information, a 3% rate may be too high. However, magnetic resonance imaging (MRI) for full-thickness rotator cuff tears is accurate in 97% to 99% of cases, and most surgeons would feel comfortable making a surgical decision with that level of accuracy. In addition, this study only evaluated a short training session. One would expect that a sur-

geon would not use ultrasound for surgical indications until additional training had been performed.

The study results demonstrated that the percentage of measurements that were both of the correct structure and within 1 mm² of the standard measurement increased from 62% to 74% ($P = .481$). The 1-mm² cutoff was chosen as this level of disagreement could lead to the difference between a positive diagnosis and a negative diagnosis. This suggests that perhaps identifying the structure itself is the key teaching point, while measuring it using the US machine is already acceptable. The mean deviation from the expert examiner's measurement was 0.8 mm². It is also encouraging that examiners tended to measure the nerve as smaller than the expert examiner. This could result in a higher rate of false negatives, but it would result in a lower rate of false positives, possibly preventing overtreatment.

The present study was not without limitations. Although there were a similar number of resident and fellow participants, the sample size was admittedly small. A future study would benefit from a larger sample size, and perhaps including more of the gamut of orthopedic trainees, including medical students and practicing surgeons. An additional limitation is that the cadaveric specimen used in the study had a normal-sized median nerve CSA of 6 mm². Combined with the fact that the US machine used can only read to the nearest 1 mm², small variations afford a larger error than if a larger median nerve CSA specimen was used. Fortunately, individuals with CTS have median nerve CSA of 10 mm² and above, allowing latitude for variability in measurements without affecting the overall outcome. Although this cutoff value may vary on an individual basis, it has been advocated as a benchmark for ease of use in daily practice by certain authors.^{8,10,18} Furthermore, the utilization of the ellipse tool for CSA measurement may have been inadequately taught, leading to a persistent discrepancy in participants' final measurements. Also, the same specimen was measured a total of 6 times by each participant by the end of the study, which could partially account for the observed improvement. A future study would benefit from including a comparison group to control for this. In addition, if the participants were to take measurements again at a later date, retention of the teaching could be studied as well. It would be helpful to see whether the training would be generalizable to different specimens and/or settings in which median nerve CSA was abnormal in future studies as well. Finally, the reference standard used is admittedly still operator dependent, and a future study would benefit from choosing an unbiased standard, such as an MRI measurement, or even dissection of the cadaveric specimen and direct measurement. However, direct measurement of the nerve can prove difficult as US measures inside the epineurium (direct measurement would be outside the epineurium), and the CSA on direct measurement would be highly susceptible to how "tight" the calipers were placed against the nerve.

The present study used only a single specimen, as opposed to using multiple specimens, which limited the authors' ability to examine interrater reliability across measurements of multiple, variable-sized nerves. Other studies have examined the reliability of US in measuring the median nerve CSA at the carpal tunnel inlet, and we felt that doing the same thing in this study would be redundant. Aleman et al used 2 observers to measure 22 wrists in patients who had CTS. They found acceptable interrater reliability measured by Pearson product coefficient with value of 0.833 for direct measurement technique and 0.802 for indirect measurement technique.¹ Impink et al also used 2 observers to measure 20 wrists of 15 able-bodied and 5 wheelchair-bound individuals. They found high interrater reliability measured by dependability D-study model, with phi value 0.632 at the level of the pisiform.¹⁴ Fowler et al used 3 observers to measure 22 wrists from 11 hand fellows and hand therapist volunteers. They found moderate interrater reliability with a Lin concordance correlation coefficient (LCCC) of 0.59.¹¹ A future study with design allowing for a large number of participants, multiple wrists on which to take measurements, and the intervention of teaching would be interesting to examine the interrater reliability both before and after teaching, especially in US-naïve individuals across all levels of training.

There also exist other methodologies for using US to verify the diagnosis of CTS. These include the ratio between CSA of the median nerve at the carpal tunnel and at the midforearm, retinacular thickness, and flattening ratio of the median nerve.^{19,20,21} Examination of CSA at the level of the carpal tunnel inlet has remained the most popular and commonly used parameter for CTS diagnosis.²¹ Although the present study only examined the latter method, a future study would benefit from identifying and testing instructional methods for other measurements as well to obtain more comprehensive measurements.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Institutional approval was obtained for cadaveric specimen included in the study.

Statement of Informed Consent

Informed consent was obtained from all individual participants included in the study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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