Skeletal Radiology (2020) 49:397–405
https://doi.org/10.1007/s00256-019-03291-0

SCIENTIFIC ARTICLE

MRI criteria for diagnosis and predicting severity of carpal tunnel syndrome

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Received: 8 June 2019 / Revised: 24 July 2019 / Accepted: 26 July 2019 / Published online: 9 August 2019

Abstract

Objective To study MRI criteria for diagnosing and predicting severity of carpal tunnel syndrome (CTS).

Methods Sixty-nine wrists in 41 symptomatic CTS patients and 32 wrists in 28 asymptomatic subjects were evaluated by MRI. Circumferential surface area (CSA), flattening ratio, relative median nerve signal intensity, and retinacular bowing were measured. CTS severity was classified as mild, moderate, or severe. Parameters for patients with and without CTS and for the three severity groups were compared. ROC curves were plotted to assess accuracy for CTS diagnosis and severity prediction.

Results Significant differences were found between CTS and control wrists for median nerve CSA, flattening ratio at inlet, relative median nerve signal intensity, and retinacular bowing. ROC curve analysis revealed a sensitivity, specificity, and accuracy of median nerve CSA > 15 mm^2 proximal to the tunnel (CSA_p) of 85.5, 100, and 90.1%. Using either CSA_p or CSA_d > 15 mm^2 as a diagnostic criterion, MRI could achieve a sensitivity of 100% and specificity of 94% for diagnosis of CTS while overall accuracy was 98%.

Significant differences were found among the three severity groups. Sensitivity, specificity, and accuracy of prediction of severe CTS using for CSA_p > 19 mm^2 were 75.0, 65.9, and 69.6%, respectively.

Conclusions MRI is highly accurate at diagnosing CTS and moderately accurate at determining CTS severity. We recommend using CSA > 15 mm^2 either proximal to or distal to the tunnel as a diagnostic criterion for CTS and CSA > 19 mm^2 proximal to the tunnel as a marker for severe CTS.

Keywords MRI · Wrist · Carpal tunnel syndrome · Median nerve · Entrapment

Introduction

Carpal tunnel syndrome (CTS) is the most common type of neural entrapment [1–3]. Nerve entrapment is due to impingement, most commonly at the tunnel inlet [4–9], though also at the tunnel outlet [10–12]. Median nerve impingement leads to neural edema with disruption of axoplasmic flow [13, 14].

The current standard for diagnosis of carpal tunnel syndrome comprises clinical assessment and nerve conduction testing [15]. Clinical assessment and nerve conduction testing are also used to segregate patients as mild, moderate, or severe CTS. However, nerve conduction testing (NCT) is recognized to be associated with a false-negative rate of about 10% and a false-positive rate of about 15% [15–19]. NCT is uncomfortable for the patient and cannot distinguish primary from secondary CTS. As a result, imaging plays a role in the diagnosis of CTS and also potentially in assessing the severity of disease. Over the past 15 years, both ultrasound and MRI have been increasingly used to diagnose CTS but the sensitivity and accuracy are still controversial, and clear diagnostic criteria, especially for MRI, have not been fully established [5–8, 11, 20]. This hinders the wider acceptance of MR or ultrasound to replace NCT in the diagnosis of CTS [4–6, 8, 10].

Almost all studies have focused on discriminatory parameters proximal to or within the carpal tunnel. Examination of the tunnel outlet area seems to enable additional capture of those patients that have a swollen median nerve only at the tunnel outlet area. A recent ultrasound-based study has shown

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how acquiring diagnostic criteria at the tunnel outlet in addition to the tunnel inlet can increase the diagnostic accuracy of ultrasound examination [21]. However, one cannot directly apply ultrasound criteria to MRI, as there is discrepancy in median nerve CSA measurements obtained by MRI and ultrasound [22]. One MR study has found no relationship between CSA distal to carpal tunnel and CTS [6]. Otherwise, no previous study has assessed the diagnostic value of measuring median nerve CSA distal to the carpal tunnel. In this MRI-based study, new diagnostic criteria were applied in patients with CTS to determine the diagnostic accuracy of MRI.

Methods

Patients and subjects

Approval for this prospective observational study was obtained from the local ethics committee with informed consent being provided by all patients. The study cohort comprised patients with CTS diagnosed clinically between April 2013 and May 2016 and a comparable number of control subjects. Patients prone to secondary CTS such as those with diabetes mellitus, gout, an inflammatory arthropathy, or previous distal radial fracture were excluded. The study cohort comprised 69 wrists of 41 CTS patients (five male, 36 female, average age 56.6 ± 6.8 years, range, 40–76 years) in which 28 patients had bilateral and 13 patients had unilateral disease. There were 36 left wrists and five right wrists. Forty-four (64%) of the 69 wrists had subsequent carpal tunnel release with symptomatic relief in all cases.

