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Ulnar Nerve Changes Associated with Carpal Tunnel Syndrome Not Affecting Median Versus Ulnar Comparative Studies

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Abstract: Objective: The present study was conducted to assess the involvement of ulnar sensory and/or motor nerve fibers in patients with carpal tunnel syndrome (CTS) and whether this affects the accuracy of the median versus ulnar comparative tests. Patients and methods: The present study included 145 CTS hands and 71 asymptomatic control hands. Clinical examination was done. The following tests were done: Sensory conduction studies: median, ulnar and dorsal ulnar cutaneous nerves; and median versus ulnar digit (D) four sensory comparative study; and motor conduction studies: median nerve, ulnar nerve and median versus ulnar motor comparative study. Results: It was found that 17 CTS hands (11.7%) had ulnar sensory abnormalities in 17 different patients. The median versus ulnar sensory and motor comparative studies were abnormal among all these 17 CTS hands. There were significant negative correlations between median motor latency and both ulnar sensory amplitudes recording D5 and D4. In conclusions, there is ulnar sensory nerve abnormality among CTS patients. This abnormality affecting the amplitude of ulnar sensory nerve action potential. This does not affect the median versus ulnar sensory and motor comparative tests accuracy for use in CTS.

Key words: Median nerve · Motor comparative study · Sensory comparative study · Motor conduction · Sensory conduction

INTRODUCTION

Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy [1]. It is a median neuropathy at the wrist due to compression of the median nerve beneath the transverse carpal ligament [2-4]. It is due to elevated pressure in the carpal tunnel [1]. The median nerve conduction study confirms the clinical diagnosis of CTS [5]. An extended nerve conduction study with supplementary tests to compare conduction between median and ulnar nerves, increases the diagnostic precision. These comparative tests are done when the routine median motor and sensory conduction studies revealed normal results [6]. There are many comparative tests used in the electrophysiological assessment of CTS that use ulnar nerve as an internal comparison nerve [2, 7]. These tests include the median versus ulnar motor comparative test and median versus ulnar sensory comparative test. These tests compare the median nerve with ulnar nerve provided that ulnar nerve is normal [2].

There are reports that stated the affection of ulnar nerve in CTS at the wrist [8-12]. This can argue for the usefulness of using ulnar nerve in comparison to the median nerve in the median versus ulnar comparative studies. This can lead to misleading findings and miss the diagnosis of CTS electrophysiologically. The aim of the current study was to investigate the involvement of the sensory and motor fibers of the ulnar nerve among CTS patients and whether these changes, if present, affect and alter the accuracy of the median versus ulnar comparative studies in the diagnosis of CTS.

Subject and Methods: The present cross sectional study included 145 clinically diagnosed idiopathic CTS hands that were obtained from 102 patients who were consecutively recruited from those attending the Outpatient Clinic of Physical Medicine, Rheumatology and Rehabilitation Department, Main University Hospital, Alexandria Faculty of Medicine. Clinical diagnosis of CTS was based on the presence of at least one of the

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following primary symptoms: (i) the presence of numbness, tingling or paresthesia in the median nerve distribution, (ii) the symptoms are precipitated by repetitive hand activities and relieved by resting, rubbing and shaking the hand, (iii) the presence of nocturnal awakening by these sensory manifestations. The clinical diagnosis of CTS was supported by the presence of positive Tinel's sign and/or Phelen's sign [13]. The study included 71 asymptomatic hands that were obtained from 55 apparently healthy volunteers as a control group. The volunteers included medical staff, their relatives and patients' relatives. Exclusion criteria included diabetes mellitus, endocrine disorders, metabolic disorders, rheumatological disorders, neurological disorders including peripheral neuropathy, cervical radiculopathy, thoracic outlet syndrome, ulnar entrapment neuropathy at the elbow or the wrist and the presence of abnormal dorsal ulnar cutaneous branch of ulnar nerve in the form of decreased amplitude, decreased conduction velocity (CV) or unobtainable response; and other conditions predispose to CTS as pregnancy, previous wrist fracture, etc... The study was explained to the participants and an informed consent was given by each. The study had been approved by the ethical committee of the Faculty of Medicine, Alexandria University, Egypt.

Patients were clinically evaluated. Demographic data and history taking were done stressing on the presence of sensory complaints along the median sensory territory (median distribution of symptoms) or extending beyond it to the whole fingers or whole hand (extra-median distribution of symptoms). The standardized semi-quantitative clinical History-Objective (Hi-Ob) scale was used to assess the CTS severity by integrating symptoms with clinical features. The Hi-Ob scale has 5 stages of severity [14].

Electrophysiological studies were conducted on a NIHON KOHDEN Neuropack MEB-7102 mobile unit with a two channel evoked potential / electromyography (EMG) measuring system (Nihon Kohden Corporation, Tokyo, Japan).

