Research Article

Role of Musculoskeletal Ultrasound in the Diagnosis of Entrapment Neuropathies of Median and Ulnar Nerves

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Abstract
Objective*:* the aim of the study was to evaluate the role of musculoskeletal ultrasound in the assessment of entrapment neuropathies of median nerve at the wrist and ulnar nerve at the elbow; and to determine the relationships of ultrasound findings with the clinical severity of carpal tunnel syndrome (CTS) and cubital tunnel syndrome (CuTS) and the electrophysiological grading scale. **Methods*:*** one hundred hands with CTS, twenty elbows with CuTS and one hundred twenty asymptomatic controls were assessed by nerve conduction studies and underwent ultrasonography of wrists and elbows. Data from patients and controls were compared to determine the diagnostic relations in patients with CTS and CuTS and the grade of severity. **Results*:*** There was a high degree of correlation between NCS of the median and ulnar nerves, clinical parameters and variable ultrasound measurements. A cut-off point of ٨.٥ mm^2 for the cross-sectional area (CSA) of the median nerve at the tunnel inlet was found to be ٩٤٪ sensitive and ٦٦% specific. Palmer bowing (PB) of the flexor retinaculum was found to have ٩١٪ sensitivity and ٩٥% specificity at cut-off point ٢.٥٥mm, while flattening ratio (FR) at ٣.٧١ cut-off point was less sensitive and highly specific (٢١٪ and ٩٩٪ respectively). The CSA of the ulnar nerve was the most sensitive parameter and a cut-off point of ٩.٥ mm^2 behind medial epicondyle was found to be ١٠٠٪ sensitive and ٨٠٪ specific. The ulnar nerve ratios (UNR) had a diagnostic accuracy of ٩٥٪ with ٨٥٪ specificity. **Conclusion**: Ultrasonographic measurements of median and ulnar nerves CSAs, FR, PB and UNR have a comparable diagnostic value as a non-invasive and an alternative modality for the evaluation of CTS and CuTS.
Keywords: Ultrasonography, nerve conduction, entrapment neuropathies.

Introduction
Carpal Tunnel Syndrome (CTS) is the commonest neuropathy of the upper extremities and accounts for ٩٠٪ of all entrapment neuropathies[١]. The Cubital tunnel syndrome (CuTS) is the second most common compressive neuropathy of the upper limb following carpal tunnel syndrome[٢] and is the most common site for entrapment for the ulnar nerve[٣]. Neuromuscular ultrasound (NMUS) has been introduced into electrodiagnostic laboratories as a complement to nerve conduction studies and electromyography for the diagnosis of a variety of nerve and muscle conditions[٤].

Characteristic symptoms and signs, and electrophysiological studies are the cornerstones in the diagnosis of CTS[٥,٦]. False negative cases can be seen in about ١٠-٢٠٪ of patients[٧].

The electrophysiological studies usually show the level of the lesion, but do not provide anatomical information about the nerve or its surroundings[٨, ٩]. In the last few years, NMUS; being inexpensive and non-invasive imaging modality; has been shown to be useful diagnostic tools in CTS, providing information on the median nerve and surrounding structures[١٠, ١١].

The aim of the current study was to evaluate the role of neuromuscular ultrasound in the assessment of idiopathic entrapment neuropathies of median nerve at the wrist and ulnar nerve at the elbow; and to determine the relationships of ultrasound findings with the clinical severity of CTS and cubital tunnel syndrome (as assessed by

validated clinical scale) and the electro-physiological grading scale.

Patients and Methods

Patients:

Between May ٢٠١٥ and January ٢٠١٦, Sixty five patients (٥٣ females and ١٢ males) with ١٠٠ diseased hands and clinically suspected to have idiopathic CTS and seventeen patients (٥ females and ١٢ males) with ٢٠ diseased elbows and clinically suspected to have idiopathic CuTS were included. One hundred twenty (١٠٠ for CTS and ٢٠ for CuTS) healthy age and sex matched individuals were served as a control group. All patients and controls were underwent nerve conduction studies and subsequent sonographic evaluation.

Excluded from the study patients with history of wrist/elbow trauma, local joint injection, fracture or surgery, Clinical, electrophysiological or radiological evidence of proximal median or ulnar neuropathy, cervical radiculopathy or polyneuropathy, history of underlying disorders (physiologic/pathologic) that can be associated with CTS: physiological e.g pregnancy, drugs e.g hormonal contraception, neuropathic causes e.g diabetes mellitus, alcoholism, endocrinal e.g hypothyroidism, acromegaly, wrist and / or elbow arthritis due to any cause e.g rheumatoid arthritis, renal failure, congestive heart failure.

