

## Ultrasonography in the evaluation of carpal tunnel syndrome: Diagnostic criteria and comparison with nerve conduction studies

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### Abstract

Ultrasound criteria for carpal tunnel syndrome (CTS) may vary in different populations. To determine the ultrasonographic criteria for CTS in a Malaysian population and compare its usefulness with nerve conduction studies (NCS), we studied patients clinically diagnosed with CTS and normal controls by ultrasonography. All patients also underwent standard NCS. Median nerve Cross-Sectional Area (CSA) and Flattening Ratio (FR) at 3 different levels – proximal to tunnel inlet, at tunnel inlet and tunnel outlet were measured. Receiver operator characteristic (ROC) analyses were used to calculate the optimal discriminatory threshold values for CTS. Of 54 CTS hands, NCS was positive in 85.2%. Median nerve CSA at all 3 levels, were significantly greater in CTS hands. FR was significantly greater at tunnel inlet. A CSA threshold of 0.1 cm<sup>2</sup> proximal to and at tunnel inlet had sensitivities of 70.4% and 63% and specificities of 85.2% and 88.5 % respectively. CSA at tunnel outlet had lower specificity. If CSA of 2 levels (viz. proximal to or at tunnel inlet) were considered together, sensitivity and specificity improved to 81.5% and 83.3%. Qualitative loss of fascicular discrimination of the nerve proximal to the inlet had sensitivity and specificity of 77.8% and 96.3%. The most useful ultrasonographic parameter was median nerve CSA either proximal to or at tunnel inlet. However, the sensitivities were lower compared to NCS. Qualitative appearance of the median nerve is a useful adjunct to diagnosis. In conclusion, ultrasonography play an important complementary role to NCS in the diagnosis of CTS.

### INTRODUCTION

Carpal tunnel syndrome (CTS) is a clinical syndrome resulting from compression of the median nerve at the wrist. Diagnosis is usually based on clinical symptoms, clinical manoeuvres on examination and is supported by nerve conduction studies (NCS).<sup>1,2</sup> In the American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM) literature reviews on the diagnosis of CTS, the sensitivity and specificity of NCS was about 85% and 95% respectively.<sup>1,2</sup>

Ultrasonography has emerged as an important diagnostic investigation for CTS.<sup>3-6</sup> A number of ultrasonographic changes have been demonstrated in CTS including swelling of the median nerve, flattening of the nerve, palmar bowing and thickening of the flexor retinaculum and changes in the median nerve appearance.<sup>3</sup> The most commonly described abnormality has been enlargement of the median nerve cross sectional area (CSA) usually proximal to the carpal

tunnel.<sup>3,5,6</sup> However, specific ultrasonographic diagnostic criteria may vary from study to study. Depending on sample size and study population, different threshold values have been found for median nerve CSA in CTS.<sup>5-8</sup> The definition of CTS in study populations has varied; some studies used positive NCS as an inclusion criteria<sup>9-14</sup> while others enrolled patients diagnosed based on clinical criteria.<sup>15-22</sup> The diagnostic accuracy of ultrasonography compared to NCS have been variable as well.<sup>15,16,17,19-21</sup> In a recent review, ultrasonography was noted to be less sensitive and specific than NCS.<sup>22</sup> Therefore, the role of ultrasonography in CTS remains to be defined. The aim of this study was to determine sonographic criteria for the diagnosis of CTS in our local population, and to compare its diagnostic accuracy with NCS.

### METHODS

Consecutive patients clinically diagnosed with CTS over a 6-month period at the Hand and

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Microsurgery Clinic, University of Malaya Medical Centre (UMMC), Kuala Lumpur were included in the study. The study had the approval of the UMMC Medical ethics committee. We used the AANEM clinical diagnostic criteria (proposed as “gold standard” in electrodiagnostic studies on CTS) and included patients if they were defined as “clinically probable CTS”.<sup>1</sup> All patients underwent NCS on a Medelec Synergy Electromyography machine (Oxford Instruments, Old Woking, Surrey, UK). The following nerve conduction tests were carried out - digit to wrist orthodromic sensory conduction studies of the median and ulnar nerves, palm to wrist mixed nerve conduction studies (comparing the conduction velocities between median and ulnar nerves) and motor conduction studies of median and ulnar nerves. Normal values for the laboratory had previously been obtained. Diagnosis of CTS was made if median sensory nerve conduction velocity (SNCV) was less than 40 m/sec when the ulnar SNCV was normal, median distal motor latency (DML) more than 4.5 msec and