The Study Included the Following:

Sensory Nerve Conduction Study: (i) Sensory nerve conduction study of the median nerve [recording digit (D) two], (ii) Sensory nerve conduction study of the ulnar nerve (recording D five) and (iii) Median versus ulnar digit four (D4) sensory latency comparative study. They were performed according to the technique described by Saba [15]. (iv) Sensory nerve conduction study of the dorsal ulnar cutaneous nerve. It was performed according to the technique described by Preston and Shapiro [16].

Motor Nerve Conduction Study: (i) Motor nerve conduction study of the median nerve, (ii) Motor nerve conduction study of the ulnar nerve and (iii) Median (recording second lumbrical muscle) versus ulnar (recording the 1st palmar interosseous muscle) (2-LINT) motor latency comparative study. They were performed according to the technique described by Saba [15].

Electrophysiological grading of the severity of CTS was rated according to Bland scale [17]. Bland scale is divided into 7 different grades: Grade 0: shows no evidence of CTS electrophysiologically. Grade 1: very mild CTS detected by the presence of two abnormal sensitive comparative tests. Grade 2: mild CTS detected by delayed median sensory conduction velocity (CV). Grade 3: moderate CTS detected by delayed median motor distal latency (DL) but less than 6.5 ms with preserved median sensory nerve action potential (SNAP). Grade 4: severe CTS detected by delayed median motor DL but less than 6.5 ms with absent median SNAP. Grade 5: very severe CTS detected by delayed median motor DL more than 6.5 ms. Grade 6: extremely severe CTS detected by delayed median motor DL with decreased median compound muscle action potentials (CMAP) amplitude (surface CMAP amplitude is less than 0.2 mV). The patients were grouped into 3 grades of CTS electrophysiological severity according to the results of Bland scale (for simplification of the obtained results). CTS electrophysiological severity grade 1 corresponds to Bland scale 0, 1 and 2. CTS electrophysiological severity grade 2 corresponds to Bland scale 3 and 4. CTS electrophysiological severity grade 3 corresponds to Bland scale 5 and 6. The wrists with grade 0 and 1 Bland scale were not excluded from the study in order to ensure an accurate calculation of ulnar nerve affection rates.

Statistical analysis of data was done by using the Statistical Package of Social Science (SPSS version 17) software [18]. Descriptive measures [count, frequency, minimum, maximum, mean and standard deviation (SD)] as well as analytic measures (t-test, ANOVA and Pearson Chi-square test) were used. If comparison of groups showed a significant difference, Bonferroni's multiple comparison test (post-hoc analysis) was performed. Correlation was conducted using Pearson correlation test. Statistical significance was assigned to any

P value at ≤0.05. The reference cut-off values of the electrophysiological studies were calculated by rounding the mean plus or minus two SD to measure the upper limit of normal or the lower limit of normal respectively.

RESULTS

The present study included 145 clinically diagnosed CTS hands that were obtained from 102 patients [83 women (81.4%) and 19 men (18.6%)]. Their mean age was 43.70±11.16 years (ranged from 21 to 70 years). The control group consisted of 71 asymptomatic hands that were obtained from 55 healthy individuals [43 women (78.2%) and 12 men (21.8%)]. Their mean age was 41.53±11.43 years (ranged from 18 to 65 years). There were no statistically significant differences between patients and control group as regards gender (X^2=0.230, *P*=0.632) and age (t=-1.330, *P*=0.185).

The clinical characteristics of the patients are summarized in Table 1. There was no patients had sensory symptoms localized only to the ulnar nerve territory only (i.e., little finger or ring and little fingers only). The distribution of CTS patients according to Hi-Ob scale was as the following: (i) there were 32 CTS hands (22.1%) had grade 1; (ii) 61 hands (42.1%) had grade 2; (iii) 35 hands (24.1%) had grade 3; (iv) 14 hands (9.7%) hand grade 4; and (v) 3 hands (2.1%) hand grade 5. The CTS hands covered all grades of Hi-Ob scale. The distribution of CTS patients according to the Bland score was as the following: (i) there were 3 hands (2.1%) had grade 0; (ii) 34 hands (23.4%) had grade 1; (iii) 42 hands (29%) had grade 2; (iv) 41 hands (28.3%%) had grade 3; (v) 8 hands (5.5%) had grade 4; (vi) 12 hands (8.3%) had grade 5; and (vii) 5 hands (3.4%) had grade 6. The CTS hands covered all Bland score grades of CTS electrophysiological severity. Bilateral affection was present in 43 patients (42.1%).

The distribution of CTS patients according to the CTS electrophysiological severity grades was as the following: (i) there were 81 patients (55.9%) had CTS electrophysiological severity grade 1; (ii) 47 patients (32.4%) had CTS electrophysiological severity grade 2; and (iii) 17 patients (11.7%) had CTS electrophysiological severity grade 3. The CTS patients covered all CTS electrophysiological severity grades. There were no statistically significant differences between patients with different CTS electrophysiological severity grades and control group as regards gender (X^2=0.683, *P*=0.877) and age (F=1.675, *P*=0.173).