Methodology

The clinical diagnosis of CTS was based on Azami et al., ٢٠١٤ diagnostic criteria [١٢]. A modified Arabic version of the Boston Carpal Tunnel Questionnaire (BCTQ) was used to obtain a patient-oriented measurement[١٣]. The Historical-Objective distribution based (Hi-Ob-Db) scale was also used to assess the condition regarding subjective symptoms as well as objective signs[١٤]. All neurophysiological studies were done using *Neuropack S١, MEB-٩٤٠٠K, ٤ channels EMG/EP Measuring System; Nihon Kohden; Japan.* An electro-diagnosis grading scale for CTS was introduced by Bland ٢٠٠٠ [١٥]. Musculoskeletal ultrasound scans were performed using *Siemens ACUSON P٣٠٠ Ultrasound System (Siemens Healthcare, Boulevard, Malvern, USA) multi-frequency ١٠-١٨ MHz linear transducer*. Subjects were seated facing the examiner with arms extended and wrists resting on the examination couch, forearms supinated, and the fingers semi-extended[١٦] as shown in fig (١).

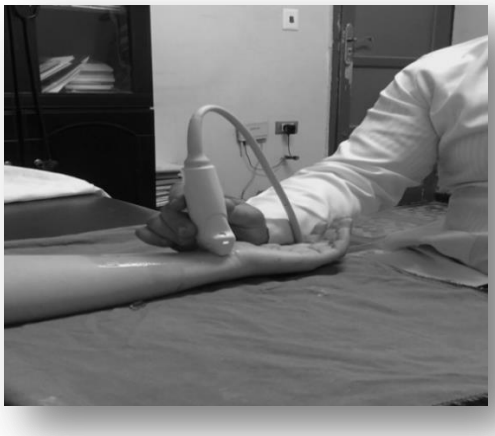

Figure (١): patient positioning during neuromuscular ultrasound of the median nerve at the wrist

The CSA of the median nerve was measured by tracing method at the tunnel inlet[١٦]; and outlet[١٦,١٧]. The median nerve then imaged in cross-section at mid forearm, then the wrist forearm ratio (WFR) was calculated[١٨,١٩]. The median nerve flattening ratio (FR) (at the pisiform or hamate level) was calculated by dividing

the major transverse axis of the nerve by its minor longitudinal axis[٢٠]. Flexor retinaculum bowing was defined as a measurement at ٩٠° from a line drawn from the hook of the hamate bone to the tubercle of the trapezium bone[٢١]. The median nerve mobility (transverse sliding) in the carpal tunnel was observed dynamically during flexion/extension of the fingers and wrist. An imaginary, transverse line was drawn bisecting the levels of the pisiform and the hook of the hamate. The mobility of the MN was evaluated on axial plane at this level[٢٢]. and finally blood flow in the MN sheath was then detected around ٢ cm above the carpal tunnel using color and power Doppler sonography[٢٣].

The clinical diagnosis of cubital tunnel syndrome was based on signs and symptoms of ulnar nerve distribution[٢٤]. Ulnar neuropathy at the elbow questionnaire (UNEQ) for symptoms severity was used[٢٥]. Electrodiagnostic studies were done according AAEM ١٩٩٩[٢٦]. Patients then divided into five grades of severity on the basis of neurophysiological classification[٢٧]. Neuro-muscular ultrasound evaluation, using the same machine; patient was in supine position and arm was abducted and flexed ٩٠ at the elbow for evaluation of the nerve from the wrist to the mid-arm[١٦] fig. (٢). To obtain a sagittal view, the transducer was placed in the ulnar groove. Then, rotated ٩٠° degrees to obtain a cross sectional view at the elbow. The transducer was then advanced distally to the mid-forearm and proximally to the mid-arm, for imaging of the nerve in the cubital tunnel, at the level of the medial epicondyle, and in the supracondylar region[١٦]. On transverse scans, the CSA of the ulnar nerve was determined using direct tracing method. Nerve size was measured at the following levels: the medial epicondyle, ٢cm proximal ٢cm distal to this level and in the middle of the upper arm and forearm.

Ulnar nerve ratios; upper arm and forearm swelling ratios were calculated by dividing the maximum ulnar nerve CSA at the elbow by the ulnar nerve CSA at the middle of the upper arm and forearm respectively[٢٨].