The age- and sex-matched control group comprised 32 wrists from 28 asymptomatic subjects (six males, 22 females, mean age 55.3 ± 16.7 years, range, 19–80 years). There were 15 left wrists and 17 right wrists. Since nerve conduction test is an invasive procedure, this was not undertaken on asymptomatic subjects. All control subjects and patients were assessed by an orthopedic hand surgeon with more than 20 years of experience. A diagnosis of CTS was made based on typical clinical symptoms supported by a positive nerve conduction test according to American Academy of Neurology standards [18]. A delay of more than 0.4 ms between median and ulnar sensory peak latencies or a prolonged median distal motor latency of more than 4 ms was taken as confirmatory electrophysiological evidence of CTS. Grading of CTS severity was undertaken by the same orthopedic surgeon based on symptom severity, objective clinical signs, and NCT (AAEM) [19, 23] as follows:

Mild CTS: Intermittent pain and paresthesia with a normal clinical examination; < 15% prolongation of motor ± sensory latencies.

Moderate CTS: Constant symptoms, with a decrease in fine touch and pin prick but normal two-point discrimination and no thenar muscle weakness; 15–30% prolongation of motor ± sensory latencies.

Severe CTS: Marked sensory loss, including decreased two-point discrimination and thenar muscle weakness; > 30% prolongation of motor ± sensory latencies.

Of the 69 wrists, 21 (30%) were classified as mild, 20 (29%) as moderate, and 28 (41%) as severe CTS.

MRI technique and analysis

All patients and control subjects underwent MRI assessment. The orthopedic surgeon was blinded to the MRI findings. All MRI examinations were performed on a 3-T imaging system (Philips Achieva X-series, Best, Netherlands) using an eight-element phased array wrist coil. The wrist was examined in a pronated position with the arm adducted above the head. The MRI protocol comprised an axial proton density with and without fat-suppression sequence. The total scan time was approximately 10 min. MRI parameters were as follows: TR/TE = 30 ms/3000 ms, 2.5-mm slice thickness, 0.5-mm intersection gap, 8-cm field of view (FOV), three excitations (NEX), 300 × 218 matrix (fat-suppressed sequence), and 472 × 327 matrix (non-fat-suppressed sequence). All parameters were assessed in each patient and control subject.

The radiologist (reader 1), with 15 years of MSK radiology experience, who measured the parameters was blinded to the CTS grading severity by the orthopedic surgeon. Median nerve measurements were made on an Osirix workstation after digital zooming and contrast adjustment to optimize median nerve delineation. Median nerve cross-sectional area (CSA) and major and minor axes were measured at four different levels, namely immediately proximal to the tunnel inlet (CSA_p), at the tunnel inlet (CSA_i), at the tunnel outlet (CSA_o), and immediately distal to the tunnel outlet (CSA_d). CSA was measured using a continuous tracing method along the outer border of the median nerve (Figs. 1, 2) on non-fat-suppressed images. The carpal tunnel was identified through recognition of the proximal and distal ends of the transverse carpal ligament. 'Proximal to the tunnel' was defined as immediately proximal to the tunnel inlet just before the nerve dips deep to enter the carpal tunnel. The tunnel inlet and outlet locations were deep to the proximal and distal margins of the transverse carpal ligament respectively. 'Distal to the tunnel' was defined as immediately distal to the tunnel just after the median nerve emerges from underneath the transverse carpal ligament (Figs. 1, 2). The ratio change in median nerve CSA from proximal to the tunnel (CSA_p) to the tunnel inlet (CSA_i) was expressed as CSA_p divided by CSA_i (or $CSA_{p/i}$), Similarly, the ratio change in median nerve CSA from the from the tunnel outlet (CSA_o) to just distal to the tunnel outlet (CSA_d) was expressed as CSA_d divided by CSA_o (or $CSA_{d/o}$). Flattening ratio (FR) of the median nerve was defined as the major axis divided by the minor axis.