The results of the nerve conduction studies of all nerves in the present study are shown in Table 2. The differences in all parameters of sensory and motor median nerve studies between CTS patients and control subjects were statistically significant. There were no statistically significant differences between patients and control group as regards parameters of ulnar motor conduction study and dorsal ulnar cutaneous nerve sensory conduction study. This excluded the presence of peripheral polyneuropathy and proximal ulnar entrapment neuropathy among the CTS patients group. The amplitudes of the SNAP of ulnar nerve recording D5 and D4 among CTS hands were statistically significantly lower than those among control hands. Reference cut-off values for all electrophysiological tests parameters obtained from the control group are presented in Table 2.

The results of the ulnar sensory and motor nerve conduction studies in the present study among different CTS electrophysiological severity grades in comparison to control are shown in Table 3. There were no statistically significant differences between different CTS electrophysiological severity grades and control group as regards all parameters of ulnar nerve motor conduction studies (recording both abductor digiti minimi and 1st

Table 1: Clinical characteristics of patients and control group

Clinical characteristics	CTS patients (n= 145 hands from 102 patients)	Control subjects (n= 71 hands from 55 healthy volunteers)	Test of significance	*P*
Women [number (percentage)]	83(81.4%)	43(78.2%)	(X^2) 0.230	0.632
Age (mean±SD, years)	43.70±11.16	41.53±11.43	(t) -1.330	0.185
Side (right/left)	85(58.6%)/60(41.4%)	43(60.6%)/28(39.4%)	(X^2) 0.075	0.785
Duration of the condition (mean±SD, years)	2.93±2.39	NA	NA	NA
Hi-Ob scale [median (range)]	2(1-5)	NA	NA	NA
Median/Extra-median distribution of symptoms [number (percentage)]	86(59.3%)/59 (40.7%)	NA	NA	NA
Bland grading [median (range)]	2(0-6)	NA	NA	NA
CTS electrophysiological severity grades [median (range)]	1(1-3)	NA	NA	NA

CTS, carpal tunnel syndrome; Hi-Ob scale, clinical History-Objective scale; n, number of hands; SD, standard deviations; NA, not applicable; X^2, value of chi-square test; t, value of t- test

* *P* is significant at ≤ 0.05

Table 2: Comparison of different nerve conduction study parameters between patients and control with the determined reference cut-off values

Nerve conduction study parameters	Patients (n=145 hands) mean±SD	Control subjects (n=71 hands) mean±SD	t	*P*
Median DL (ms)(4.3)	4.57±1.47	3.52±0.38	-5.925	<0.0001*
Median CMAP amp (mV)(3.8)	7.51±3.12	7.62±1.90	0.253	0.801
Ulnar DL (ms)(3.4)	2.65±0.32	2.69±0.36	0.830	0.407
Ulnar CMAP amp (mV)(4.2)	7.69±2.68	8.30±2.05	1.632	0.104
Median 2-L DL (ms)(3.8)	4.44±1.61	3.19±0.29	-6.506	<0.0001*
Median 2-L amp (mV)(0.2)	1.73±1.05	1.74±0.78	0.061	0.952
Ulnar INT DL (ms)(3.5)	2.88±0.30	2.95±0.28	1.614	0.108
Ulnar INT amp (mV)(0.3)	4.26±1.97	3.89±1.78	-1.311	0.191
Median - Ulnar 2-LINT (ms)(0.6)	1.55±1.56	0.23±0.19	-7.044	<0.0001*
Median sensory CV (m/s)(45.6)	42.04±8.49	54.52±4.47	11.525	<0.0001*
Median SNAP amp (µV)(6.8)	17.74±9.79	30.50±11.88	8.158	<0.0001*
Ulnar sensory CV (m/s)(46)	56.54±5.96	55.79±4.92	-0.922	0.358
Ulnar SNAP amp (µV)(12.4)	27.07±11.18	31.93±9.79	3.117	0.002*
Median SNAP D4 PL (ms)(3.9)	4.42±0.88	3.35±0.27	-9.932	<0.0001*
Median SNAP D4 amp (µV)(2.8)	15.45±9.95	21.68±9.46	4.244	<0.0001*
Ulnar SNAP D4 PL (ms)(3.8)	3.199±.301	3.17±0.29	-0.491	0.624
Ulnar SNAP D4 amp (µV)(7.6)	23.39±12.37	26.87±9.64	2.083	0.038*
Median- Ulnar D4 PL (ms)(0.5)	1.602±1.050	0.19±0.17	11.179	<0.0001*
Dorsal sensory CV (m/s)(45.3)	57.71±5.53	56.34±5.50	-0.464	0.643
Dorsal SNAP amp (µV)(6.2)	16.75±6.484	17.86±5.81	1.223	0.223