/ or median versus ulnar palm to wrist mixed nerve conduction velocity difference was more than 10 m/sec. CTS classified as mild (abnormal median SNCV with normal median DML), moderate (abnormal median SNCV and prolonged median DML) or severe (absent median sensory responses).<sup>23</sup> Severity of clinical symptoms and hand function were assessed using the Levine Symptom Severity Score (SSS) and Functional Severity Score (FSS).<sup>24</sup>

Ultrasonography of the carpal tunnel was carried out by a single radiologist who was blinded to the NCS results. A Philips IU 22 ultrasound machine with a Linear 17-5 MHz probe was used in the study. Cross-sectional ultrasound was carried out on the subjects' wrists at three levels - proximal end of the lunate (rising sun appearance of the lunate) corresponding to a site proximal to the carpal tunnel inlet; scaphoid tubercle - corresponding to the inlet of the carpal tunnel and just beyond the scaphoid, corresponding to the tunnel outlet (Figure 1). Subjects were seated facing the examiner, with their wrists resting on

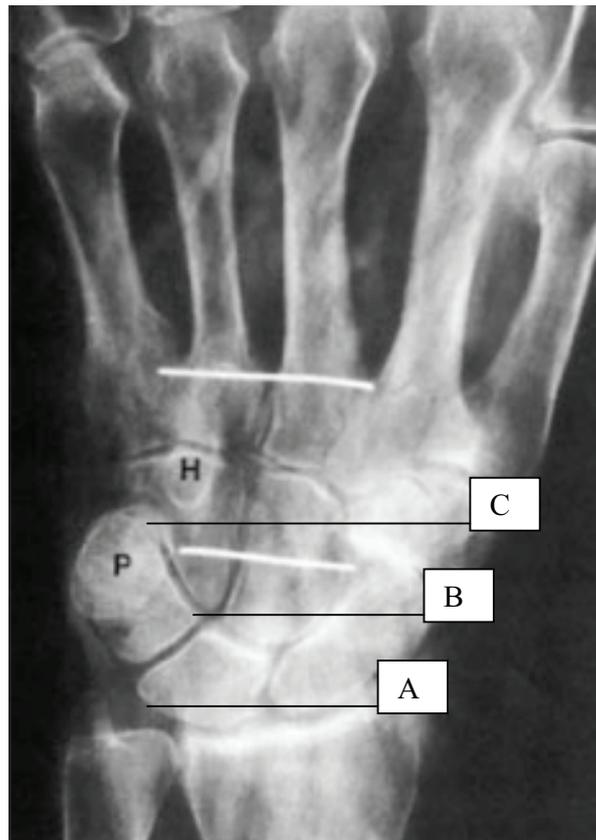


Figure 1 The three levels at which median nerve cross-sectional area were measured by ultrasound – A, proximal to tunnel inlet (lunate rising sun appearance); B, at the tunnel inlet at scaphoid tubercle; C, at the tunnel outlet beyond scaphoid tubercle

a pillow in supination and fingers semi-extended. Cross-sectional area (CSA) of the median nerve (cm<sup>2</sup>) was determined using the trace method (electronic calipers around the margin of the nerve at the time of ultrasonography) while Flattening Ratio (FR), was calculated using the ratio of the medio-lateral diameter to the antero-posterior diameter on cross-section. At each level, 3 measurements of CSA and FR were taken and averaged. In addition the sonographer also qualitatively assessed the median nerve at each level using loss of fascicular discrimination as the determinant. The ultrasound technique used is novel in that the linear transducer is shifted from the distal radius to beyond the scaphoid along the radial aspect of the wrist with no change in transverse position to search for the hamate. (Figure 2). For comparison, normal controls with no history of hand symptoms, previous hand injury or surgery to the wrist were also studied.

Statistical analyses were carried out using GraphPad InStat and Prism software (Macintosh version). Student's t-tests were used to compare mean CSA and FR between CTS hands and controls. Receiver operator characteristic (ROC) curves were used to determine the area under the curve for the CSA and FR and to determine the optimal discriminatory threshold values for CTS. Pearson correlation coefficients were calculated to assess the strength of association between the symptom severity score (SSS), functional severity score (FSS) and median nerve CSA, FR as well as between ultrasonographic and NCS measurements.

## RESULTS

There were 39 patients, of which 37 (94.9%) were women, with a mean age was 52.4 years (26 - 82). In these patients, 54 hands were diagnosed to have clinically probable CTS and underwent both NCS and ultrasonography. In addition, 54 normal hands from 29 healthy controls (all women, mean age 39.8 years, range 24 - 65 years) were also studied by ultrasound. On NCS, 46 (85.2%) hands were positive for CTS.

