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Risk assessment models for development of carpal tunnel syndrome: clinical, anthropometric, and neuromuscular ultrasound predictors

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Abstract

Background Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy with multifactorial etiologies. We intended in this case–control study to identify, out of a comprehensive set of risk factors, the relatively important ones and develop a quantitative risk assessment model for this disorder. It was also legitimate to define the hazard of those factors in a dose-related manner and the acceptable safe limit especially for work-related stresses.

Results Age and female predominance were comparable between the 60 patients (89 hands with electrophysiologically confirmed CTS) and 50 controls (100 hands). Occupation of the studied sample varied between housewives only, employed housewives, and manual workers with a distribution that differed significantly between patients and controls. Significantly higher body mass index (BMI) and mean wrist depth were found in patients than controls. Wrist ratio (clinically or sonographically) was significantly squarer in patients than controls. Overall workload and number of hours spent daily performing work with repeated hand movements or awkward hand position were significantly higher among patients than controls.

ROC curves were constructed for wrist measurements and occupational stresses. Cut-off points of wrist ratio and internal carpal tunnel ratio (by ultrasound) to discriminate subjects with CTS were > 0.68 and ≤ 1.854, respectively. The best cut-off value for number of hours spent daily performing work with repeated hand movements was 3 h/ day. As for working with awkward hand position or cold exposure, cut-off value was 0.6 h/day for both.

Two logistic regression models were conducted to investigate nonoccupational and occupational predictors of CTS. The independent predictors concluded from the first model were BMI, positive family history of CTS, wrist ratio, and decrease grip strength. As for the occupational model, predictors were tasks requiring awkward hand position and cold exposure.

Conclusion Occupational risk assessment by clinical, anthropometric, and ultrasonographic measurement should be used in professions requiring repetitive or awkward hand movements, so that in overweight persons with square wrists appropriate workplace setup measures or assistive technology at work or home could be taken to prevent or decrease the impact of work hazards or help choose individuals with low risk for appropriate jobs.

Keywords CTS, Occupational risk, Anthropometric measurements, Ultrasonography, Electrophysiology

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Background

Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy with a relatively high prevalence among the general population ranging between 1 and 16%. It is characterized by numbness along the sensory territory of median nerve (MN) that can be accompanied by pain or weakness of the thenar muscles [1].

Diagnosis of CTS is usually based on a combination of clinical signs such as Tinel and Phalen signs, together with nerve conduction studies and sonographic assessment [2, 3].

Its etiological background has been studied extensively and identified CTS as a multifactorial disorder brought upon by personal factors, occupational challenges, and psychosocial stresses at work. Personal factors such as old age, female gender, anthropometric measurements like obesity and square-type wrist, medical conditions causing increased pressure within the carpal tunnel (e.g., diabetes mellitus), and pregnancy may increase an individual's susceptibility to focal median nerve entrapment. Manual stresses involving repetitive use of hands (e.g., woodworking, household chores, and crocheting) and intensive activities at work can aggravate the damage inflicted upon MN by increasing the hydrostatic pressure around it within the carpal tunnel. Also, psychosocial factors related to negative perceptions at work such as work time pressure and social conflict have been found to significantly contribute to undesirable outcomes [4–6]. How much is harmful from those factors is still not defined, which poses a great challenge when dealing with safe occupational stresses not increasing the risk of CTS whether at home or work.

No study has addressed this issue combining both the occupational and nonoccupational risk factors in the same cohort. Sonographic assessment of internal wrist measurements was also added to increase the validity of some debatable issues concerning wrist anthropometry. We, therefore, attempted in this study to identify, out of a comprehensive set of risk factors, the relatively important ones and develop a quantitative risk assessment model for this disorder. It was also legitimate to define the hazard of those factors in a dose-related manner and highlight the acceptable safe limit especially for work-related stresses, beyond which the risk of CTS increases.

Methods

This was a case–control study, approved by the local Ethics Committee for Human Research, Faculty of Medicine (IRB no.: 00012098), carried out between January 2020 and December 2022.

Sample size calculation

Using matched case–control power analysis in NCSS and PASS program, a minimum sample size to identify risk factors for developing CTS is 45 per group to achieve 80% power with a target significant level at 5%.