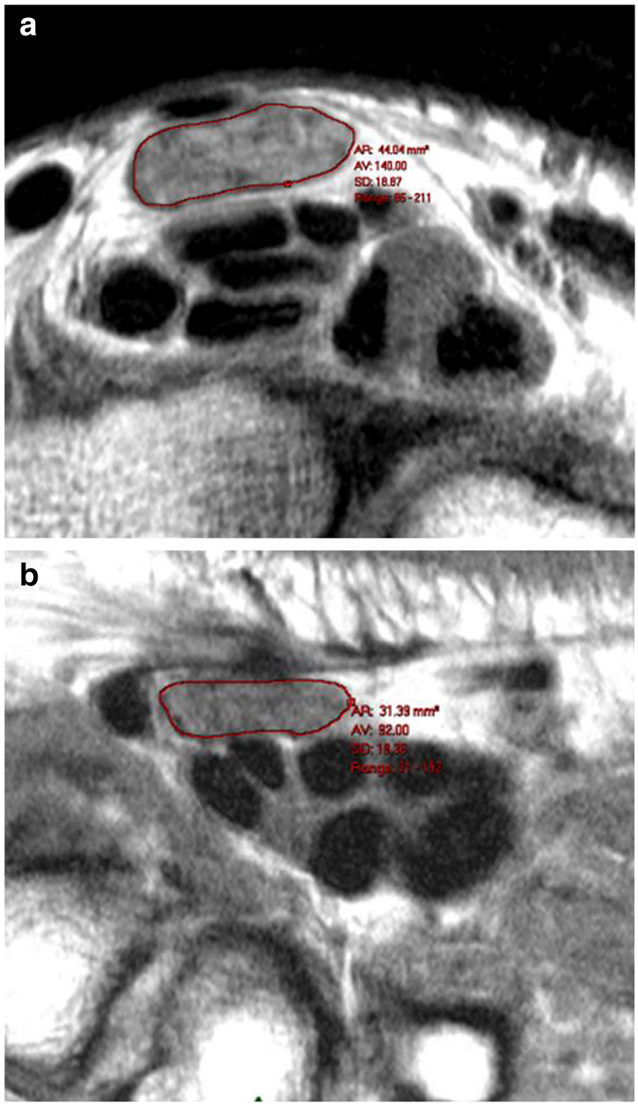

Fig. 1 **a** Proton density axial MR image of a 51-year-old woman with CTS proximal to the carpal tunnel. The median nerve CSA outlined by the *solid line* is increased (44.04 mm^2). **b** Proton density axial MR image of the same patient distal to the carpal tunnel. The median nerve CSA outlined by the *solid line* is also increased (31.39 mm^2) but to a lesser degree than proximal to the carpal tunnel

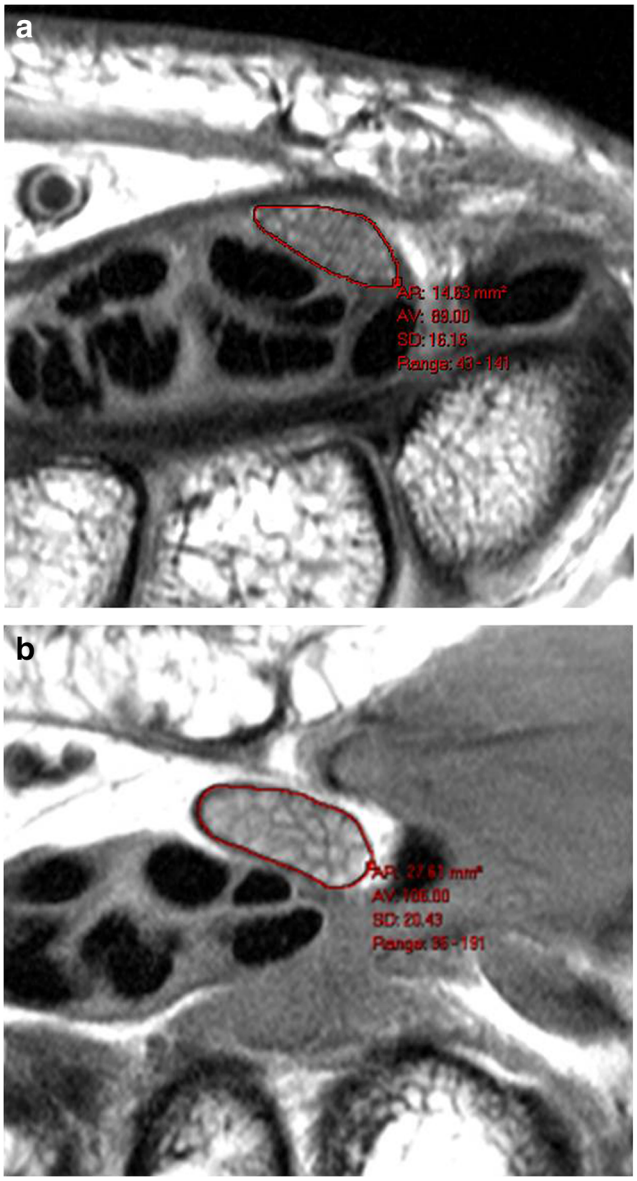

Fig. 2 **a** Proton density axial MR image of another 50-year-old woman with CTS proximal to the carpal tunnel. The median nerve CSA outlined by the *solid line* is mildly enlarged (14.63 mm^2) but less than 15 mm^2 (the designated optimal cut-off value). **b** Proton density axial MR image of the same patient distal to the carpal tunnel. Median nerve CSA outlined by the *solid line* is markedly increased (27.61 mm^2)

Median nerve edema as reflected by T2-hyperintensity was also measured. The signal intensity (SI) ratio was obtained by dividing median nerve SI by the hypothenar muscle SI at the level of the tunnel outlet (Fig. 3) [24]. Maximum median nerve signal intensity was measured at the proximal to tunnel level.