The ultrasonographic findings are summarised in Table 1. Median nerve CSA was significantly larger in CTS hands compared to controls, at all 3 levels viz. proximal to the carpal tunnel, at the tunnel inlet and at the tunnel outlet. There was also a significant difference in the FR at the tunnel inlet but not at the levels proximal to the inlet and the tunnel outlet. ROC curves were used to determine optimal discriminatory threshold values for CSA at all 3 levels and FR at the tunnel inlet (Table 2 and Figure 3). CSA proximal to the tunnel inlet with a threshold of 0.10 cm<sup>2</sup> gave the best diagnostic accuracy with a sensitivity and specificity of 70.4% and 85.2% respectively, followed by CSA at the tunnel inlet with a threshold of 0.10 cm<sup>2</sup> which gave a sensitivity and specificity of 63.0% and 88.5% respectively. CSA at the tunnel outlet, with a threshold of 0.09 cm<sup>2</sup> yielded a sensitivity of 66.7% but a lower specificity of 75%. FR of 2.65 at the tunnel inlet gave a sensitivity of 70.4% but a lower specificity of only 53.7%. If CSA at either of 2 levels viz. proximal to or at the tunnel inlet were considered together the resulting sensitivity and specificity increased to 81.5% and 83.3% respectively (Table 3).

**Table 1: Mean ultrasonographic measurements of cross sectional area at various levels of the median nerve in both carpal tunnel syndrome patients and controls.**

Ultrasonographic measurements	Carpal tunnel syndrome	Controls	p value
Mean CSA proximal to tunnel, cm <sup>2</sup>	0.122	0.075	p<0.0001*
Mean CSA at tunnel inlet, cm <sup>2</sup>	0.124	0.078	p<0.0001*
Mean CSA at tunnel outlet, cm <sup>2</sup>	0.107	0.077	p<0.0001*
Mean FR at proximal to tunnel	3.174	3.397	p=0.1353
Mean FR at tunnel inlet	3.111	2.746	p=0.0226*
Mean FR at tunnel outlet	2.702	2.591	p=0.4421

CSA: median nerve cross sectional area; FR: flattening ratio of median nerve

\*statistically significant (P<0.05)

**Figure 2A:** Normal control - normal heterogeneous echogenicity with speckled linear hyperechoic and hypoechoic appearance of median nerve (small arrows) at the level of the lunate's rising sun appearance as transducer is moved from proximally to distally across the lunate. Normal measurement is taken to be 0.1cm<sup>2</sup> or less in cross sectional area. Fascicular discrimination within the nerve is possible.

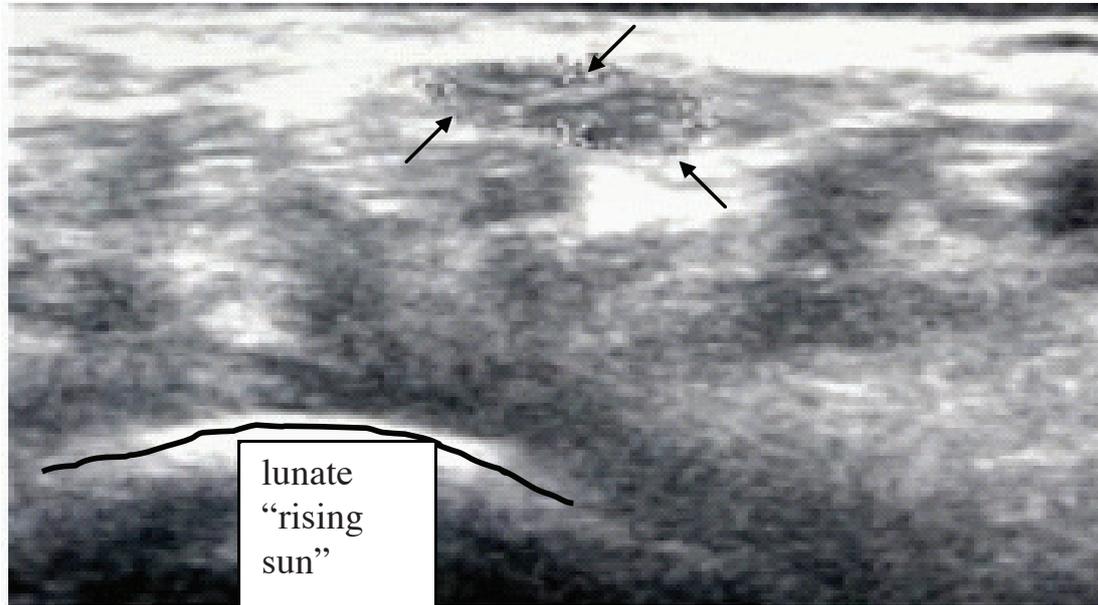


Fig 2A

**Figure 2B:** Left carpal tunnel syndrome - median nerve showing diffuse loss of the hyperechoic linear appearance (loss of fascicular discrimination) in the median nerve at the tunnel inlet (scaphoid tubercle). This change in appearance is what was used in the qualitative assessment. Note the trace area of the median nerve is 0.208cm<sup>2</sup>. More than 10mm<sup>2</sup> is considered significant. More than 0.13cm<sup>2</sup> in our study was almost always associated with severe carpal tunnel syndrome.