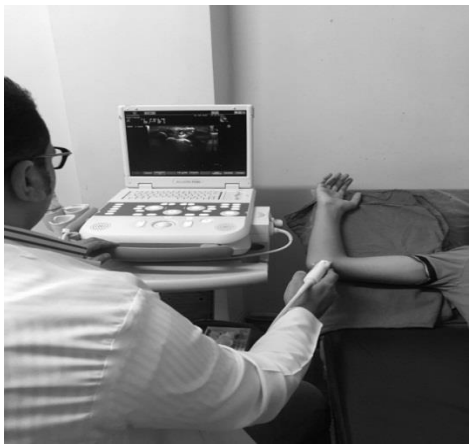

Figure (٢): Positioning for ulnar nerve imaging

Statistical analysis

Analysis of data was done by personal computer using SPSS (Statistical program for social science) version ١٦. Data were expressed as mean ± SD for parametric variables and as number and percent for non-parametric variable. Comparison between groups for parametric data was done by independent samples t-test (unpaired t-test). Chi – square ($X^٢$) test was used to compare qualitative variables. The difference was expressed as probability of value (P value). The difference was considered significant if $P < ٠.٠٥$.

Results

Concerning CTS group; their ages ranged from ١٨ to ٥٥ years with a mean of ٣٥.٨٦±٩.٧٤ and their illness duration was ranged from ٢ to ٢٠ weeks with a mean of ٦.٢٤±٣.٣٩.

Measures of CSA of the MN at the inlet, CSA at the outlet, palmer bowing and inlet/forearm ratio in the CTS patients were significantly different compared to control group (p<٠.٠٠١ for all) and flattening ratio p=٠.٠٢ (table ١). The accuracy of ultrasonographic measurements was evaluated by using cut off points of ROC curve. The area under the curve (AUC) of CSA was ٠.٩٥, indicating a sensitivity and specificity of ٩٤٪ and ٦٦% respectively, at cut off value of ٨.٥ mm^2. The AUC of inlet/forearm ratio was ٠.٩٠ at cut off value of ٢.٠٨ indicating a sensitivity and specificity of ٧٠٪ and ٩٢٪ respectively. The AUC of FR was ٠.٥٥ at cut off value of ٣.٧ indicating a sensitivity and specificity of ٢١% and ٩٩% respectively. The AUC of PB was ٠.٩٥ at cut off value of ٢.٥٥ mm indicating a sensitivity and specificity of ٩١% and ٩٥% respectively (table ٢).

Our results showed that CSA and Palmer bowing were the most statistically significant parameters that had correlation with the clinical parameters There was positive correlation between symptom severity score and US parameters as regards CSA at the inlet, inlet/forearm ratio, palmer bowing and mobility (r=٠.٣٠, p=٠.٠٠٣, r=٠.٢١, p=٠.٠٤, r=٠.٢٢, p=٠.٠٣ and r=٠.٢٦, p=٠.٠٠٨ respectively) moreover there was positive correlation between functional score and US parameters as regards CSA at the inlet, CSA at the outlet, inlet/forearm ratio, flattening ratio and palmer bowing (r=٠.٢٧, p=٠.٠٠٧, r=٠.٢٨, p=٠.٠٠٤, r=٠.٣٣, p=٠.٠٠١, r=٠.٢٧, p=٠.٠٠٨ and r=٠.٢٠, p=٠,٠٤ respectively)

The Hi-Ob-Db. score showed positive correlation with US parameters as regards CSA at the inlet, CSA at the outlet, inlet/forearm ratio, palmer bowing, mobility and doppler signals (r=٠.٢٩,p= ٠.٠٠٣, r=٠.٢٠, p= ٠.٠٤, r=٠.٣١ p=٠.٠٠٢, r=٠.٢٩ p= ٠.٠٠٤, r=٠.٢٨ p=٠.٠٠٥ and r=٠.٢٩, p=٠,٠٠٤ respectively).

Concerning CuTS group; their ages ranged from ٢٥ to ٦٠ years with a mean of ٣٨.٢٥ ± ٩.٩٠ and disease duration ranged from ٢ to ٣٤ weeks with a mean of ١٣.١٥ ± ١٠.٥٤.

CSA of the ulnar nerve at the medial epicondyle ranged from ١٠ to ٢٠ mm^2 with a mean of ١٣.٩٥mm^2 ± ٢.٩٥, while the CSA ٢ cm proximal to the medial epicondyle ranged from ٦ to ١١ mm^2 with a mean of ٨.٥ mm^2 ± ١.٨٥. The CSA ٢ cm distal to the medial epicondyle ranged from ٦ to ١٠ mm^2 with a mean of ٨.٥٥ mm^2 ± ١.٣٩. The medial epicondyle /mid arm CSA ratio was found to be from ١.٢٠ to ٢.٨١ with a mean of ٢.٠٨± ٠.٥٠ while the medial epicondyle /mid forearm CSA ratio as found to be from ١.٥٠ to ٤.٥٠ with a mean of ٢.٧٨± ٠.٨٤. Power Doppler signals was found to be positive in ١١ (٥٥٪) of diseased elbows. There was a difference in the CSA of the ulnar nerve at the medial epicondyle in controls (٨.٧٥ mm٢) compared to those with UNE (١٣.٩٥ mm٢), which was statistically significant (*P* = ٠.٠٠١) (fig.٣). The ulnar nerve ratios at the medial epicondyle and mid arm and mid forearm were also statistically significant with p < ٠.٠٠١ (table ٣).