Palmar retinacular bowing (BR) was measured at the inlet and outlet levels and defined as the height from the deep margin of the retinaculum perpendicular to a tangential line drawn between the most volar aspects of the pisiform and scaphoid bones at the tunnel inlet or the trapezium and hook of hamate at the tunnel outlet (Fig. 4). A positive value designated a palmar reticulum above the tangential line while a negative value designated a palmar retinaculum below the tangential line.

To test inter-reader reliability, another staff radiologist (reader 2) with MSK specialty experience more than 5 years, independently measured the same MR parameters on each MR examination of all the patients and compared these to the previous radiologist's findings. The same parameters were further measured after 4 weeks by the same radiologist who did the first examination (reader 1) blinded to the initial findings.

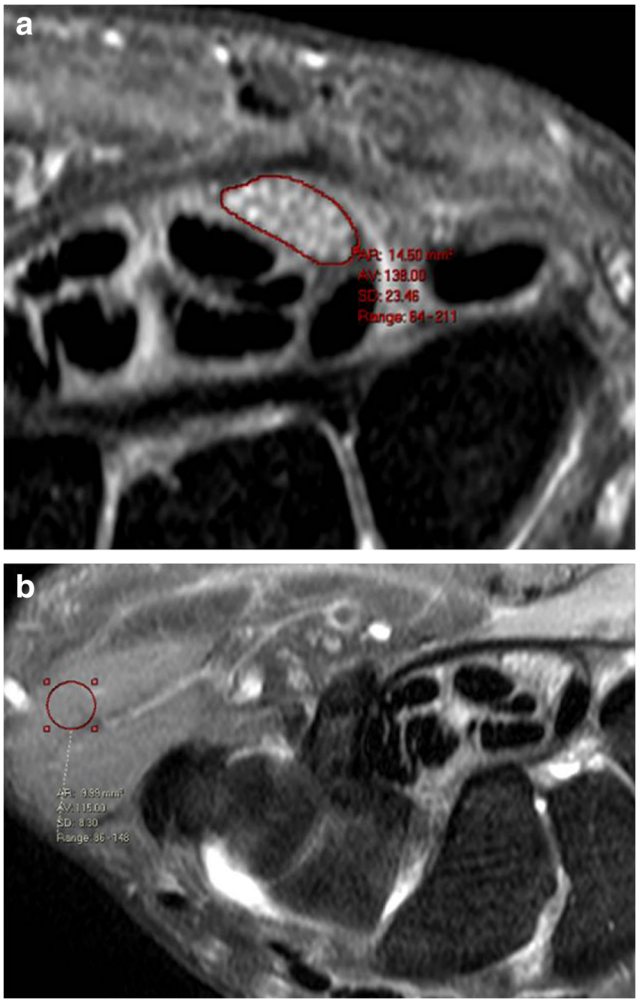

Fig. 3 **a** Proton density fat-saturated axial MR image of a 46-year-old woman with CTS proximal to the carpal tunnel. The median nerve shows T2 hyperintensity of the swollen nerve fibers. The average SI of the nerve measures 138.00. **b** Proton density fat-saturated axial MR image of the same CTS patient at the carpal tunnel outlet. The ROI is placed in the hypothenar muscle and the average SI used as a reference to calculate relative median nerve SI. In this case, the median nerve has increased relative SI at 1.20