DL, distal latency; CMAP, compound muscle action potentials; amp, amplitude; 2-L, second lumbrical muscle; INT, first palmar interosseous muscle; 2-LINT, Median versus ulnar (second lumbrical muscle/ first palmar interosseous muscle) motor latency difference; CV, conduction velocity; SNAP, sensory nerve action potential; D4, digit four recording; Dorsal, dorsal ulnar cutaneous nerve; SD, standard deviation. The first brackets represent the unit being used in each electrophysiological parameter. The number in second brackets represents the reference cut-off value used [upper (latency) or lower (CV) limit of normal]; t, value of t- test

* *P* is significant at ≤ 0.05

Table 3: Comparison of different ulnar nerve conduction studies parameters between patients with different CTS electrophysiological severity grades and control subjects

Nerve conduction study parameters	Control subject (n=71 hands) mean±SD	CTS severity grade 1 (n=79 hands) mean±SD	CTS severity grade 2 (n=49 hands) mean±SD	CTS severity grade 3 (n=17 hands)mean±SD	F	*P*
U DL (ms)	2.69±0.36	2.61±0.32	2.70±0.33	2.71±0.25	0.962	0.411
U CMAP amp (mV)	8.30±2.25	7.84±2.91	7.48±2.17	7.58±2.91	1.083	0.357
U INT DL (ms)	2.95±0.28	2.88±.274	2.92±0.32	2.82±0.34	1.306	0.273
U INT amp (mV)	3.89±1.78	4.12±1.71	4.42±2.10	4.48±2.71	0.906	0.439
U SNAP CV (m/s)	55.79±4.92	57.56±6.58	56.12±5.44	55.70±6.49	1.084	0.357
U SNAP amp (µV)	31.93±9.79	30.16±10.72	25.04±9.42†‡	18.01±12.13§ ¶	11.023	<0.0001*
U SNAP D4 PL (ms)	3.17±0.29	3.16±.313	3.23±0.30	3.27±0.21	1.196	0.312
U SNAP D4 amp (µV)	26.87±9.64	27.05±12.64	21.99±9.65	9.80±6.31§¶#	14.292	<0.0001*
Dorsal SNAP CV (m/s)	56.34±5.50	56.44±5.83	57.01±5.30	57.13±4.87	0.210	0.889
Dorsal SNAP amp (µV)	17.86±5.81	16.64±6.45	17.05±7.10	16.43±4.93	0.553	0.647

CTS severity, carpal tunnel syndrome electrophysiological severity; U, ulnar nerve; DL, distal latency; CMAP, compound muscle action potentials; amp, INT, first palmar interosseous muscle; SNAP, sensory nerve action potential; CV, conduction velocity; D4, digit four recording; Dorsal, dorsal ulnar cutaneous nerve; SD, Standard deviation; F, value of ANOVA test

† Significant difference (post hoc comparison) between CTS severity grade 2 and control (*P*=0.003)

‡ Significant difference (post hoc comparison) between CTS severity grade 1 and grade 2 (*P*=0.042)

§ Significant difference (post hoc comparison) between CTS severity grade 3 and control (*P*<0.0001)

¶ Significant difference (post hoc comparison) between CTS severity grade 1 and grade 3 (*P*<0.0001)

Significant difference (post hoc comparison) between CTS severity grade 2 and grade 3 (*P* <0.0001)

* *P* is significant at ≤ 0.05

Table 4: Correlation between median motor distal latency and median sensory conduction velocity and ulnar sensory and motor conduction studies parameters among carpal tunnel syndrome patients

	Median motor DL		Median sensory CV	
Nerve conduction study parameters	r	*P*	R	*P*
Ulnar DL (ms)	0.133	0.113	-0.150	0.089
Ulnar CMAP amp (mV)	-0.085	0.317	-0.007	0.942
Ulnar INT DL (ms)	-0.010	0.909	-0.010	0.907
Ulnar INT amp (mV)	0.087	0.306	-0.081	0.360
Ulnar SNAP CV (m/s)	0.034	0.688	-0.027	0.762
Ulnar SNAP amp (μV)	-0.341	<0.0001*	0.284	0.001*
Ulnar SNAP D4 PL (ms)	0.046	0.588	-0.081	0.359
Ulnar SNAP D4 amp (μV)	-0.370	<0.0001*	0.182	0.039*

DL, distal latency; CMAP, compound muscle action potentials; amp, amplitude; INT, first palmar interosseous muscle; SNAP, sensory nerve action potential; CV, conduction velocity; D4, digit four recording

r= Pearson correlation coefficient

* *P* is significant at ≤ 0.05

palmar interosseous muscles) and dorsal ulnar cutaneous nerve sensory conduction study. There were no statistically significant differences between different CTS electrophysiological severity grades and control group as regards ulnar D5 sensory CV and ulnar D4 sensory peak latency (PL).