CSA at the medial epicondyle was found to be the most sensitive parameter in diagnosis of CuTS. It showed the highest sensitivity ١٠٠٪ and specificity ٨٠٪ with ٩٨.٥٪ for the AUC at cut off point ٩.٥mm^2, compared to other US parameters. Combined CSA at the medial epicondyle and ulnar nerve ratio add no more values to sensitivity or specificity (table ٤).

Table (١): US findings in CTS patients and control

	Patients (n=١٠٠)	Control (n=١٠٠)	P value
CSA inlet	١١.٨٩ ± ٢.٦٤	٧.٨٥ ± ١.٠٨	<٠.٠٠١*
CSA outlet	١٠.٣٤ ± ٢.٣٦	٦.٧٦ ± ١.٢٩	<٠.٠٠١*
Inlet/forearm ratio	٢.٥٣ ± ٠.٦٩	١.٦٧ ± ٠.٢٩	<٠.٠٠١*
Flattening ratio	٣.١٠ ± ٠.٨٣	٢.٨٨ ± ٠.٤٨	٠.٠٢*
Palmer bowing	٤.٢٧ ± ١.٣٦	١.٩٥ ± ٠.٣٦	<٠.٠٠١*

*Independent sample t test *Significant p-value < ٠.٠٥, CSA; Cross Sectional Area*

Table (٢): accuracy of ultrasonographic parameters in CTS group:

	AUC	sensitivity	specificity	Cut off value	P value
CSA inlet	٩٥٪	٩٤٪	٦٦٪	٨.٥	<٠.٠٠١*
CSA outlet	٩٢٪	٨٠٪	٨٩٪	٨.٥	<٠.٠٠١*
Inlet/ forearm ratio	٩٠٪	٧٠٪	٩٢٪	٢.٠٨	<٠.٠٠١*
Flattening ratio	٥٥٪	٢١٪	٩٩٪	٣.٧١	٠.٢٦٧
Palmar bowing	٩٥٪	٩١٪	٩٥٪	٢.٥٥	<٠.٠٠١*

*ROC curve, CSA; Cross Sectional Area, *Significant p-value < ٠.٠٥*

Table (٣): Ultrasonographic findings in cubital tunnel syndrome group and control

		Elbows (No = ٢٠)	control	p-value
CSA at the medial epicondyle	Range	١٠ - ٢٠	٨-١٠	<٠.٠٠١*
	Mean± SD	١٣.٩٥ ± ٢.٩٥	٨.٧٥±٠.٧٩	
CSA ٢ cm proximal to media epicondyle	Range	٦ - ١١	٦-٨	٠.٠٠١*
	Mean± SD	٨.٥±١.٨٥	٦.٩٠±٠.٧٩	
CSA ٢ cm distal to media epicondyle	Range	٦ - ١٠	٥-٧	<٠.٠٠١*
	Mean± SD	٨.٥٥±١.٣٩	٥.٩٥±٠.٦٩	
medial epicondyle CSA/ arm ratio	Range	١.٢٠ - ٢.٨١	٠.٨٠- ١.٣٣	<٠.٠٠١*
	Mean± SD	٢.٠٨±٠.٥٠	١.١٠±٠.١٩	
medial epicondyle CSA/ forearm Ratio	Range	١.٥٠ – ٤.٥٠	١-٢	<٠.٠٠١*
	Mean± SD	٢.٧٨±٠.٨٤	١.٥٣±٠.٢٩	

Table (٤): Diagnostic value of ultrasonographic parameters in cubital tunnel syndrome:

	AUC	Sensitivity	Specificity	Cutoff value	P value
CSA at the medial epicondyle	٩٨.٥٪	١٠٠٪	٨٠٪	٩.٥	<٠.٠٠١ *
CSA ٢ cm proximal to medial epicondyle	٧٦٪	٧٥٪	٧٥٪	٧.٥	٠.٠٠٥*
CSA ٢ cm distal to medial epicondyle	٩٤٪	٩٠٪	٨٠٪	٦.٥	<٠.٠٠١ *
medial epicondyle CSA/arm ratio	٩٥.٥٪	٩٠٪	٨٥٪	١.٢٩	<٠.٠٠١ *
medial epicondyle CSA/forearm ratio	٩٥٪	٩٥٪	٨٥٪	١.٧	<٠.٠٠١ *
Combined CSA at the med. Epicondyle and delta arm	٩٩٪	١٠٠	٨٠٪	٣٨٤.٦٤	<٠.٠٠١ *