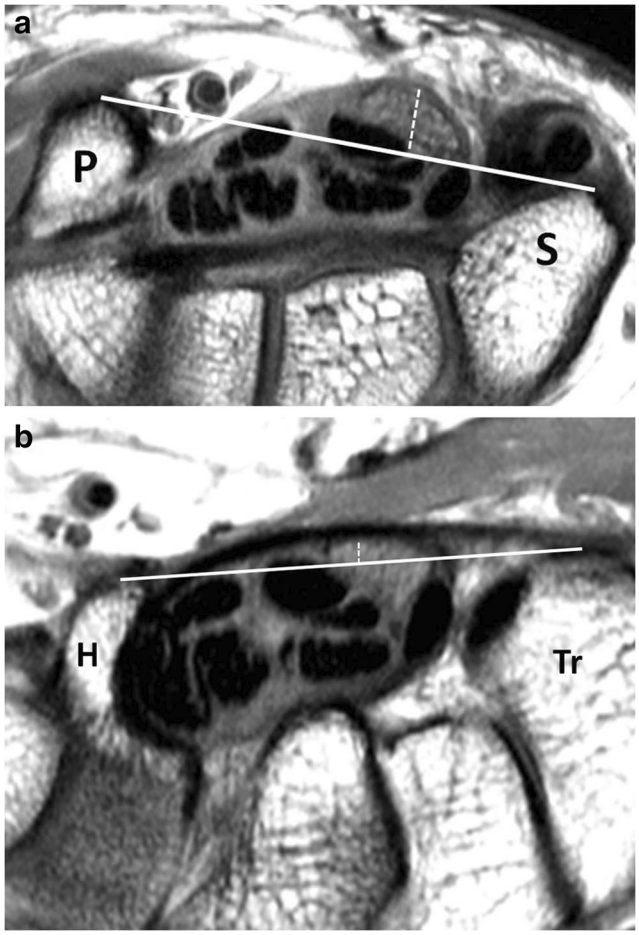

Fig. 4 **a** Proton density axial MR image of a 52-year-old man with CTS showing significant palmar bowing of the retinaculum (*broken line*) above the tangential line (*solid white line*) connecting the scaphoid tubercle (S) and the pisiform bone (P). **b** Proton density axial MR image of the same CTS patient at the tunnel outlet showing significant palmar bowing of the retinaculum (*broken line*) above the tangential line (*solid white line*) connecting the trapezium tubercle (Tr) and the hook of hamate (H)

Statistical analysis

Statistical software (SPSS, version 16.0.1 for Windows) was used for data analysis. To compare differences between control subjects and CTS patients, the unpaired *t* test was used. To compare differences between mild, moderate, and severe CTS patients, the ANOVA test was used. Chi-square test was used to assess for gender and wrist laterality differences. Cohen's weighted κ statistic was used to assess inter- and intra-observer agreement. A κ value of less than 0.20 implied poor agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–1.00 excellent agreement [25].

ROC curves were plotted for median nerve CSA, flattening ratio, retinacular bowing and relative median nerve signal intensity to calculate the cut-off value which provided the highest sensitivity, specificity, and accuracy for predicting CTS. Other ROC curves were drawn using the most significant criteria to calculate the cut-off value which provided the highest sensitivity, specificity, and accuracy for predicting severity of CTS.

Results

No significant difference ($p > 0.05$) existed between control subjects and CTS patients for age, gender, or laterality. The mean ± standard deviation of all parameters assessed between control subjects and CTS patients is listed in Table 1. Excellent intra-observer (0.85–0.92) and good inter-observer (0.78–0.86) agreement was found for all parameters measured (Table 1). Figures 1, 2, 3, and 4 show examples of CTS

Table 1 Mean ± standard deviation of all parameters assessed in control subjects and CTS patients along with the level of statistical significance

	Control subjects	CTS patients	*p* value	Interobserver variation (κ)	Intraobserver variation (κ)
CSA proximal to tunnel inlet (mm^2)	11.2 ± 2.1	22.4 ± 8.8	**< 0.0001**	0.86	0.92
CSA at tunnel inlet (mm^2)	11.9 ± 2.1	16.3 ± 3.8	**< 0.0001**	0.82	0.86
CSA at tunnel outlet (mm^2)	11.9 ± 2.2	13.7 ± 3.1	**0.001**	0.79	0.85
CSA at distal to tunnel outlet (mm^2)	12.7 ± 2.0	21.3 ± 7.2	**< 0.0001**	0.83	0.87
BR at tunnel inlet (mm)	2.1 ± 1.2	3.7 ± 1.2	**< 0.0001**	0.78	0.85
BR at tunnel outlet (mm)	0.1 ± 0.67	1.4 ± 0.8	**< 0.0001**	0.78	0.85
FR at tunnel inlet	2.2 ± 0.52	2.7 ± 0.9	**< 0.0001**	0.79	0.89
FR at tunnel outlet	2.3 ± 0.62	2.6 ± 0.7	0.068	0.81	0.88
Ratio change of CSA at tunnel inlet	1.0 ± 0.15	1.4 ± 0.6	**< 0.0001**	0.84	0.90
Ratio change of CSA at tunnel outlet	1.1 ± 0.21	1.6 ± 0.6	**< 0.0001**	0.81	0.86
Relative signal intensity	1.0 ± 0.3	1.3 ± 0.3	**< 0.0001**	0.80	0.85

$p < 0.05$ was considered as significant and was bolded in the table. The interobserver and intraobserver variation of measuring different parameters using Cohen weighted κ statistic are also listed in the table. *CSA* cross-sectional area, *FR* flattening ratio, *BR* retinacular bowing, *κ* Cohen weighted κ value

patients with swelling of the median nerve proximal and distal to the carpal tunnel (Fig. 1 and 2), abnormal signal intensity (Fig. 3), as well as retinacular palmar bowing (Fig. 4).