There were statistically significant differences between different CTS electrophysiological severity grades and control group as regards the amplitudes of ulnar SNAP recording D5 and D4. The ulnar SNAP amplitude recording D4 in hands with grade 3 CTS electrophysiological severity was significantly smaller than in control hands and hands with grade 1 and 2 CTS electrophysiological severity. The ulnar SNAP amplitudes recording D5 in hands with grade 2 and 3 CTS electrophysiological severity were significantly smaller than in control hands and hands with grade 1 CTS electrophysiological severity (Table 3).

Correlation study between different parameters of ulnar sensory and motor nerve conduction studies against median motor DL and sensory CV are shown in Table 4. There were statistically significant negative correlations between median DL and both ulnar SNAP amplitudes recording D5 and D4. There were statistically significant positive correlations between median sensory CV and both ulnar SNAP amplitudes recording D5 and D4.

It was found that 17 CTS hands (11.7%) had ulnar sensory abnormalities in 17 different patients. Ten hands (58.8%) of them associated with CTS severity grade 3 and the other 7 hands (41.1%) with CTS severity grade 2. The abnormality was in the form of reduced amplitude (less than the reference cut-off values obtained from the control subjects) of ulnar SNAP recording D5 and D4. But the peak latencies of ulnar SNAP recording D5 and D4 were within the reference cut-off values in all CTS hands. Both ulnar SNAP amplitude recording D5 and D4 were abnormal in 4 CTS hands (2.8%). Ulnar SNAP amplitude recording D5 was the only abnormality in 8 CTS hands (5.5%) while ulnar SNAP amplitude recording D4 was the only abnormality in 5 CTS hands (3.5%). All these CTS hands which had abnormal ulnar SNAP amplitude recording D5 and/or D4 had median versus ulnar (sensory and motor) comparative tests exceeded the reference cut-off values. There was no CTS hands with abnormal ulnar CMAP amplitude or latency recording ADM or INT muscles.

The frequency of abnormality of ulnar SNAP amplitude recording D4 was significantly higher in hands with CTS severity grade 3 than its frequency in hands with CTS severity grade 1 and 2 (X^2=55.437,*P*<0.0001). The frequency of abnormality of ulnar SNAP amplitude recording D5 was significantly higher in hands with CTS severity grade 2 and 3 than its frequency in hands with CTS severity grade 1 (X^2=24.905,*P*<0.0001).

There was no statistically significant difference between different form of sensory symptoms distribution (median and extramedian) as regards the frequency of abnormality of ulnar SNAP amplitude recording D4 (X^2=0.056, *P*=0.813), as well as, the frequency of abnormality of ulnar SNAP amplitude recording D5 (X^2=3.658, *P*=0.056).

DISCUSSION

The aim of the present study was to investigate the involvement of the sensory and motor fibers of the ulnar nerve among patients suffering of CTS and whether these changes, if present, affect and alter the accuracy of the median versus ulnar comparative studies in the diagnosis of CTS.

The presence of normal dorsal ulnar cutaneous nerve sensory conduction study excludes the presence of ulnar neuropathy proximal to the wrist.

The ulnar sensory fibers were found to be affected. The ulnar SNAP amplitude recording D5 and D4 were significantly lower among CTS hands versus controls. Among each grade of CTS electrophysiological severity, it was found that the ulnar SNAP amplitude recording D5 and D4 were significantly lower among CTS hands of moderate and severe CTS grades than among controls and hands with mild CTS severity. There were statistically significant negative correlations between both ulnar SNAP amplitude recording D5 and that of D4 and median DL. There were statistically significant positive correlations between both ulnar SNAP amplitude recording D5 and that of D4 and median sensory CV. These significant correlations indicated that different ulnar sensory fibers (i.e. sensory fibers supplying D5 and D4) were equally involved at the same time with more advancement of median nerve entrapment at the wrist.

The current study did not detect any ulnar motor fibers involvement among CTS patients as a whole and among each grade of CTS electrophysiological severity from mild to severe grades in comparison to control hands. There is few explanation of these findings. This could be due to the presence of minimal impairment within the ulnar motor fibers that could not be detected by using standard electrophysiological techniques [8]. This could be also due to different biological and physical properties between ulnar sensory and motor fibers which made the sensory fibers to be more sensitive to compression than motor fibers [19,20].

In the current work, there were only 17 CTS hands (11.7%) had ulnar sensory abnormalities in 17 different patients. They were localized in the moderate and severe CTS severity grades. There were no ulnar sensory abnormalities among the mild degree of CTS electrophysiological severity. This can be explained by the direct relationship between the Guyon's canal and the transverse carpal ligament [21-23].

The pathological process responsible for the generation of CTS was found to affect the ulnar nerve within the Guyon's canal as well. This could be due to compressive force acting on the ulnar nerve. Its source is the high pressure within the carpal tunnel. It is not a sort of Guyon's canal syndrome which is associated with CTS. The transverse carpal ligament is a ligament that constitutes the roof of the carpal tunnel in the wrist. At the same time, this ligament forms the floor and medial wall of the Guyon's canal. Increase pressure in the carpal tunnel causes a mechanical traction on the transverse carpal ligament which in turn increases the pressure within Guyon's canal [21-23]. This high pressure results in functional changes in the ulnar nerve. This takes the form of changes in the membrane potential and ion channels function [10]. It was found that carpal tunnel decompression surgery for management of CTS resulted in decrease in the Guyon's canal pressure with spontaneous relief of the ulnar nerve symptoms, which suggesting the presence of functional rather than mechanical changes contribute for the ulnar nerve changes associated with CTS [10,12,20].

