

ORIGINAL ARTICLE

Cross-sectional Area Ratio of Median-to-Ulnar and Median-to-Superficial Radial Nerve at the Wrist for Diagnosis of Carpal Tunnel Syndrome

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Objectives: This study aimed to evaluate the diagnostic properties for carpal tunnel syndrome (CTS) of the median-to-ulnar cross-sectional area ratio (MUR) and the median-to-superficial radial cross-sectional area ratio (MRR). **Methods:** A case-control study was conducted. A physician, blinded to the CTS status of the subjects, assessed the cross-sectional area of the median nerve (CSA-m), MUR, and MRR at the distal wrist crease for the CTS and control groups. The relationship of CSA-m, MUR, and MRR with CTS severity was tested using Spearman's correlation. The overall diagnostic accuracy was determined using the area under the receiver operating characteristic curve (AUC). The cut-off values to diagnose CTS were chosen to achieve similar values for sensitivity and specificity. **Results:** There were 32 hands in the CTS group and 33 hands in the control group. The correlations of CSA-m, MUR, and MRR with CTS severity were 0.66, 0.56, and 0.34, respectively. The AUCs of CSA-m, MUR, and MRR were 0.86 (95%CI: 0.77–0.95), 0.79 (0.69–0.90), and 0.69 (0.56–0.82), respectively. The cut-off values of CSA-m, MUR, and MRR were 12 mm² (sensitivity, 81.3%; specificity, 81.8%), 2.6 (sensitivity, 68.8%; specificity, 69.7%), and 10 (sensitivity, 65.6%; specificity, 63.6%), respectively. **Conclusions:** MUR and MRR had acceptable diagnostic abilities but did not show superiority over CSA-m for CTS diagnosis.

Key Words: ultrasonography; median nerve; ulnar nerve; superficial radial nerve; carpal tunnel syndrome

INTRODUCTION

Median neuropathy at the wrist, or carpal tunnel syndrome (CTS), is the most common compressive neuropathy¹⁾ with a prevalence of 7.8% among the working population.²⁾ The diagnosis of CTS normally relies on patient history and physical examination. For diagnostic tests of CTS, nerve conduction studies (NCS) are considered the gold standard diagnostic tool.³⁾ Additionally, the severity of CTS is graded using the degree of abnormality of sensory and/or motor NCS findings.^{4,5)}

Neuromuscular ultrasound (US) is another diagnostic test that is increasingly used as a standard assessment for nerve

and muscle diseases.⁶⁾ Swelling of the proximal nerve at the entrapment site is the typical clinical finding of compressive neuropathies.^{6,7)} The cross-sectional area of the median nerve (CSA-m) at the wrist is commonly used to determine the extent of nerve swelling.⁸⁾ However, the cut-off value for a swollen median nerve at the wrist would likely differ across studies depending on the population and sonographic techniques.^{9–12)} To reduce the effect of patients' idiosyncratic characteristics on CSA-m at the wrist, the ratio of CSA-m at the wrist to that at the forearm has been suggested. However, the measurement of CSA-m was found to be less reliable at the forearm than at the wrist.¹³⁾ Therefore, ratios of the CSA of the median nerve and other nerves of the wrist, such as the

Received: May 19, 2022, Accepted: July 5, 2022, Published online: July 22, 2022

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ulnar (CSA-u) or superficial radial (CSA-r) nerves, could be considered.

Some previous studies used CSA-u as an internal control and were conducted to establish the overall diagnostic value of the median-to-ulnar cross-sectional area ratio (MUR) at the wrist for CTS diagnosis.^{14–17} However, the results showed no statistically significant superiority of MUR over CSA-m.^{14–16} To the best of our knowledge, no studies using the median-to-superficial radial cross-sectional area ratio (MRR) to diagnose CTS have been conducted. To investigate whether MRR may be a new helpful evaluation for CTS, the present study aimed to assess the overall diagnostic accuracy of MUR and MRR and to establish the most effective cut-off point of MUR and MRR for diagnosing CTS.