Median nerve CSA

CSA_p in control subjects (11.2 ± 2.1 mm^2) was significantly smaller than in CTS patients (22.4 ± 8.8 mm^2, $p < 0.0001$). CSA_d in control subjects (12.7 ± 2.0 mm^2) was also significantly smaller than in CTS patients (21.3 ± 7.2 mm^2, $p < 0.001$). CSA_i and CSA_o also showed significant differences between patients and control subjects (Table 1).

Using the ROC curve, a cut-off of > 15 mm^2 proximal to the tunnel inlet provided a diagnostic sensitivity, specificity, and accuracy of 85.5, 100.0, and 90.1%, respectively for CTS (Table 2). A cut-off of > 15 mm^2 distal to the carpal tunnel outlet provided a diagnostic sensitivity, specificity, and accuracy of 85.5, 90.6, and 87.1%, respectively, for CTS. Using either $CSA_p > 15$ mm^2 or $CSA_d > 15$ mm^2 as diagnostic criteria yielded a sensitivity of 100% and a specificity of 93.8% for diagnosis of CTS, while overall accuracy was 98% (Table 3).

Significant differences in median nerve CSA proximal to the carpal tunnel were found among patients with mild, moderate, and severe CTS ($p = 0.018$). Using a cut-off of > 19 mm^2 proximal to the tunnel inlet provided a diagnostic sensitivity, specificity, and accuracy of 75.0, 65.9, and 69.6%, respectively, for severe CTS.

Relative change of median nerve CSA

Relative change in median nerve CSA at the tunnel inlet in control subjects (1.0 ± 0.15) was significantly smaller than in CTS patients (1.4 ± 0.6, $p < 0.0001$). Relative change in median nerve CSA at the tunnel outlet in control subjects (1.1 ± 0.21) was also significantly smaller than in CTS patients (1.6 ± 0.6, $p < 0.0001$) (Table 1). However, ratio change for tunnel inlet CSA to tunnel outlet CSA provided only fair accuracy (73.3–77.2%) for CTS diagnosis (Tables 2 and 4).

Table 2 Sensitivity, specificity, and accuracy in diagnosing CTS using most significant criteria from Table 1

Diagnostic criteria	Sensitivity (%)	Specificity (%)	Accuracy (%)
CSA at proximal to tunnel inlet (> 15 mm^2)	85.5	100.0	90.1
CSA at distal to tunnel inlet (> 15 mm^2)	85.5	90.6	87.1
Either CSA at proximal to tunnel inlet (> 15 mm^2) or distal to tunnel outlet (> 15 mm^2)	100	93.8	98.0
FR at tunnel inlet > 2.4	72.5	65.6	70.3
BR at tunnel inlet (> 2.8 mm)	73.9	75.0	74.3
BR at tunnel outlet (> 1 mm)	69.6	96.9	78.2
Relative signal intensity (> 1.05)	88.4	68.8	82.2
Ratio change of CSA at tunnel inlet (> 1.1)	63.8	93.8	73.3
Ratio change of CSA at tunnel outlet (> 1.3)	72.5	87.5	77.2

CSA cross-sectional area, *FR* flattening ratio, *BR* retinacular bowing

Table 3 Significant difference of the parameters assessing the different degree of severity of CTS patients with the level of statistical significance, $p < 0.05$

	(1) Mild	(2) Moderate	(3) Severe	p value of linear trend
CSA proximal to tunnel inlet (mm^2)	20.2 ± 7.4	19.4 ± 9.0	26.1 ± 8.6[a,b]	0.018
FR at tunnel inlet	2.4 ± 0.7	2.6 ± 0.6	3.1 ± 1.0[a]	0.007
Ratio change of CSA at tunnel inlet	1.3 ± 0.3	1.2 ± 0.4	1.7 ± 0.8[a,b]	0.006
Relative signal intensity	1.3 ± 0.3	1.2 ± 0.2	1.5 ± 0.3[a,b]	0.002

CSA cross-sectional area, *FR* flattening ratio

[a] $p < 0.05$ comparing severe (3) with mild (1)

[b] $p < 0.05$ comparing severe (3) with moderate (2)

Flattening ratio of median nerve

The flattening ratio at the tunnel inlet in control subjects (2.2 ± 0.52) was significantly less than that in CTS patients (2.7 ± 0.9, $p < 0.0001$) (Table 1) while no difference was found between both groups at the tunnel outlet ($p = 0.068$) (Table 1). Using the ROC curve, a cut-off for flattening ratio of > 2.4 for the carpal tunnel inlet provided a diagnostic sensitivity, specificity, and accuracy of 72.5, 65.6, and 70.3%, respectively, for CTS (Table 2). Significant differences in FR at the tunnel inlet were found among mild, moderate, and severe CTS patients ($p = 0.007$). Using a cut-off of > 2.5 at the tunnel inlet provided a diagnostic sensitivity, specificity, and accuracy of 82.1, 53.7, and 65.2%, respectively, for severe CTS.