Sixty patients diagnosed clinically and confirmed electrophysiologically as having CTS according to the criteria proposed by American Association of Neuromuscular & Electrodiagnostic Medicine were enrolled in the study [7]. Based on slowing of MN sensory conduction velocity across the wrist of <40 m/s and prolongation of MN distal motor latency of >4.4 ms without abnormalities in the ulnar nerve or proximal MN parameters, CTS was diagnosed bilaterally in 29 patients (48.3%) and unilaterally in 31 (51.7%). Since assessments obtained from the right- or left-hand wrists were accepted as separate and independent cases, a total of 89 hands with CTS were studied, in addition to 50 controls with 100 control hands. Bland's electrophysiological grading scale was then used to categorize patients into six grades of CTS severity [8]. All patients and controls underwent demographic data collection, occupational history analysis (job related or household chores), anthropometric measurements, hand strength, and ultrasonographic assessment of carpal tunnel.

Anthropometric measurements were obtained for all patients and controls including body mass index (BMI) calculation (weight in kilograms divided by height in meters square (kg/m^2) [9] and external wrist dimensions). The external wrist dimensions were measured from the palmar side of the hand with fingers fully extended on a hard flat surface using a 6″ stainless steel (M-E-BAAGAR tools) digital dial caliper (accurate to 0.1 mm). These measurements included the following: wrist depth (measured as the antero-posterior depth at level of the distal flexor wrist crease) and wrist width (measured as the maximum transverse distance between the borders at level of the distal flexor wrist crease), and then wrist ratio was calculated as wrist depth/wrist width [10]. In addition to this, grip and pinch strength were measured by Preston hand dynamometer and pinch gauge respectively [11].

Occupational history was also taken for the whole cohort as regards duration (number of hours), frequency (number of days/week), and awkward hand position of current job and household chores, with further analysis of manual hand loads and work demanding high hand grip forces regarding weight of the load (force in kg), duration, and frequency sustained. Furthermore, duration of activities requiring thumb pressing, pressure on base of the palm, forearm rotation (supination/pronation) $>45°$, wrist bending $>30°$, forced axial deviation of the wrist, and working with a vibrating tool or in cold environment (i.e., t < 1 8°C) were recorded.

Sonographic examination was performed in the sitting position using a linear 7–16 MHz transducer (Samsung) to all 89 hands with CTS and 100 control hands. It was done by two musculoskeletal ultrasonographers with > 10-year experience in musculoskeletal US, and one of them was EULAR certified. It included measurements of MN cross-sectional areas (CSA) at the carpal tunnel inlet (at level of pisiform bone) as well as 2 cm proximal to the distal wrist crease by tracing a continuous line within the hyperechogenic boundary of the nerve. Wrist-forearm ratio was then calculated by dividing distal over proximal MN CSA. Flattening ratio of MN at the carpal tunnel inlet was calculated (ratio of the major-to-minor axis of MN). The maximum height of the retinaculum was measured above a line subtended between its radial and the ulnar carpal attachments. Increased palmar bowing was considered if this height was ≥ 2 mm. To measure the internal carpal tunnel dimensions, radioulnar and the dorsopalmar diameters were measured at defined levels between the scaphoid and the pisiform bone, the flexor retinaculum above the median nerve, and the lunate bone, respectively. The internal carpal tunnel ratio (ICR) was calculated by dividing width/depth [12]. Finally, different values for nerve CSA, flattening ratio of MN, and internal sonographic tunnel measurements were evaluated as independent covariates to construct the receiver operating characteristic (ROC) curves. The optimal cut-off values for each measurement were chosen based on the maximization of the sensitivity and specificity products. The area under ROC curve and the confidence intervals were estimated to examine the accuracy of each measurement to discriminate subjects with CTS from subjects without CTS.

Exclusion criteria were polyneuropathy, concomitant cervical radiculopathy, or treatment with steroid injection or carpal tunnel decompression before the assessment.

Statistical analysis

Data were analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp.). Qualitative data were presented using number and percent. The Shapiro–Wilk test was used to verify the normality of distribution. Quantitative data were presented using range, mean, standard deviation, and median. Comparisons between categorical data were done using chi-square test. Fisher's exact or Monte Carlo was used when more than 20% of the cells have expected count less than 5. As for normally and abnormally distributed quantitative data, they were compared using Student *t*-test and Mann–Whitney test respectively. Significance of the obtained results was set at 5%.