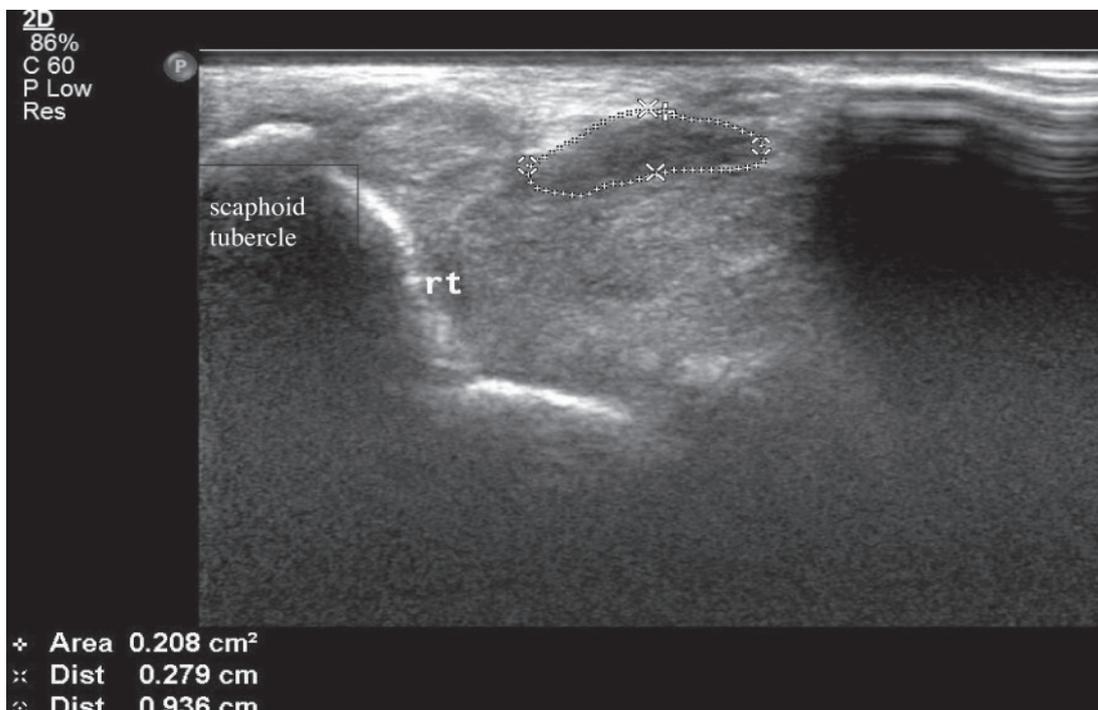


Figure 2: Sonographic appearance of the normal and abnormal median nerve on cross-section.

**Table 2: Optimal discriminatory threshold, sensitivity and specificity of ultrasonographic criteria for median nerve cross sectional area (CTS).**

Measurements	Optimal discriminatory threshold	Sensitivity (%)	Specificity (%)	Area under the curve	p value
CSA proximal to tunnel	0.10 cm <sup>2</sup>	70.4	85.2	0.85	<0.0001
CSA tunnel inlet	0.10 cm <sup>2</sup>	63.0	88.5	0.84	<0.0001
CSA tunnel outlet	0.09 cm <sup>2</sup>	66.7	75.0	0.73	<0.0001
FR tunnel inlet	2.65	70.4	53.7	0.62	0.036 (<0.05)