Bowing retinaculum

The retinaculum was less bowed in control subjects than CTS patients at both the inlet (2.1 ± 1.2 vs. 3.7 ± 1.2 cm, $p < 0.0001$) and outlet (0.1 ± 0.67 vs. 1.4 ± 0.8 cm, $p < 0.0001$) in control subjects than in CTS patients (Table 1). Using the ROC curve, a cut-off of > 2.8 mm for retinacular bowing at the tunnel inlet provided a diagnostic sensitivity, specificity, and accuracy of 73.9, 75.0, and 74.3%, respectively, while a cut-off of > 1 mm for retinacular bowing at the tunnel outlet provided a diagnostic sensitivity, specificity, and accuracy of 69.6, 96.9, and 78.2%, respectively, for CTS (Table 2). There is no significant difference in retinacular bowing at the inlet among mild, moderate, and severe CTS patients ($p > 0.05$).

Signal intensity of median nerve

Signal intensity ratio was lower in control subjects (1.0 ± 0.30) than in CTS patients (1.30 ± 0.3, $p < 0.0001$) (Table 1). Using the ROC curve, a cut-off for signal intensity ratio of > 1.05 provided a diagnostic sensitivity, specificity, and accuracy of 88.4, 68.8, and 82.2%, respectively, for CTS (Table 2). Significant differences in median nerve signal intensity ratio were found between mild, moderate, and severe CTS patients ($p = 0.002$). Using a cut-off of > 1.4 at the inlet provided a diagnostic sensitivity, specificity, and accuracy of 67.7, 85.4, and 78.3%, respectively, for severe CTS.

Discussion

There is no perfect gold standard for the diagnosis of CTS. A combination of symptom characteristics and NCT findings currently provides the most accurate diagnosis [14]. Ultrasound and MRI are usually used to exclude secondary causes of CTS. When clinical assessment or NCT are somewhat equivocal regarding a diagnosis of CTS, hand surgeons may have hesitancy in undertaking surgery. At this juncture, ultrasound or MRI may be helpful in supporting a diagnosis of CTS [25–28]. Also, in patients with non-specific hand symptoms, recognition of a significantly enlarged median nerve may allow one to suggest the likelihood of CTS. MRI has advantages over ultrasound in being less operator-dependent, allowing clearer delineation of the carpal tunnel contents, and enabling the entire median nerve to be measured [22, 29, 30]. MRI, which requires only two standard axial sequences, is being increasingly used to diagnose CTS [4, 7–10, 20].

MRI-based studies have stressed several different parameters to diagnose CTS including cross-sectional area (CSA), flattening ratio (FR), and signal intensity (SI) of the median nerve and as well as palmar retinacular bowing (BR) [4, 5, 7, 9, 10]. Median nerve T2-hyperintensity is due to vascular congestion, disruption of axoplasmic flow, increase in endoneural connective tissue, epineural and endoneural edema, as well as Wallerian degeneration [31, 32] and is reversible after carpal tunnel release [10, 24, 33].

The most useful discriminatory parameters identified to date are median CSA proximal to the carpal tunnel and palmar retinacular bowing [3, 7, 9]. However, diagnostic criteria have not been firmly established hindering the wider acceptance of MR imaging in replacing NCT in the diagnosis of CTS [4–6, 8, 10, 34].

Table 4 Sensitivity, specificity, and accuracy in diagnosing severe CTS using most significant criteria from Table 3

Diagnostic criteria on MRI	Sensitivity (%)	Specificity (%)	Accuracy (%)
CSA at proximal to tunnel (> 19 mm^2)	75.0	65.9	69.6
Ratio change of CSA at tunnel inlet (> 1.5)	53.6	82.9	71.0
FR at tunnel inlet > 2.5	82.1	53.7	65.2
BR at tunnel inlet (> 3.6 mm)	60.7	53.7	56.5
Relative signal intensity (> 1.4)	64.3	85.4	76.8

CSA proximal to tunnel

The median nerve proximal to the carpal tunnel is recognized to increase in size [5, 10, 11, 24, 33] and be significantly larger in CTS patients than in normal subjects. Median nerve CSA proximal to the tunnel is the most commonly applied criterion for diagnosing CTS on MRI with a recommended cut-off level of larger than 15 mm^2. In our study, we found that a median nerve CSA of > 15 mm^2 yielded a sensitivity of 85.5%, a specificity of 100% and an accuracy of 90.1% for the diagnosis of CTS. This result is comparable to other studies where sensitivity varied from 23 to 75% and specificity varied from 76 to 87.5% [8, 20, 21, 35].