Spearman correlation was done to correlate between electrophysiologic grading of CTS severity and different anthropometric measures and different workload parameters. ROC curve was constructed to estimate the predictive value of wrist ratio, ICR, and number of hours spent daily in repeated hand movement for the diagnosis of CTS. The optimal cut-off value for each measurement was then determined based on maximization of sensitivity and specificity.

Logistic regression analysis was finally done, starting with the univariate regression, where variables like age, female sex, smoking, family history of CTS, side of dominant hand, previous and current jobs, height, weight, BMI, external wrist depth, width and ratio, sonographic radioulnar diameter, dorsopalmar diameter, and ICR, as well as pinch and grip strength, were included. Another model was constructed for factors related to occupational stresses. Variables that were found in the univariate analysis to significantly ($p < 0.05$) predict the development of CTS were then included in the multivariable regression analysis to determine their odds ratio (OR) as well as 95% confidence interval (CI) [13].

Results

The studied cohort showed no statistically significant difference between patients and controls as regards mean age which was 43.38 ± 10.67 years for the former and 41.74 ± 10.38 years for the latter. Female predominance also showed no significant difference between both groups which was 57 females (95%) in patients and 46 females (92%) in controls. Those females were only housewives (all household chores were manually done by them without any assistance) in 66.6% of patients and 42% of controls or were additionally employees in 3.3% of patients and 42% of controls. As for manually demanding jobs, this was the occupation of 29.9% of patients (males and females) and 10% of controls. On the contrary, none of the patients was solely employee, while 8% of the controls were. This distribution was statistically significantly different between patients and controls ($\chi^2 = 32.8$, $^{MC}p < 0.001$). Family history revealed that 32 patients (53.3%) had family history of CTS compared to 15 controls (30.0%), which was statistically significant ($\chi^2 = 6.1$, $p = 0.014$).

Concerning anthropometric measurements, patients had significantly higher BMI (32.80 ± 5.42 kg/m^2) than controls (28.41 ± 4.10 kg/m^2) ($p < 0.001$). External clinical and internal sonographic wrist measurements are displayed in Table 1 and show a statistically significant increase of the patients' mean wrist depth more than controls whether measured externally or sonographically.

Table 1 Comparison between the two studied groups according to external and internal sonographic wrist measurements

External wrist measurements	Patient's hands ($n=89$)	Controls hands ($n=100$)	*t*	*P*
Wrist depth (cm)				
Mean ± SD	3.89 ± 0.46	3.57 ± 0.46	**4.757***	**< 0.001***
Wrist width (cm)				
Mean ± SD	5.43 ± 0.66	5.31 ± 0.63	1.324	0.187
Wrist ratio				
Mean ± SD	0.71 ± 0.04	0.67 ± 0.02	**8.310***	**< 0.001***
Internal sonographic measurements	**Patient's hands ($n=89$)**	**Controls hands ($n=100$)**	***U***	***p***
Radioulnar diameter (cm)				
Median (min–max)	2.33 (1.85–3.9)	2.37 (1.98–3.17)	3921.5	0.159
Dorsopalmar diameter (cm)				
Median (min–max)	1.34 (0.91–2.42)	1.21 (0.83–1.83)	**2793.0***	**< 0.001***
Internal carpal tunnel ratio				
Median (min–max)	1.74 (1–3.17)	1.97 (1.3–2.78)	**2764.0***	< 0.001*
Sonographic evaluation of median nerve	**Patient's hands ($n=89$)**	**Controls hands ($n=100$)**	***U***	***p***
MN CSA at inlet (cm^2)				
Median (min.–max.)	0.14 (0.07–0.36)	0.09 (0.04–0.14)	**951.0***	**< 0.001***
MN CSA proximal (cm^2)				
Median (min.–max.)	0.10 (0.01–0.19)	0.09 (0.04–0.15)	**3084.5***	**< 0.001***
MN wrist forearm ratio				
Median (min.–max.)	1.36 (0.71–18.33)	0.9 (0.42–2)	**1403.0***	**< 0.001***
MN flattening ratio at wrist				
Median (min.–max.)	3.10 (1.7–5.7)	2.6 (0.88–6.8)	**2788.5***	**< 0.001***

Student *t*-test, *U* Mann Whitney test

p *p*-value for comparing between the studied groups. *Statistically significant at $p \le 0.05$

MN median nerve, *CSA* cross-section area,

SD standard deviation, *min* minimum, *max* maximum

Same thing was noted for the wrist ratio which was significantly different between both groups denoting a squarer wrist in patients. Table 1 presents ultrasonic evaluation of the MN, and statistically significant increase of all its parameters was noted in patients more than controls.