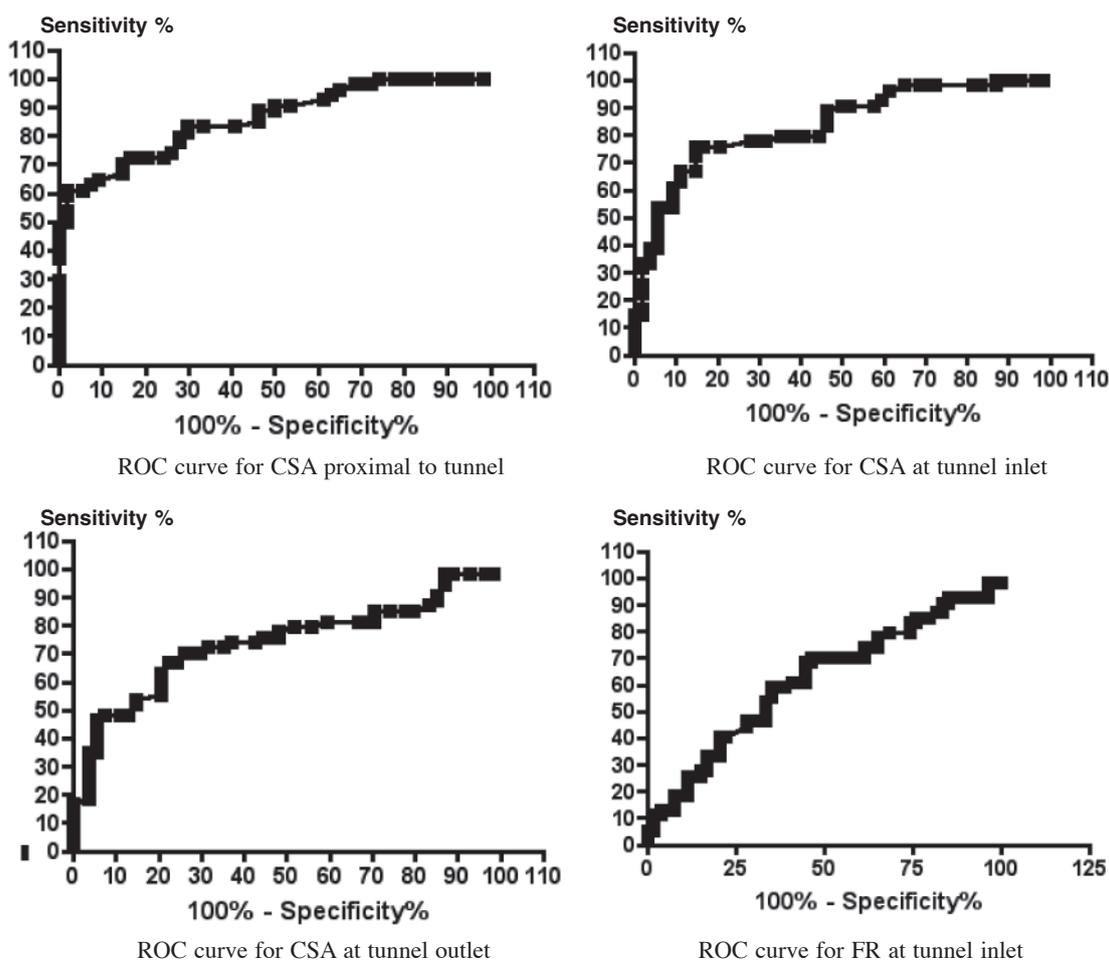
CSA: median nerve cross sectional area; FR flattening ratio of median nerve

Qualitative appearance of the median nerve at the level proximal to the carpal tunnel yielded a sensitivity and specificity of 77.8% and 96.3% respectively (Table 4).

All 10 (18.5%) CTS hands classified as electrophysiologically as severe (i.e. absent median sensory responses), had median nerve

CSA of more than 0.1 cm<sup>2</sup> proximal to the tunnel inlet. ROC curve analyses for this subgroup of severe CTS found CSA threshold of 0.133 cm<sup>2</sup> which gave a diagnostic sensitivity of 90% and specificity of 88.8%.

Symptom severity scores (SSS) correlated with CSA at tunnel outlet (p=0.022) and functional



**Figure 3: Receiver operator characteristic (ROC) curves for cross sectional area (CSA) and Flattening Ratio (FR) of the median nerve, taking into account both carpal tunnel syndrome and controls.**

**Table 3: Sensitivity and specificity of ultrasonography for carpal tunnel syndrome using median nerve cross sectional area (CSA) cut-off values at either proximal to the tunnel inlet or at the tunnel inlet**

	Carpal tunnel syndrome group	Controls	p value
CSA proximal to tunnel >0.1 cm <sup>2</sup> OR CSA at tunnel inlet >0.1 cm <sup>2</sup>	44	9	p<0.0001
CSA less than or equal to 0.1 cm <sup>2</sup> at level proximal to tunnel AND at tunnel inlet	10	45	
	Sensitivity: 81.5%	Specificity: 83.3%	

CSA: median nerve cross sectional area

severity scores (FSS) correlated with FR at tunnel outlet (p=0.042) but not with other ultrasound parameters or with NCS. CSA at the tunnel inlet correlated with median DML (p=0.003).