The present study showed that not all CTS hands with ulnar sensory nerve changes had concomitant changes in the ulnar SNAP recording D5 and D4. Ulnar SNAP amplitude recording D4 was the only abnormality among 5 CTS hands (3.5%) while ulnar SNAP amplitude recording D5 was the only abnormality among 8 CTS hands (5.5%). The cause of the preferential compression of the ulnar sensory branch supplying the D4 or D5 could be due to its location in the periphery of the ulnar nerve where ulnar nerve compression occurs. The current study found that ulnar motor fibers were not affected. This could be due to the central location of the motor fibers within the ulnar nerve trunk [24].

In the present study, there was no statistically significant difference between different form of sensory symptoms distribution (median and extra-median symptoms distribution) as regards the frequency of abnormality of ulnar SNAP amplitude recording D4, as well as, the frequency of abnormality of ulnar SNAP amplitude recording D5.

Neuropathic pain mechanism could explain this issue [25]. The presence of high median nerve intrafunicular pressure in CTS could be the trigging factor for spontaneous discharges in the sensory fibers and leads to ectopic discharges in the dorsal root ganglion [26]. There are evidences indicating the presence of abnormal afferent processing in the brainstem and the cerebral cortex among CTS patients [27,28]. This means that there is evidence of enlargement of the hand representation in the sensory cortex. The plastic changes at cortical and/or subcortical level (which might be caused by peripheral deafferentation and/or ectopic activity secondary to median nerve entrapemnt) may contribute to irradiation of sensory symptoms in CTS and might contribute to the extra-median spread of symptoms [25,29]. This could be an explanation of how median nerve ectopic discharge, play a role (through spinal or supraspinal plastic changes) in the spread of sensory symptoms into the ulnar nerve

territory in CTS [29,30]. It was reported that ulnar nerve sensory symptoms associated with CTS improved marvelously after surgical release of carpal tunnel [12].

The median versus ulnar motor comparative test was not affected in the current study. This test assesses the difference in the latency between the median and ulnar motor nerves but not the difference of the amplitude between them. There were no ulnar motor abnormalities among all grades of CTS electrophysiological severity. This indicated that the median versus ulnar motor comparative test was accurate for assessment of median neuropathy across the wrist.

The median versus ulnar sensory comparative test were not affected in the current study. This test assesses the difference in the PL between the median and ulnar sensory nerves but not the difference of the amplitude between them. The current study showed that ulnar sensory fibers were found to be affected in the form of decreased ulnar SNAP amplitude recording D4 and D5 in the moderate and severe grades of CTS electrophysiological severity. The median versus ulnar sensory comparative test is used in diagnosis of very mild CTS, i.e. when the routine median sensory and motor studies are within normal. There are not used in cases with abnormal routine median sensory study with or without abnormal routine median motor study. As there were no ulnar sensory abnormalities among the mild degree of CTS electrophysiological severity and the ulnar sensory abnormality was in the form of reduced amplitude and not changes in the conduction, then the utility of the median versus ulnar sensory comparative study was not affected and had no role in misleading the diagnosis of CTS in spite of the ulnar sensory neuropathy in CTS.

Ginanneschi *et al*. [10] reported that ulnar SNAP amplitudes recording D4 and D5 were significantly lower in CTS patients than in controls and the ulnar motor DL was not significantly differed than control. They found that patients with more severely delayed median conduction had smaller ulnar SNAP. Cassvan *et al*. [11] reported that ulnar nerve entrapment at wrist was present in 46% of their sample. There were 15% of their studied CTS hands had abnormal ulnar motor conduction study. They found that ulnar nerve abnormalities were frequently occurred among patients with cervical radiculopathy; which were excluded from the present study [11]. Gozke *et al*. [31] reported that abnormalities were found only among the ulnar sensory fibers (in 18.4% of their studied group) with no abnormalities among the ulnar motor fibers. The ulnar nerve affection was mainly among CTS patients with moderate and severe degrees. There were no abnormalities in ulnar nerve among patients with the very mild degree of CTS [31]. Moghtaderi and Ghafarpoor [32] reported that 7.5% of CTS patients had delayed onset latency for ulnar sensory branches and 4.6% had delayed DL for ulnar nerve motor branches.

The present study is not in agreement with Ginanneschi *et al*. [8]. They reported the absence of any ulnar sensory or motor abnormalities between CTS hands and controls. They reported the presence of reduced recruitment abnormalities in ulnar never motor axons among CTS patients [8]. The current study is not in accordance with this study due to difference in the inclusion criteria of CTS patient's selection [8].