Concerning overall workload, number of hours spent daily performing work with repeated hand movements was significantly higher among patients (mean = 6.08 ± 2.86, range = 0.5–14.0) compared to controls (mean = 3.79 ± 1.51, range = 1.0–8.0) ($U = 738.5$, $p < 0.001$). Furthermore, awkward hand position during work was sustained in 79 hands (88.8%) among the total 89 hands with CTS in comparison to 36 (36.7%) control hands ($p < 0.001$). Table 2 shows statistically significant increase in the number of hours/day of different hand loads that patients sustained in comparison to controls.

Correlation studies

Anthropometric measurements and different parameters of workload were then correlated with electrophysiologic grading of CTS severity and showed a significant positive correlation with BMI and internal sonographic dorsopalmar diameter, i.e., increase in BMI or depth of the tunnel (more squaring) corresponded to increase in CTS severity (Table 3). Furthermore, daily hours of cold exposure also positively and significantly correlated with CTS severity. As for daily hours of repeated hand movement, it could not reach statistical significance.

ROC curves

Values for wrist anthropometric measurements and number of hours spent daily in repeated hand movements were used to construct ROC curves (Fig. 1). The best cut-off point of wrist ratio to discriminate subjects with CTS from those without was > 0.68, with sensitivity of 77.53%, specificity of 63.0%, positive predictive value (PPV) of 65.1%, negative predictive value (NPV) of 75.0%, and total accuracy of 82.4%. As for the best cut-off point for ICR to detect patients with CTS, it was found to be ≤ 1.854 with a sensitivity of 68.54%, a specificity of 69.0%, a PPV of 66.3%, a NPV of 71.1%, and a total accuracy of 68.9%. The best cut-off value for number of hours spent daily performing work with repeated hand movements was 3 h per day with a sensitivity of 57.3%, a specificity of 76.0%, a PPV of 68%, and a NPV of 66%.

Table 2 Comparison between the two studied groups according to overall workload

No. of hours/day for overall workload	Patients hands ($n=89$)		Controls hands ($n=100$)		χ^2	^{MC}p
	No	%	No	%		
Pressure on base of palm						
0 to 0.5	38	42.7	30	30.6	18.481	< 0.001*
0.6 to 1	25	28.1	52	53.1		
1.1 to 2	13	14.6	14	14.3		
2.1 to 3	8	9.0	2	2.0		
> 3	5	5.6	0	0.0		
Thumb pressure						
0 to 0.5	27	30.3	72	73.5	46.518*	< 0.001*
0.6 to 1	17	19.1	16	16.3		
1.1 to 2	24	27.0	2	2.0		
2.1 to 3	9	10.1	6	6.1		
> 3	12	13.5	2	2.0		
Forearm rotation						
0 to 0.5	11	12.4	46	46.9	35.486*	< 0.001*
0.6 to 1	28	31.5	28	28.6		
1.1 to 2	30	33.7	20	20.4		
2.1 to 3	14	15.7	2	2.0		
> 3	6	6.7	2	2.0		
Wrist bending						
0 to 0.5	19	21.3	30	30.6	34.177*	< 0.001*
0.6 to 1	17	19.1	44	44.9		
1.1 to 2	20	22.5	16	16.3		
2.1 to 3	16	18.0	8	8.2		
> 3	17	19.1	0	0.0		
Forced position of wrist						
0 to 0.5	33	37.1	72	73.5	33.549*	< 0.001*
0.6 to 1	20	22.5	16	16.3		
1.1 to 2	23	25.8	10	10.2		
2.1 to 3	10	11.2	0	0.0		
> 3	3	3.4	0	0.0		
Work with vibration tools					2.915	0.105
0 to 0.5	86	96.6	98	100.0		
0.6 to 1	1	1.1	0	0.0		
1.1 to 2	0	0.0	0	0.0		
2.1 to 3	0	0.0	0	0.0		
> 3	2	2.2	0	0.0		
Cold exposure					48.186*	< 0.001*
0 to 0.5	24	27.0	70	71.4		
0.6 to 1	24	27.0	14	14.3		
1.1 to 2	22	24.7	14	14.3		
2.1 to 3	12	13.5	0	0.0		
> 3	7	7.9	0	0.0		