MATERIALS AND METHODS

Participants and Study Design

A case–control study with convenience sampling was conducted on Thai adults (18 years or older) from August 2019 to May 2020. Inclusion criteria for the CTS group were clinical and electrophysiological findings of CTS, whereas, for the control group, subjects who had no history of hand numbness were recruited. However, patients with CTS who were suspected of having other neurological diseases (such as peripheral neuropathy, nerve injuries, or cervical radiculopathy), wrist deformities, a history of wrist surgery, or carpal tunnel steroid injection were excluded. Moreover, participants in either group who had a bifid median nerve were excluded from the study. Participants received an ultrasonographic imaging assessment on the day they were enrolled.

Ethical Considerations

Ethical approval for this study was obtained from the Institutional Review Board, Royal Thai Army Medical Department (IRB number: R080h/62), and all subjects provided written informed consent for participation in the study.

Nerve Conduction Studies

Nerve conduction studies were performed for all participants in the CTS group to confirm their diagnosis using either Nicolet VikingQuest (Natus Medical, San Carlos, CA, USA) or Synergy On Nicolet EDX systems (Natus Medical). The NCS protocol for CTS in this study consisted of a 14-cm sensory nerve conduction study and an 8-cm motor nerve conduction study of the median and ulnar nerves on both hands. The normal values adopted by Shan Chen and colleagues were used.¹⁸ For the median nerve, distal sensory

latency (DSL) ≤ 4.0 ms, distal motor latency (DML) ≤ 4.5 ms, and compound muscle action potentials (CMAPs) amplitude ≥ 4.1 mV were considered to be normal results, whereas for the ulnar nerve, DSL ≤ 4.0 ms, DML ≤ 3.7 ms, and CMAPs amplitude ≥ 7.9 mV were considered to be normal results. Also, the electrophysiological severities of CTS were categorized into three groups, mild, moderate, and severe, based on the grading criteria of Stevens.⁵

Ultrasonographic Studies

Ultrasonographic studies were performed on all participants in both groups by a single physiatrist with 7 years of experience in neuromuscular US. The US examiner was blinded with respect to the group to which participants belonged. The US investigations were conducted using a SONIMAGE HSI (Konica Minolta, Tokyo, Japan) with an L18-4 linear array transducer. Participants were examined in the sitting position with their wrists resting in a neutral position during the examination. The CSAs (mm^2) of the median, ulnar, and superficial radial nerves were measured at the distal wrist crease by tracing the margin of the nerves using a free-hand drawing tool. CSA measurements were performed once for each nerve.

Statistical Analysis

The sample size determination was based on the area under the receiver operator characteristics curve (AUC). An alpha level of 0.05 and a beta level of 0.1 were selected. A total sample size of 50 hands (25 hands for each group) was required if an expected AUC of 0.75 was set for MUR.¹⁵ The baseline characteristics are presented as means with standard deviations for continuous data and as the number count with percentages for categorical data. Mean values of continuous variables in the CTS and control groups were compared using unpaired *t*-tests. Spearman's correlation analysis was carried out to evaluate the relationship between two variables because one or both variables were skewed or ordinal. Overall diagnostic accuracy was determined using the AUC of the receiver operating characteristic curve, and a cut-off value was selected that approximately equalized sensitivity and specificity.¹⁹

RESULTS

A total of 44 eligible participants (23 cases and 21 controls) were prospectively enrolled in the study. Most participants were women (79.1%) with a mean (SD) age of 50.9 (12.3) years. Due to bifid median nerves, five hands in the CTS