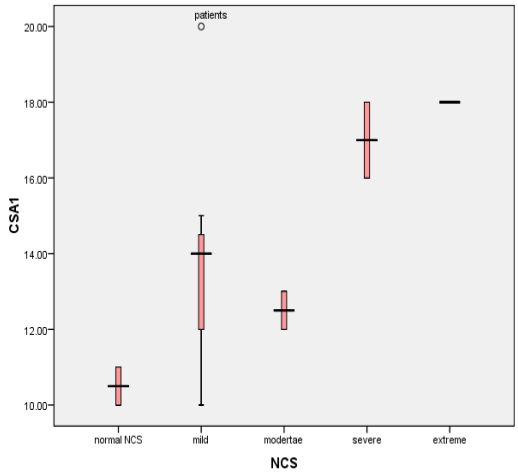

Fig. (٣): Range of CSA in CuTS group

Discussion

In most instances, the value of complementary testing should be determined by the extent to which it affects the probability of the patient having the diagnosis that had been established clinically. Clearly, there are diagnoses that cannot be well established on the basis of clinical criteria alone and appropriate testing. Confirmation of CTS is usually evaluated by electrophysiological study[٢٩]. However, sometimes, it is difficult to diagnose CTS using only this modality, early cases and even severe CTS that show no response to the stimulation, elderly patients and associated peripheral polyneuropathy patients[٢٠].

Recently, US techniques came into advancement as a tool to complement the diagnosis of CTS[٢٠].

In the present study, the efficacy of ultrasound for the assessment of CTS and CuTS was evaluated. Electrodiagnostic studies and clinical criteria were used as gold standard diagnostic procedures.

The sensitivity of the CSAs for diagnosis of CTS was ranged from ٤٨٪ to ٨٩٪ [٧, ٢٠, ٣٠-٣٢] and the CSA cutoff at which the values were considered abnormal, varied from ٩-١٥ mm^٢ [٧,٩,٢٠,٣٢-٣٥]. Our study showed ٩٤٪ sensitivity and ٦٦٪ specificity at ٨.٥ mm^٢ cut off value for the mean CSA at the inlet which was the same cut off value for the study of Mohammadi et al., ٢٠١٠[٣٦] with near equal sensitivity (٩٧٪) and different specificity (٩٨٪). This higher specificity probably was due to higher number of patients included in that study (١٦٤ wrists vs. ١٠٠ wrists in our study). Kim et al., ٢٠١٤ results showed a higher sensitivity ٨٨.٥٪ probably due to less number of their control (٣٠ wrists vs. ١٠٠ wrists in our study) and higher sample size (٢٤٦ wrists) and showed a higher specificity ٩٠٪ probably due to higher cutoff value of ١٠mm^٢.

The sensitivities of increased palmer bowing of the flexor retinaculum varied from ٤٠٪ to ٨٧.٢٪[٩,٢٠,٣٤,٣٧] and sensiti-vities of flattening ratio ranged from ٣٧٪ to ١٠٠٪ [٢٠,٣٧,٣٨]. Our results showed a sensitivity of ٩١٪ and ٩٥٪ specificity at cut off value of ٢.٥٥ mm for the PB. These data of sensitivities corresponds with the findings reported in earlier studies. Sensitivity of FR was found to be ٢١٪ at cut off value of ٣.٧ mm which is less than previous data by kim et al., ٢٠١٤ (٧٧.٨٪ vs. ٢١٪ in this study) due to higher cutoff value (٣.٤ vs. ٣.٧ respectively). FR had a poor predictive value as found by [٣٠,٣٩].

In our study, CSA and FR, PB of US were significantly increased in the CTS group than the control group. Among them, CSA at the inlet and PB were found to have a relatively higher accuracy than FR according to the ROC curve. Therefore, measurement of CSA at the inlet and/or PB can be considered as an alternative modality to distinguish CTS patients from asymptomatic controls. These data found to be in concordant with previous data[٩,٢٠,٣٤,٣٧,٣٨].

Mild CTS cannot show abnormal findings on US study in previous studies [٩, ٢٠]. In our results, US could detect abnormalities as regards CSA at the inlet and PB (٨٥٪ and ٩٥٪ of patients in subgroup ١ respectively) with a significant difference in comparison to control group which is in concordant with Mhoon et al., ٢٠١٢.

Results from Keles et al., ٢٠٠٥ and Kim et al. ٢٠١٤, could not show a significant difference of US parameters regards CSA in patients with normal NCS that is different from our results; as their cut off value was higher compared to our results (٩.٣ mm^2 and ١٠ mm^2 vs. ٨.٥ mm^2 respectively) as regards CSA and ٣.٧ mm and ٣ mm vs. ٢.٥٥ mm respectively as regards PB.