## DISCUSSION

Our results are consistent with previous studies of ultrasound in CTS in showing enlargement of median nerve in CTS hands.<sup>3-5</sup> There were significant differences in median nerve CSA between CTS and controls hands at all levels measured – proximal to the tunnel inlet, at the inlet and outlet, as well as in the FR at the tunnel inlet. In the published literature, CSA threshold values for different levels of the carpal tunnel have ranged from 0.09 cm<sup>2</sup> to 0.15 cm<sup>2</sup> with varying sensitivities and specificities ranging from 70% to 88% and 63% to 97% respectively [6-21]. However, these values are variable and

not universally applicable as there are differences in study population viz. demographic differences and the “gold standard” used in the diagnosis of CTS. In our population, ROC curves estimated the optimal CSA thresholds to be 0.1 cm<sup>2</sup> proximal to and at the inlet and 0.09 cm<sup>2</sup> at the tunnel outlet and 2.65 for the FR at the tunnel inlet with the highest sensitivities and specificities found for median nerve CSA proximal to and at the tunnel inlet.

The sensitivity of ultrasonography may increase if more than one parameter is combined in the diagnostic criteria. In our study, combined CSA criteria at either of 2 levels (proximal to or at the tunnel inlet) yielded higher sensitivity and specificity than if they were considered alone. One study used the mean carpal nerve area (average of CSA of all three levels) and improved its diagnostic sensitivity from 43% to 67%.<sup>15</sup> In another study,

**Table 4: Sensitivity and specificity of the qualitative features of the nerve in determining carpal tunnel syndrome**

Nerve appearance on cross section proximal to inlet	Carpal tunnel syndrome group	Controls	p value
Normal heterogeneous echogenicity	12	52	p<0.0001
Loss of heterogeneous echogenicity	42	2	
	Sensitivity: 77.8%	Specificity: 96.3%	

a CSA of 0.11 cm<sup>2</sup> proximal to the tunnel yielded high specificity (98%) but had also high numbers of false negatives (26.4%). However, when this was combined with a qualitative ultrasonographic sign of longitudinal median nerve compression, the false negative rate was reduced to 10.9%.<sup>16</sup>

Qualitative appearance of the median nerve is a useful ultrasonographic parameter.<sup>3</sup> Several studies have commented on the loss of fascicular discrimination in the median nerve.<sup>7,15,25</sup> Other qualitative features reported included the compressed appearance of the nerve on longitudinal view<sup>16</sup> and the presence of intraneural hypervascularisation using Colour Doppler ultrasound.<sup>26</sup> In our study, a hazy, homogeneous appearance with loss of fascicular discrimination in the compressed nerve at the level proximal to the tunnel inlet had a relatively high sensitivity and specificity of 77.8% and 96.3% respectively. However, qualitative assessment of the nerve is subjective and as such cannot be used as a stand alone criterion for CTS but as complementary to quantitative measurements.

Sensitivity of median nerve CSA at individual levels in our study, were lower compared to NCS. It was comparable only when we combined CSA criteria for 2 levels, proximal to or at the tunnel inlet. Most previous studies have reported lower sensitivities of ultrasonography compared to NCS.<sup>15,16,19-21</sup> In a recent review, the diagnosis of CTS was confirmed only in 55% compared to more than 90% for NCS.<sup>22</sup> However, NCS is not always abnormal in CTS<sup>1,2,27,28</sup>, and in two studies, ultrasonography revealed abnormal findings in CTS patients who had normal NCS.<sup>17,29</sup> On the other hand, as studies including ours have shown, ultrasonography appear to be relatively quite specific for CTS.<sup>15,21</sup> Furthermore, ultrasonography may be useful in severe CTS, where NCS may be unrecordable. There was correlation between median nerve CSA at the tunnel inlet and median DML. As prolonged median DML is a marker of focal nerve demyelination across the carpal tunnel, this provides a biological basis for the ultrasonographic finding in CTS. However, median nerve CSA on the whole, did not correlate well with symptom severity and functional severity scores.