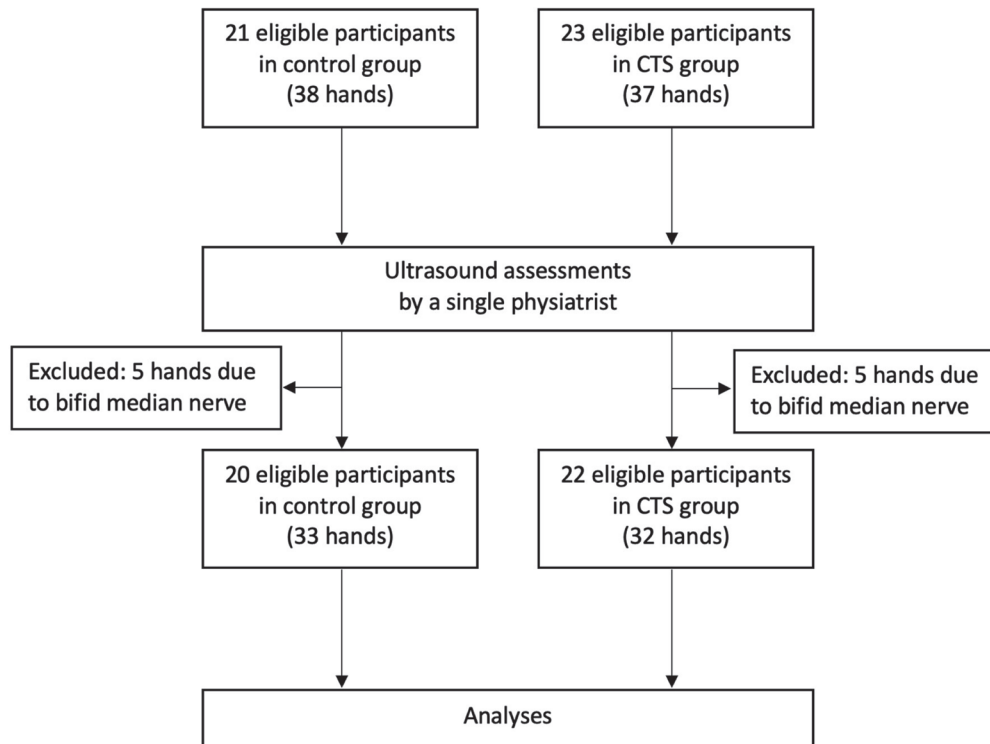


Fig. 1. Flow diagram of patient enrolment and selection. CTS, carpal tunnel syndrome.

group and another five hands in the control group were excluded. Consequently, there were 33 hands (20 participants) in the control group and 32 hands (22 participants) in the CTS group (**Fig. 1**). In the CTS group, 37.5%, 46.9%, and 15.6% were graded with mild, moderate, and severe degree CTS, respectively. The median (min–max) symptom duration in the CTS hands was 5 (1–72) months.

The correlation coefficients of CSA-m, MUR, and MRR with CTS severity (no, mild, moderate, severe) were 0.66 ($P < 0.0001$), 0.56 ($P < 0.0001$), and 0.34 ($P = 0.005$), respectively. Moreover, for the 32 CTS hands, there was no significant correlation between symptom duration and CSA-m ($r_s = 0.11$, $P = 0.53$), MUR ($r_s = -0.16$, $P = 0.36$), or MRR ($r_s = 0.02$, $P = 0.91$). The average values of CSA-m, MUR, and MRR for CTS hands were significantly greater than those for control hands ($P < 0.0001$, $P = 0.0001$, and $P = 0.003$, respectively) (**Table 1**). There were no statistically significant differences of CSA-u ($P = 0.37$) or CSA-r ($P = 0.27$) between the CTS and control groups. The AUC of CSA-m, MUR, and MRR was 0.86 (95%CI: 0.77–0.95), 0.79 (0.69–0.90) and 0.69 (0.56–0.82), respectively (**Fig. 2**). Additionally, the accuracy, sensitivity, and specificity of the cut-off values for each US parameter are presented in **Table 2**.

Table 1. Ultrasonographic parameters of CTS and control hands

	CTS hands (n = 32)	Control hands (n = 33)	P-value
CSA-m (mm ²)	14.1 (3.2)	10.0 (2.5)	<0.0001*
CSA-u (mm ²)	4.3 (1.3)	4.6 (1.3)	0.37
CSA-r (mm ²)	1.4 (0.7)	1.2 (0.4)	0.27
MUR	3.7 (1.7)	2.3 (0.8)	0.0001*
MRR	11.8 (5.0)	8.7 (2.9)	0.003*

Data are shown as the mean (standard deviation).