The diagnosis of ulnar neuropathy at the elbow is usually made by clinical neurologic examination and standard nerve conduction studies[٤٠]. In the majority of cases it is usually easily diagnosed by means of NCS; however, clinical examination is often non-localizing, the role of provocative tests only marginal, while electrophysiological tests may be normal or non-localizing with sensitivities ranging from ٣٧٪ to ٨٦٪ [٢٦, ٤١].

Our finding from the ultrasound measurement at different levels around the elbow showed positive correlation with NCS in concordant with Volpe et al., ٢٠٠٩; Omejec and Podnar, ٢٠١٥.

The CSA behind the medial epicondyle was found to be the site of maximum enlargement (CSA max.) with the highest sensitivity and specificity (١٠٠٪ and ٨٠٪ respectively) at ٩.٥ mm^2 cut off value and the AUC was ٩٨.٥٪. This cut off value was in concordant with Pompe and Beekman ٢٠١٣[٢٨].

In a study by Simon et al, ٢٠١٥[٤٢]; the CSA max was comparable to our results (١٣.٠± ١.٤ vs. ١٣.٩٥±٢.٩٥ respectively) and they found a significant difference to their control ($p<٠.٠١$).

The range of CSA max was ١٠-٢٠mm^2 which was the same range of our study. Also data from Omejec and Podnar ٢٠١٥[٤٣] found that CSA max was comaprable to our results and ranged from ١٠-١٤mm^2.

As regards the ulnar nerve ratios; Simon et al., ٢٠١٥ found that mid-arm ratio to be ٢.٢±٠.٢ which was significant regarding their control. These data was comprarable to our results.

In terms of sensitivity and specificity the ulnar nerve ratio was found to be ٩٠٪ and ٨٥٪ respectively at cut off value ١.٢٩ which was comparable to results gained from Omejec and Podnar, ٢٠١٥. Pompe and Beekman, ٢٠١٣ concluded that ROC-analysis of their results did not show a cut-off point for the swelling ratio with much higher sensitivity (without loss of too much specificity). The lower specificity found in their study compared to our results may be explained by thier control group which consisted of disease not healty controls.

The AUC of The forearm ratio was found to be ٩٥٪. The sensitivity and specificity was ٩٠٪ and ٨٥٪ respectively, which was more than those found by Bayrak et al., ٢٠١٠[٤٤]; ٨٨٪ and ٦٦٪ respectively probably due to lower number of controls compared to their patients (٢١vs. ٤١ healthy controls).

In conclusion, US is considered a new diagnostic modality in entrapment neuropathies of the median and ulnar nerves and several cut off values are considered nowadays as a diagnostic criteria for CTS and CuTS.

References

١. Ibrahim I, Khan W, Goddard N, Smitham P. Suppl ١: Carpal Tunnel Syndrome: A Review of the Recent Literature. Open Orthop J ٢٠١٢,٦:٦٩.

٢. Roberts G, Maclean A, Logan A. Ulna Nerve Decompression at the Elbow in Patients with Normal Nerve Conduction Tests. J Hand Surg Am ٢٠١٥,٢٠:٢٦٠-٢٦٥.

٣. Qing C, Zhang J, Wu S, Ling Z, Wang S, Li H, et al. Clinical classification and treatment of cubital tunnel syndrome. Exp Ther Med ٢٠١٤,٨:١٣٦٥-١٣٧٠.

٤. Walker F, Cartwright M, Wiesler E, Caress J. Ultrasound of nerve and

muscle. Clin Neurophysiol ٢٠٠٤,١١٥: ٤٩٥-٥٠٧.

٥. Jablecki C, Andary M, Ball R, Cherington M, Fisher M, Phillips L, et al. Practice parameter for electrodiagnostic studies in carpal tunnel syndrome (Summary statement). Muscle Nerve ١٩٩٣,١٦: ١٣٩٠-١٣٩١

٦. Beekman R, Visser L. Sonography in the diagnosis of carpal tunnel syndrome: a critical review of the literature. Muscle nerve ٢٠٠٣,٢٧:٢٦-٣٣.

٧. Duncan I, Sullivan P, Lomas F. Sonography in the diagnosis of carpal tunnel syndrome. AJR ١٩٩٩,١٧٣:٦٨١-٦٨٤.

٨. Deniz F, Oksuz E, Sarikaya B, Kurt S, Erkorkmaz U, Ulusoy H, et al. Comparison of the diagnostic utility of electromyography, ultrasonography, computed tomography, and magnetic resonance imaging in idiopathic carpal tunnel syndrome determined by clinical findings. Neurosurgery٢٠١٢,٧٠:٦١٠-٦١٦.

٩. Keles I, Kendi A, Aydn G, Zog S, Orkun S. Diagnostic precision of ultrasonography in patients with carpal tunnel syndrome. Am J Phys Med Rehabil ٢٠٠٥,٨٤:٤٤٣-٤٥٠.