The present study is the first study in literature that assessed the effect of ulnar nerve affection across the wrist in CTS patients on the results of median versus ulnar comparative tests.

The presence of abnormal ulnar sensory or motor conduction study among CTS patients is important to exclude concomitant pathological lesions associated with CTS as ulnar neuropathy across the elbow. The median versus ulnar (motor and sensory) comparative tests were not affected among CTS patients associated with ulnar nerve affection at the wrist. The presence of abnormalities in ulnar nerve occur in moderate and severe degrees of CTS patients, makes the accuracy of these comparative tests adequate for its use in electrophysiological diagnosis of very mild CTS. The abnormality in ulnar nerve is in the form of decreased amplitude of the ulnar SNAP which is not involved in the assessment of median versus ulnar sensory comparative test which is depended on PL differences between median and ulnar SNAP recording D4.

The current study had some limitations. The first one was the lack of electromyographic assessment of abductor digiti minimi. EMG can detect minor motor fiber affection which can be undetectable by the motor conduction study. It is not applicable to assess these muscles among CTS patients with no associated clinical or electrophysiological evidence of ulnar motor neuropathy. This is not recommended by the American Association of Electrodiagnostic Medicine practice parameters [33]. The current study had an exclusion criterion of absence of any clinical evidence of ulnar neuropathy in the wrist. It was not ethically to assess patients with CTS by EMG which is an invasive technique and not recommended [33]. Second one was the relatively small number of CTS hands with grades 4, 5 and 6 Bland scale. This could be due to the medical awareness of patients and physicians about CTS with early diagnosis and management. If the number of CTS hands with these

grades (grades 4, 5 and 6 Bland scale) was increased, the frequency of ulnar nerve abnormality could be increased and ulnar motor abnormality (if present) could be detected in the more advanced cases of CTS. Further researches are needed on a larger scale to verify the results of the current study.

In conclusion, there is ulnar sensory nerve abnormality in CTS in the form of decreasing the ulnar SNAP amplitude without changes in the sensory conduction. There are no abnormalities in the ulnar motor nerve. The presence of abnormalities in ulnar nerve occurs in moderate and severe degrees of CTS. Therefore, the median versus ulnar sensory and motor comparative tests are valid and accurate for use in electrophysiological diagnosis of CTS. The ulnar sensory nerve changes do not contribute to extra-median spread of sensory symptoms.

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REFERENCES

1. Kiernan, M.C., I. Mogyoros and D. Burke, 1999. Conduction block in carpal tunnel syndrome. Brain, 122: 933-941.
2. Werner, R.A. and M. Andary, 2011. Electrodiagnostic evaluation of carpal tunnel syndrome. Muscle Nerve, 44: 597-607.
3. Stevens, J.C., 1997. AAEM minimonograph #26: the electrodiagnosis of carpal tunnel syndrome. American Association of Electrodiagnostic Medicine. Muscle Nerve, 20: 1477-1486.
4. Uchiyama, S., T. Itsubo, K. Nakamura, H. Kato, T. Yasutomi and T. Momose, 2010. Current concepts of carpal tunnel syndrome: pathophysiology, treatment and evaluation. J Orthop Sci., 15: 1-13.
5. Biesek, D., K. Szabat, J. Magdziak and K. Pilecka, 2011. Electrophysiological testing of carpal tunnel syndrome complex treatment results at patients with increased risk of median nerve entrapment mononeuropathy at the wrist. Przegl Lek, 68: 175-178.
6. Todnem, K. and T. Sand, 2013. Neurography for diagnosing carpal tunnel_syndrome. Tidsskr Nor Laegeforen, 133: 170-173.
7. Lee, W.J., Y.C. Liao, S.J. Wei, C.W. Tsai and M.H. Chang, 2011. How to make electrodiagnosis of carpal tunnel syndrome with normal distal conductions? J Clin Neurophysiol, 28: 45-50.
8. Ginanneschi, F., F. Dominici, P. Milani, A. Biasella and A. Rossi, 2007. Evidence of altered motor axon properties of the ulnar nerve in carpal tunnel syndrome. Clin Neurophysiol, 118: 1569-1576.
9. Gupta, K. and J. Benstead, 1997. Symptoms experienced by patients with carpal tunnel syndrome. Can J. Neurol Sci., 24: 338-342.
10. Ginanneschi, F., P. Milani, M. Mondelli, F. Dominici, A. Biasella and A. Rossi, 2008. Ulnar sensory nerve impairment at the wrist in carpal tunnel syndrome. Muscle Nerve, 37: 183-189.
11. Cassvan, A., A. Rosenberg and L.F. Rivera, 1986. Ulnar nerve involvement in carpal tunnel syndrome. Arch Phys Med Rehabil, 67: 290-292.
12. Silver, M.A., R.H. Gelberman, H. Gellman and C.E. Rhoades, 1985. Carpal tunnel syndrome: associated abnormalities in ulnar nerve function and effect of carpal tunnel release on these abnormalities. J. Hand Surg., 10: 710-713.
13. Chang, M.H., Y.C. Lee and P.F. Hsieh, 2008. The role of forearm mixed nerve conduction study in the evaluation of proximal conduction slowing in carpal tunnel syndrome. Clin Neurophysiol, 119: 2800-2803.
14. Giannini, F., R. Cioni, M. Mondelli, R. Padua, B. Gergori, P.D. Amico and L. Padua, 2002. A new clinical scale of carpal tunnel syndrome: validation of the measurement and clinical-neurophysiological assessment. Clin Neurophysiol, 113: 71-77.
15. Saba, E.K., 2014. Median versus ulnar medial thenar motor recording in diagnosis of carpal tunnel syndrome. Egyptian Rheumatologist, http:// dx.doi.org/ 10.1016/j.ejr.2014.11.001
16. Preston, D. and B. Shapiro, 2005. Electromyography and neuromuscular disorders: Clinical-electrophysiologic correlation. 2nd edition. Pennsylvania: Elsevier, pp: 117-143.
17. Bland, J.D., 2000. A neurophysiological grading scale for carpal tunnel syndrome. Muscle Nerve, 23: 1280-1283.
18. Statistical Package of Social Science. Version 17 London: University of Cambridge computing service. Documentation: 2007.