CSA-m, cross-sectional area of median nerve; CSA-u, cross-sectional area of ulnar nerve; CSA-r, cross-sectional area of superficial radial nerve; MUR, median-to-ulnar cross-sectional area ratio; MRR, median-to-superficial radial cross-sectional area ratio.

* $P < 0.05$, by unpaired t-test.

DISCUSSION

The primary aim of this study was to evaluate the overall diagnostic accuracy of MUR and MRR. The main findings showed that MUR (AUC, 0.79) and MRR (AUC, 0.69) had acceptable diagnostic abilities,²⁰ but were not superior to

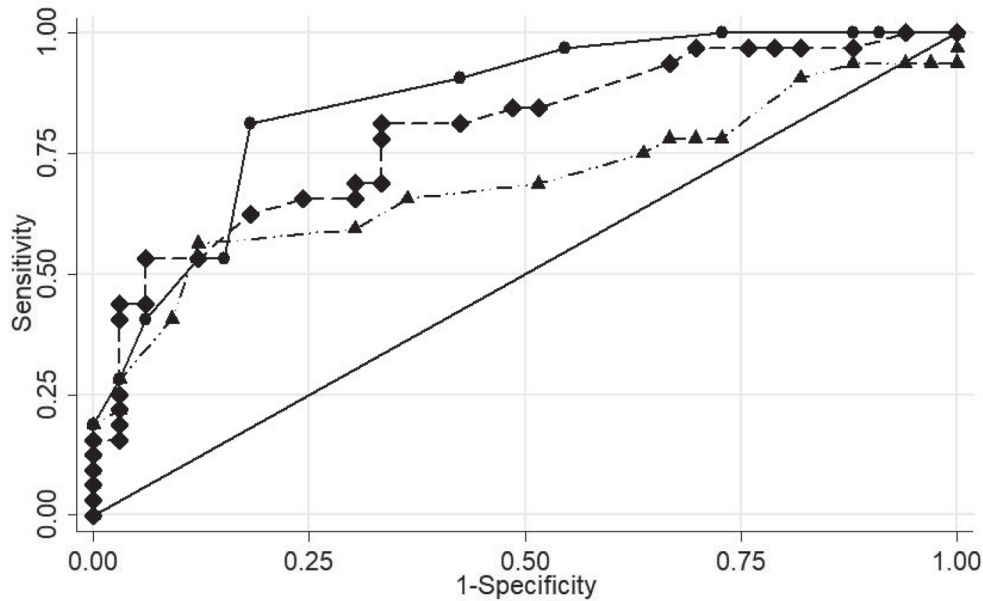


Fig. 2. Receiver operating characteristic curves for cross-sectional area of median nerve (circles), median-to-ulnar cross-sectional area ratio (diamonds), and median-to-radial cross-sectional area ratio (triangles).

Table 2. Accuracy, sensitivity, and specificity of the optimal cut-off value selected for each parameter

	Accuracy (95%CI)	Sensitivity (95%CI)	Specificity (95%CI)
CSA-m ≥ 12 mm ²	81.5% (69.9%–90.1%)	81.3% (63.6%–92.8%)	81.8% (64.5%–93.0%)
MUR ≥ 2.6	69.2% (56.5%–80.1%)	68.8% (50.0%–83.9%)	69.7% (51.3%–84.4%)
MRR ≥ 10	64.6% (51.8%–76.1%)	65.6% (46.8%–81.4%)	63.6% (45.1%–79.6%)

CSA-m (AUC, 0.86) in CTS diagnosis. However, overlapping confidence intervals of the AUCs for all three US parameters were observed. The results of overall accuracy were consistent with the study of Atan and Gunendi, which reported an AUC of 0.83 (95%CI: 0.75–0.91) for MUR and 0.89 (0.83–0.95) for CSA-m.¹⁴⁾ In contrast with the current study, however, some previous studies suggested that MUR was comparable or superior to CSA-m.^{15,16,21)} For example, Jiwa et al. reported that the AUCs of MUR and CSA-m were 0.91 (95%CI: 0.84–0.97) and 0.92 (0.86–0.99), respectively, whereas El-Bahnasawy et al. measured the AUCs of MUR and CSA-m as 0.89 (0.86–0.94) and 0.79 (0.71–0.87), respectively.