١٠. Chiou H, Chou Y, Cheng S, Hsu C, Chan R, Tiu C, et al. Cubital tunnel syndrome: diagnosis by high-resolution ultrasonography. J Ultrasound Med ١٩٩٨,١٧:٦٤٣-٦٤٨.

١١. Ginn S, Cartwright M, Chloros G, Walker F, Yoon J, Brown M, et al. Ultrasound in the diagnosis of a median neuropathy in the forearm: case report. J Brachial Plex Peripher Nerve Inj ٢٠٠٧, ٢:١.

١٢. Azami A, Maleki N, Anari H, Iranparvar M, Kalantarhormozi M, Tavosi Z. The diagnostic value of ultrasound compared with nerve conduction velocity in carpal tunnel syndrome. Int J Rheum Dis ٢٠١٤,١٧:٦١٢-٦٢٠.

١٣. El Miedany Y, Mehanna A, El Gaafary M, Ashour S. Validation of the arabic self-administered questionnaires for clinical diagnosis, global assessment of symptoms severity and functional status of patients with carpal tunnel syndrome. In: Ann Rheum Dis: BMJ publishing group british med assoc house; ٢٠٠٧. pp. ٢٣٨-٢٣٩.

١٤. Rao BH, Kutub M, Patil S. Carpal tunnel syndrome: Assessment of correlation between clinical, neurophysiological and ultrasound characteristics. J Sci Soc ٢٠١٢,٣٩:١٢٤.

١٥. Bland J. A neurophysiological grading scale for carpal tunnel syndrome. Muscle nerve ٢٠٠٠,٢٣:١٢٨٠-١٢٨٣.

١٦. Cartwright M, Walker F. Neuromuscular ultrasound in common entrapment neuro-pathies. Muscle nerve ٢٠١٣,٤٨: ٦٩٦-٧٠٤.

١٧. Klauser A, Ellah M, Halpern E, Siedentopf C, Auer T, Eberle G, et al. Sonographic cross-sectional area measurement in carpal tunnel syndrome patients: can delta and ratio calculations predict severity compared to nerve conduction studies? Eur Radiol ٢٠١٥, (٢٥):٢٤١٩–٢٤٢٧.

١٨. Hobson L, Massey J, Juel V, Sanders D. The ultrasonographic wrist-to-forearm median nerve area ratio in carpal tunnel syndrome. Clin Neurophysiol ٢٠٠٨, ١١٩:١٣٥٣-١٣٥٧.

١٩. Mhoon J, Juel V, Hobson L. Median nerve ultrasound as a screening tool in carpal tunnel syndrome: Correlation of cross-sectional area measures with electrodiagnostic abnormality. Muscle nerve ٢٠١٢,٤٦:٨٦١-٨٧٠.

٢٠. Kim M, Jeon H, Park S, Park D, Nam H. Value of ultrasonography in the diagnosis of carpal tunnel syndrome: correlation with electrophysiological abnormalities and clinical severity. J Korean Neurosurg Soc ٢٠١٤,٥٥:٧٨-٨٢.

٢١. Choi S, Ahn J, Ryu D, Kang C, Jung S, Park M, et al. Ultrasonography for nerve compression syndromes of the upper extremity.Ultrasonography٢٠١٥,٣٤: ٢٧٥.

٢٢. Ooi C, Wong S, Tan A, Chin A, Bakar R, Goh S, et al. Diagnostic criteria of carpal tunnel syndrome using high-resolution ultrasonography: correlation with nerve conduction studies. Skeletal Radiol. ٢٠١٤,٤٣:١٣٨٧-١٣٩٤.

٢٣. Mohammadi A, Ghasemi M, Mladkova N, Ansari S. Correlation Between the Severity of Carpal Tunnel Syndrome and Color Doppler Sonography Findings. AJR ٢٠١٢,١٩٨:W١٨١-W١٨٤.

٢٤. Palmer B, Hughes T. Cubital tunnel syndrome. J Hand Surg Am ٢٠١٠, ٣٥:١٥٣-١٦٣.

٢٥. Mondelli M, Padua L, Giannini F, Bibbo G, Aprile I, Rossi S. A self-administered questionnaire of ulnar neuropathy at the elbow. J Neurol Sci ٢٠٠٦,٢٧:٤٠٢-٤١١.

٢٦. American Association of Electro-diagnostic Medicine. Practice parameter for electrodiagnostic studies in ulnar neuropathy at the elbow: summary statement. Muscle Nerve ١٩٩٩,٢٢:٤٠٨-٤١١.

٢٧. Padua L, Aprile I, Mazza O, Padua R, Pietracci E, Caliandro P, et al., Neurophysiological classification of ulnar entrapment across the elbow. Neurol Sci ٢٠٠١,٢٢:١١-١٦.