^{2} chi-square test, *MC* Monte Carlo test

p p-value for comparing between the studied groups. *Statistically significant at $p \leq 0.05$

The best cut-off point of MN CSA at inlet to detect patients with CTS was found to be > 0.11, with a sensitivity of 77.53%, a specificity of 91.0%, a PPV of 82.6%, a NPV of 82.5%, and a total accuracy of 89.3%. Cut-off point of MN wrist-forearm ratio to detect the patient group was found to be > 1, with a sensitivity of 85.39%, a

Table 3 Correlation between anthropometric parameters and electrophysiological severity of CTS in the studied patients ($n=89$)

	Electrophysiological severity	
	r_s	p
Height (m)	0.166	0.121
Weight (kg)	0.321*	0.002*
BMI (kg/m^2)	0.255*	0.016*
Wrist depth (AP) (cm)	0.086	0.424
Wrist width (ML) (cm)	0.023	0.833
Wrist ratio (AP/ML)	0.192	0.071
Radioulnar diameter (cm)	0.028	0.792
Dorsopalmar diameter (cm)	0.241	0.023*
Internal carpal tunnel ratio	−0.143	0.182
Median nerve CSA at tunnel inlet	0.620*	<0.001*
Daily hours of repeated hand movement	0.191	0.072
Pressure on base of palm hours/day	0.045	0.676
Thumb pressure hours/day	−0.052	0.625
Forearm rotation hours/day	0.162	0.130
Wrist bending hours/day	0.113	0.291
Cold exposure hours/day	0.216*	0.042*

r_s, Spearman coefficient

* Statistically significant at $p \leq 0.05$

specificity of 69.0%, a PPV of 71.0%, a NPV of 84.1%, and a total accuracy of 84.2%. As for the flattening ratio of MN, its cut-off point was found to be > 2.66, with a sensitivity of 75.28%, a specificity of 55.0%, a PPV of 5908%, a NPV of 71.4%, and a total accuracy of 68.7%.

Multifactorial logistic regression analysis was conducted to investigate the significant factors affecting development of CTS (Tables 4 and 5). The univariable regression revealed the risk of CTS increased significantly with increase in BMI, family history of CTS, wrist depth, wrist ratio, and internal sonographic dorsopalmar diameter as well as decrease in ICR and pinch and grip strength after adjustment for other variables. The risk of CTS also increased significantly with different work-related stresses, e.g., number of hours per day engaged in repetitive hand and wrist movement, manual hand loads, working with high force or awkward hand position, tasks requiring thumb pressure, forearm rotation, wrist bending, or cold exposure. After the multivariate regression, the independent predictors of CTS increased the risk by 1.38 times for every unit increase of BMI, 4.9 times for positive family history of CTS, 1.5 times for every unit increase in wrist ratio, and decrease in grip strength. As for work-related stresses, multiple logistic regression analyses showed the risk of CTS increased by 9.742 times and 3.3 times with tasks requiring awkward hand position and cold exposure < 18° respectively. On the other hand, tasks requiring high force were found to be protective against the development of CTS (*OR* < 1).

Discussion

This study aimed to identify, out of a comprehensive set of risk factors, the relatively important ones and develop a quantitative risk assessment model for this disorder, as well as define a cut-off value for the significant ones to ensure an acceptable safe work limit especially those at increased risk for CTS. Since its etiological background is multifactorial, several factors have been assessed especially body and wrist anthropometric measures as well as occupational stresses whether job related or household chores. The current logistic regression models were thus constructed and were most inclusive of important CTS risk factors. The first model found that BMI, family history of CTS, weak hand grip, and wrist anthropometric measurements were independent predictors of CTS. As for the second model studying different occupational stresses, it found that working with awkward hand position and cold exposure were independent predictors.