CSA distal to tunnel

Almost all MRI studies have focused on discriminatory parameters proximal to or within the carpal tunnel. Only one MRI has investigated the relationship of CSA_d and CTS but could not demonstrate any significant difference ($p = 0.06$) at 1.5 T [6]. A recent study showed that CSA immediately distal to the tunnel outlet (CSA_d) on ultrasound is a useful discriminatory diagnostic criterion for CTS [21] prompting us to investigate the usefulness of this parameter on MRI. The site of maximum median nerve compression may be at the inlet or the outlet and, as such, the site of maximum median nerve swelling is variable [34, 36]. Using either CSA either proximal or distal to the tunnel as a diagnostic criterion yielded a sensitivity of 100% and specificity 94% for diagnosis of CTS while overall accuracy was 98%. Median nerve compression in CTS is a continuum rather than an all-or-none phenomenon [21]. As such, it is not surprising that using a combination of discriminatory criteria rather than a single criterion will enhance the diagnostic capability of MRI for CTS. One or more criteria may be unequivocally positive in some CTS patients whereas others may be unequivocally positive in other CTS patients [21, 37].

The resultant increase in sensitivity for CTS is easy to understand as in the present study, the median nerve in nine patients were only swollen > 15 mm^2 distal to the outlet and not at other locations. These size criteria (CSA > 15 mm^2 proximal or distal to the carpal tunnel) are easily remembered and thus easily implemented into routine clinical practice. These results concur with a recent ultrasound study, which showed that measuring the median nerve both proximal and distal to the tunnel increased the diagnostic accuracy for CTS [21].

Parameters to predict severity

In our study, we also tried to assess the usefulness of CSA of median nerve to predict the severity of the CTS patients. We found a significant difference in median nerve CSA proximal to the tunnel and inlet ratio change ($p < 0.05$) for patients among the three severity groups. When using > 19 mm^2 as the cut-off value proximal to the tunnel, the sensitivity and specificity to predict severe disease was 75.0 and 65.9%, respectively. Using ratio change of CSA at tunnel inlet > 1.5 as a cut-off value to predict severe disease has a high specificity (82.9%) but low sensitivity (53.6%). Although we were not able to define MRI criteria that could accurately discriminate mild, moderate, or severe CTS, these results suggest that the more swollen the median nerve and the more severe the caliber change, the more likely the patient is to have severe CTS. Further prospective study is needed to delineate specific severity criteria.

Although flattening ratio, median nerve signal intensity ratio, and palmar bowing all showed significant differences between patients and control subjects as well as between patients with mild, moderate, or severe CTS, they did not significantly add to median nerve CSA with regard to the diagnosis of CTS or discrimination between severity groups.

This study has some limitations. MR examinations were performed with the patient or subject in a prone position and the arm adducted above the head. Newer coils allow wrist examination with the patient in a supine position with the arm alongside the body. This changes wrist rotation from a pronated to a supinated position. Intercarpal pressures are known to be higher in the pronated position but whether this affects median nerve size or appearance is not known [37]. Second, only a relatively small number of patients and control subjects were examined. Third, no nerve conduction test was performed in control subjects. Fourth, readers were not blinded to the clinical status of participants though CTS severity status was blinded. Fifth, other potentially useful MR techniques such as diffusion tensor imaging were not performed.

Conclusions

Although flattening ratio, median nerve signal intensity, and bowing ratio all showed significant differences, none of these MR criteria proved as discriminatory as median nerve CSA for the diagnosis of CTS and discriminating disease severity. We recommend using median nerve CSA > 15 mm^2 either proximal or distal to the tunnel as the MR diagnostic criterion for CTS and CSA > 19 mm^2 proximal to the tunnel as the MR marker of severe CTS. Using these criteria, MRI yielded a high accuracy for the diagnosis of CTS and a modest accuracy for discriminating severe CTS.

Acknowledgements The work described in this paper was partially supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No.SEG_CUHK02). Special thanks to Jason Leung, CUHK statistician, for his help with this manuscript.

Compliance with ethical standards

Ethical approval All procedures performed in this study were in accordance with the ethical standards of our institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Written informed consent was obtained from all individual participants included in the study.

Conflict of interest There are no conflicts of interest for any of the authors.

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