٢٨. Pompe S, Beekman R. Which ultrasonographic measure has the upper hand in ulnar neuropathy at the elbow? Clin Neurophysiol ٢٠١٣,١٢٤:١٩٠-١٩٦.

٢٩. AAEM AAoEM, Neurology AAo, Rehabilitation AAoPMa. Practice parameter for electrodiagnostic studies in carpal tunnel syndrome: summary statement. Muscle nerve ٢٠٠٢,٢٥:٩١٨-٩٢٢.

٣٠. Wong S, Griffith J, Hui A, Tang A, Wong K. Discriminatory sonographic criteria for the diagnosis of carpal tunnel syndrome. Arthritis Rheum ٢٠٠٢,٤٦: ١٩١٤-١٩٢١.

٣١. El Miedany Y, Aty S, Ashour S. Ultrasonography versus nerve conduction study in patients with carpal tunnel syndrome: substantive or complementary tests? Rheumatology (Oxford) ٢٠٠٤,٤٣:٨٨٧-٨٩٥.

٣٢. Wiesler E, Chloros G, Cartwright M, Smith B, Rushing J, Walker F. The use of diagnostic ultrasound in carpal tunnel syndrome. J Hand Surg Am ٢٠٠٦, ٣١:٧٢٦-٧٣٢.

٣٣. Nathan P, Keniston R, Meadows K, Lockwood R. Predictive value of nerve conduction measurements at the carpal tunnel. Muscle nerve ١٩٩٣,١٦:١٣٧٧-١٣٨٢.

٣٤. Altinok T, Baysal O, Karakas H, Sıgırcı A, Alkan A, Kayhan A, et al. Ultrasonographic assessment of mild and moderate idiopathic carpal tunnel syndrome.Clin Radiol ٢٠٠٤,٥٩:٩١٦-٩٢٥.

٣٥. Ahn S, Hong Y, Koh Y, Chung Y, Lee S, Yang H. Pressure measurement in carpal tunnel syndrome: correlation with electrodiagnostic and ultrasonographic findings. J Korean Neurosurg Soc ٢٠٠٩, ٤٦:١٩٩-٢٠٤.

٣٦. Mohammadi A, Afshar A, Etemadi A, Masoudi S, Baghizadeh A. Diagnostic value of cross-sectional area of median nerve in grading severity of carpal tunnel syndrome. Arch Iran Med ٢٠١٠, ١٣:٥١٦-٥٢١.

٣٧. Buchberger W, Schon G, Strasser K, Jungwirth W. High-resolution ultra-sonography of the carpal tunnel. J Ultrasound Med ١٩٩١,١٠:٥٣١-٥٣٧.

٣٨. Yesildag A, Kutluhan S, Sengul N, Koyuncuoglu H, Oyar O, Guler K, et al. The role of ultrasonographic measure-ments of the median nerve in the diagnosis of carpal tunnel syndrome. Clin Radiol ٢٠٠٤,٥٩:٩١٠-٩١٥.

٣٩. Sarria L, Cabada T, Cozcolluela R, Martinez-Berganza T, Garcia S. Carpal tunnel syndrome: usefulness of sono-graphy. Eur Radiol ٢٠٠٠,١٠:١٩٢٠-١٩٢٥.

٤٠. Logigian E, Villanueva R, Twydell P, Myers B, Downs M, Preston D, et al. Electrodiagnosis of ulnar neuropathy at the elbow (UNE): a bayesian approach. Muscle nerve ٢٠١٤,٤٩:٣٣٧-٣٤٤.

٤١. Beekman R, Schreuder A, Rozeman C, Koehler P. The diagnostic value of provocative clinical tests in ulnar neuropathy at the elbow is marginal. J Neurol Neurosurg Psychiatry ٢٠٠٩,٨٠: ١٣٦٩-١٣٧٤.

٤٢. Simon N, Ralph J, Poncelet A, Engstrom J, Chin C, Kliot M. A comparison of ultrasonographic and electrophysiologic ‘inching’in ulnar neuropathy at the elbow. Clin Neurophysiol ٢٠١٥,١٢٦: ٣٩١-٣٩٨.

٤٣. Omejec G, Podnar S. Normative values for short-segment nerve conduction studies and ultrasonography of the ulnar nerve at the elbow. Muscle nerve ٢٠١٥, ٥١:٣٧٠-٣٧٧.

٤٤. Bayrak A, Bayrak I, Turker H, Elmali M, Nural M. Ultrasonography in patients with ulnar neuropathy at the elbow: Comparison of cross-sectional area and swelling ratio with electrophysiological severity. Muscle nerve ٢٠١٠,٤١:٦٦١-٦٦٦.