In the present study, CSA-m had the highest overall accuracy among the three US parameters tested. This observation

could be explained by the fact that measurements of CSA-m at the carpal tunnel inlet are easy to perform and have excellent reliability.^{13,16,22)} In contrast, CSA-u and CSA-r measurements reportedly exhibit poor to moderate reliability.^{16,22,23)} Conversely, MRR provided the lowest diagnostic accuracy. This result might indicate that CSA-r is a poor internal control for determining the swelling of the median nerve at the carpal tunnel inlet. Furthermore, this could explain why the study of Bae and An found no correlation of CSA-r with the subjects' height, weight, or BMI, and no difference in CSA-r between age groups or genders.²⁴⁾

In the current study, MUR ≥ 2.6 (sensitivity, 68.7%; specificity, 69.7%) was chosen as the cut-off value. Five previous studies have also determined a cut-off value of MUR for CTS diagnosis. In 2016, the study of Yurdakul et

al. reported MUR ≥ 1.79 as a cut-off value with a sensitivity of 70% and a specificity of 76%.¹⁷⁾ In 2018, Atan et al. revealed that MUR ≥ 2.95 provided a sensitivity of 86% and a specificity of 72%,¹⁴⁾ whereas the study of Jiwa et al. selected MUR ≥ 2.09 as a cut off with a sensitivity of 86% and a specificity of 84%.¹⁶⁾ In 2019, Chang et al. found that MUR ≥ 3.28 produced a sensitivity of 63% and a specificity of 84%.¹⁵⁾ Lastly, in 2020, El-Bahnasawy et al. reported that MUR ≥ 2.97 achieved a sensitivity of 84% and a specificity of 88%.²¹⁾ Clearly there is variation in the optimal cut-off value of MUR chosen across different studies and in the overall performance achieved. These variations might result from differences in the US protocol and machine, the study population, and the criteria for CTS diagnosis. Because US examinations are highly operator dependent, each institution might have its own preferred US protocol. It is difficult to unify US protocols across different institutions. As a result, determining the cut-off value for MUR separately for each US setup is recommended.

Additionally, CSA-m and MUR had moderate positive correlations with CTS severity, whereas MRR had a low positive correlation with CTS severity. For CSA-m, the current result was similar to those of previous studies in which positive correlations of 0.52–0.61 were found.^{25–27)} No previous study has evaluated the correlation between MUR and CTS severity, but the study of Jiwa et al. found a low positive correlation ($r_s=0.34$, $P=0.03$) between MUR and median nerve DML.¹⁶⁾

There are some limitations of the present study that should be taken into consideration. Confidence intervals of the diagnostic properties were large because of the relatively small sample size. Therefore, these findings should be interpreted cautiously. Inter-rater and intra-rater reliability was not evaluated because the measurements were carried out by a single experienced US operator. Also, because the present study was a case–control study, the findings could have been affected by spectrum bias.²⁸⁾ Lastly, in the current study, NCS was not performed to confirm that the control group did not have CTS. However, the study results showed that CSA-m was significantly lower in the control group than in the CTS group. Therefore, it is unlikely that there were subjects with asymptomatic CTS in the control group.

CONCLUSIONS

The overall accuracies of MUR and MRR for CTS diagnosis were acceptable but were found not to be superior to that of CSA-m. However, in studies where other nerves are used

as an internal control to determine the degree of swelling of the median nerve at the wrist, the ulnar nerve can be recommended rather than the superficial radial nerve. Inconsistent results concerning MUR across studies suggest that a larger prospective cohort study would be informative.

ACKNOWLEDGMENTS

The authors would like to acknowledge all participants and staff at Phramongkutkiao hospital who supported and helped us conduct the study and to thank Dr. Jamie Alexander O'Reilly who helped proofread the manuscript.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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