19. Lin, C.S., S. Kuwabara, C. Cappelen-Smith and D. Burke, 2002. Responses of human sensory and motor axons to the release of ischaemia and to hyperpolarizing currents. J. Physiol., 541: 1025-1039.
20. Ginanneschi, F., P. Milani and A. Rossi, 2008. Anomalies of ulnar nerve conduction in different carpal tunnel syndrome stages. Muscle Nerve, 37: 1155-1160.
21. Ablove, R.H., C.A. Peimer, E. Diao, R. Oliverio and J.P. Kuhn, 1994. Morphologic changes following endoscopic and two-portal subcutaneous carpal tunnel release. J Hand Surg [Am], 19: 821-826.
22. Ablove, R.H., O.J. Moy, C.A. Peimer, D.R. Wheeler and E. Diao, 1996. Pressure changes in Guyon's canal after carpal tunnel release. J Hand Surg [Br], 21: 664-665.
23. Richman, J.A., R.H. Gelberman, B.L. Rydevik, P.C. Hajek, R.M. Braun and V.M. Gylys-Morin, 1989. Carpal tunnel syndrome: morphologic changes after release of the transverse carpal ligament. J Hand Surg [Am], 14: 852-857.
24. Stewart, J.D., 2003. Peripheral nerve fascicles: anatomy and clinical relevance. Muscle Nerve, 28: 525-541.
25. Zanette, G., S. Marani and S. Tamburin, 2006. Extra-median spread of sensory symptoms in carpal tunnel syndrome suggest the presence of pain-related mechanisms. Pain, 122: 264-270.
26. Bridges, D., S.W.N. Thompson and A.S.C. Rice, 2001. Mechanisms of neuropathic pain. Br J. Anaesth, 87: 12-26.
27. Tecchio, F., L. Padua, I. Aprile and P.M. Rossini, 2002. Carpal tunnel syndrome modifies sensory hand cortical somatotopy: a MEG study. Hum Brain Mapp, 17: 28-36.
28. Napadow, V., N. Kettner, A. Ryan, K.K. Kwong, J. Audette and K.K.S. Hui, 2006. Somatosensory cortical plasticity in carpal tunnel syndrome. A cross-sectional fMRI evaluation. NeuroImage, 31: 520-530.
29. Zanette, G, S. Marani and S. Tamburin, 2007. Proximal pain in patients with carpal tunnel syndrome. A clinical-neurophysiological study. J. Peripher Nerv Syst, 12: 91-97.
30. Tamburin, S., C. Cacciatori, M.L. Praitano, S. Marani and G. Zanette, 2009. Ulnar nerve impairment at the wrist does not contribute to extramedian sensory symptoms in carpal tunnel syndrome. Clin Neurophysiol, 120: 1687-1692.
31. Gozke, E., N. Dortcan, A. Kocer, M. Cetinkaya, G. Akyuz and O. Us, 2003. Ulnar nerve entrapment at wrist associated with carpal tunnel syndrome. Neurophysiologie clinique, 33: 219-222.
32. Moghtaderi, A. and M. Ghafarpoor, 2009. The dilemma of ulnar nerve entrapment at wrist in carpal tunnel syndrome. Clin Neurol Neurosurg, 111: 151-155.
33. American Association of Electrodiagnostic Medicine, American Academy of Neurology and American Academy of Physical Medicine and Rehabilitation, 2002. Practice parameter for electrodiagnostic studies in carpal tunnel syndrome: summary statement. Muscle Nerve, 25: 918-22.