Our study has several limitations. Firstly, the ultrasonographer was not blinded to the diagnosis of CTS, although he was blinded to the NCS results, raising the possibility of observer bias. Secondly, due to logistical reasons, the recruitment of patients was from CTS cases seen consecutively at the clinic while recruitment of

normal controls was based on their willingness to participate in the study. This resulted in a younger mean age for controls compared to patients and a disproportionately high number of females overall. We also did not take additional biophysical measurements for example height, weight or wrist size/circumference. Characteristics such as gender, BMI and wrist index have been shown to correlate with CTS<sup>30,31</sup>, while a recent study has shown the median nerve CSA to correlate significantly with wrist circumference and that this has to be taken into account when determining CSA cut-off values.<sup>32</sup>

The role of ultrasonography vis-à-vis NCS remains unclear. Compared to NCS, its sensitivity is less, although it is quite specific. In view of its relatively painless nature, high specificity, some have suggested that ultrasonography be used as a screening test for CTS before performing NCS.<sup>21</sup> The radiologist has also introduced in this paper a simple method to locate the proximal tunnel and tunnel inlet based on the lunate “rising sun appearance” and the location of the scaphoid tubercle. Unlike NCS it can only demonstrate median nerve lesions/compression and not investigate for other causes of upper paraesthesiae.<sup>22</sup> Where the median nerve is normal in appearance on ultrasound, suspicion of origin of symptoms could be shifted to include the more proximal nerves. However, it can show morphology of the median nerve and demonstrate other pathology e.g. synovitis<sup>16</sup> which can contribute to the development of CTS. Another diagnostic imaging modality that has been shown to be useful in CTS is MRI<sup>33</sup> but the ease and comparative lower cost of ultrasonography will make it a better choice.

In conclusion, this study affirms previous studies in demonstrating the usefulness of ultrasonography in diagnosing CTS. The main median nerve abnormality an enlargement of the median nerve proximal to and at the inlet, although we find that qualitative appearance of the median nerve on ultrasonography is an important adjunctive finding in CTS.

## REFERENCES

1. Jablecki CK, Andary MT, Floeter MK, et al. Second AAEM literature review of the usefulness of nerve conduction studies and needle electromyography for the evaluation of patients with carpal tunnel syndrome. *Muscle & Nerve* 2002; 26 (Suppl):S924-78.
2. Jablecki CK, Andary MT, So YT, Wilkins DE, Williams FH. Literature review of the usefulness of nerve conduction studies and electromyography for the evaluation of patients with carpal tunnel

- syndrome. *Muscle Nerve* 1993; 16:1392-414.
3. Bodner G. Nerve compression syndromes. In: Peer S, Bodner G, eds: High-resolution sonography of the peripheral nervous system. 2<sup>nd</sup> ed. Springer Verlag Berlin Heidelberg, 2008:72-122.
  4. Buchberger W, Schon G, Strasser K, Jungwirth W. High-resolution ultrasonography of the carpal tunnel. *J Ultrasound Med* 1991; 10:531-7.
  5. Buchberger W, Judmaier W, Birbamer G, Lener M, Schmidauer C. Carpal tunnel syndrome: diagnosis with high-resolution sonography. *AJR Am J Roentgenol* 1992; 159:793-8.
  6. Duncan I, Sullivan P, Lomas F. Sonography in the diagnosis of carpal tunnel syndrome. *AJR Am J Roentgenol* 1999; 173:681-4.
  7. Lee D, van Holsbeeck M, Janevski PK, Ganos DL, Ditmars DM, Darian VB. Diagnosis of carpal tunnel syndrome: ultrasound versus electromyography. *Radiol Clin North Am* 1999; 37:859-72.
  8. Wong SM, Griffith JF, Hui ACF, Tang A, Wong KS. Discriminatory sonographic criteria for diagnosis of carpal tunnel syndrome. *Arthritis & Rheumatism* 2002; 46:1914-21.
  9. Sarria L, Cabada T, Cozcolluela R, Martinez-Berganza T, Garcia S. Carpal tunnel syndrome: usefulness of sonography. *Eur Radiol* 2000; 10:1920-5.
  10. Wong SM, Griffith JF, Hui AC, Lok SK, Fu M, Wong KS. Carpal tunnel syndrome: diagnostic usefulness of sonography. *Radiology* 2004; 232(1):93-9.
  11. Yesildag A, Kutluhan S, Sengul N, et al. The role of ultrasonographic measurements of the median nerve in the diagnosis of carpal tunnel syndrome. *Clin Radiol* 2004; 59(10):910-5.
  12. Wiesler ER, Chloros GD, Cartwright MS, Smith BP, Rushing J, Walker FO. The use of diagnostic ultrasound in carpal tunnel syndrome. *J Hand Surg Am* 2006; 31(5):726-32.
  13. Sernik RA, Abicalaf CA, Pimentael BF, Braga-Baiak A, Braga L and Cerri GC. Ultrasound features of carpal tunnel syndrome: a prospective case-control study. *Skeletal Radiology* 2008; 37:49-53.
  14. Mondelli M, Filippou G, Gallo A, Frediani B. Diagnostic utility of ultrasonography versus nerve conduction studies in mild carpal tunnel syndrome. *Arthritis Rheum* 2008; 59(3):357-66.
  15. Nakamichi K, Tachibana S. Ultrasonographic measurement of median nerve cross-sectional area in idiopathic carpal tunnel syndrome: Diagnostic accuracy. *Muscle Nerve* 2002; 26:798-803.
  16. Kele H, Verheggen R, Bittermann HJ, Reimers CD. The potential value of ultrasonography in the evaluation of carpal tunnel syndrome. *Neurology* 2003; 61:389-91.
  17. Altinok T, Baysal O, Karakas HM, et al. Ultrasonographic assessment of mild and moderate idiopathic carpal tunnel syndrome. *Clin Radiol* 2004; 59(10):916-25.
  18. Visser LH, Smidt MH, Lee ML. High resolution sonography versus EMG in the diagnosis of carpal tunnel syndrome. *J Neurol Neurosurg Psychiatry* 2008; 79(1):63-7.
  19. Swen WA, Jacobs JW, Bussemaker FE, de Waard JW, Bijlsma JW. Carpal tunnel sonography by the rheumatologist versus nerve conduction study by the neurologist. *J Rheumatol* 2001; 28:62-9.
  20. Kwon BC, Jung KI, Baek GH. Comparison of sonography and electrodiagnostic testing in the diagnosis of carpal tunnel syndrome. *J Hand Surg Am* 2008; 33(1):65-71.
  21. Pastare D, Therimadasamy AK, Lee E, Wilder-Smith E. Sonography versus nerve conduction studies in patients referred with a clinical diagnosis of carpal tunnel syndrome. *J Clin Ultrasound* 2009; 37(7):380-93.
  22. Seror P. Sonography and electrodiagnosis in carpal tunnel syndrome, an analysis of the literature. *Eur J Radiol* 2008; 67: 146-52.
  23. Stevens JC. AAEE Minimonograph #26: The electrodiagnosis of carpal tunnel syndrome. *Muscle Nerve* 1987; 10:99-113.
  24. Levine DW, Simmons BP, Koris MJ, et al. A self-administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. *J Bone Joint Surg Am* 1993; 75:1585-92.
  25. Martinolli C, Bianchi S, Gandolfo N, Valle M, Simonetti S, Derchi LE. Ultrasound of nerve entrapments in osteofibrous tunnels of the upper and lower limbs. *Radiographics* 2000; 20:S199-213.
  26. Mallouhi A, Püzl P, Trieb T, Piza H, Bodner G. Predictors of carpal tunnel syndrome : accuracy of gray-scale and color Doppler sonography. *AJR Am J Roentgenol* 2006; 186(5):1240-5.
  27. Witt JC, Hentz JG, Stevens JC. Carpal tunnel syndrome with normal nerve conduction studies. *Muscle & Nerve* 2004; 29:515-22.
  28. Goh KJ, Tan CB, Yeow YK, Tjia HTL. The electrodiagnosis of carpal tunnel syndrome- a comparison of the sensitivities of various nerve conduction tests. *Neurol J Southeast Asia* 1999; 4:37-43.
  29. Koyuncuoglu HR, Kutluhan S, Yesildag A, Oyar O, Guler K, Ozden A. The value of ultrasonographic measurement in carpal tunnel syndrome in patients with negative electrodiagnostic tests. *Eur J Radiol* 2005; 56(3):365-9.
  30. Kouyoumdjian JA, Zanetta DMT, Morita MPA. Evaluation of age, body mass index and wrist index as risk factors for carpal tunnel syndrome severity. *Muscle Nerve* 2002; 25:93-7.
  31. Moghtaderi A, Izadi S, Sharafadinzadeh N. An evaluation of gender, body mass index, wrist circumference and wrist ratio as independent risk factors for carpal tunnel syndrome. *Acta Neurol Scand* 2005; 112:375-9.
  32. Claes F, Meulstee J, Claessen-Oude Luttikhuis TTM, Huygen PLM, Verhagen WIM. Usefulness of additional measurements of the median nerve with ultrasonography. *Neurol Sci* 2010; 31(6):721-5.
  33. Jarvik JG, Comstock BA, Heagerty PJ, et al. Magnetic resonance imaging compared with electrodiagnostic studies in patients with suspected carpal tunnel syndrome: predicting symptoms, function and surgical benefit at 1 year. *J Neurosurg* 2008; 108:541-50.