The first model found that every unit increase in BMI corresponded to 1.38-fold increased risk of CTS development. BMI has also been found to be significantly correlated with the severity of CTS grading, i.e., increase in BMI corresponds to increase in CTS severity. This has been also confirmed in a recent meta-analysis which concluded that being overweight increased CTS risk 1.5-fold, and that every unit increase in BMI increases CTS risk by 7.4% [14]. As a matter of fact, fat tissue accumulation inside the carpal tunnel exerts its compressive effect on MN by increasing the hydrostatic pressure inside the tunnel. This compressive force could impair the blood circulation of MN leading to nerve ischemia, local demyelination, and finally axonal loss. Additionally, this high carpal tunnel pressure may lead to fibrosis and thickening of the connective tissue in the canal. On the other hand, Werner et al. [15] found that obesity did not influence carpal canal pressure but is supposed through a localized metabolic mechanism to cause endoneurial edema and intrafascicular swelling of MN, thus resulting in slowing of its sensory conduction velocity [6].

Wrist anthropometric measurements were among the independent predictors of CTS and were measured in this study from several perspectives, externally and internally by ultrasound, which further adds to the credibility of our results. Univariate analysis showed that wrist depth and ratio as well as dorsopalmar diameter and ICR were significant predictors. After multiple regression analysis, wrist ratio was the only independent predictor ($p < 0.001$), where every unit increase in wrist ratio corresponded to 1.5 times increase in CTS risk. As for wrist

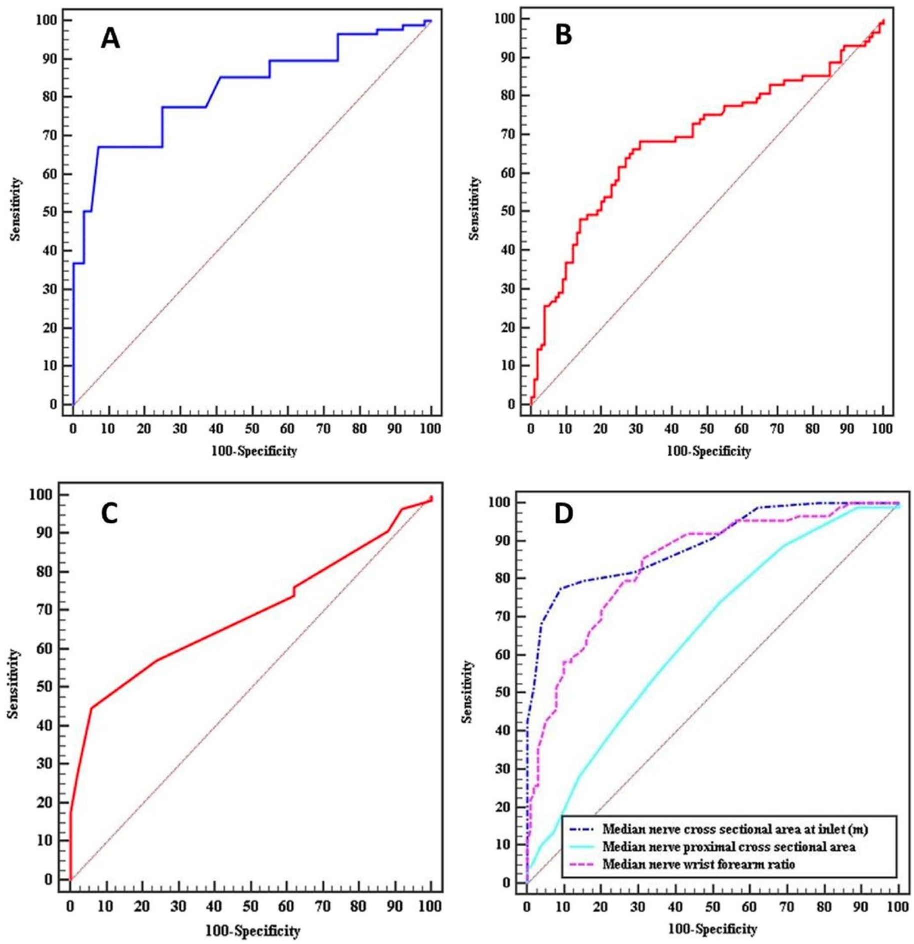

Fig. 1 ROC curve for wrist ratio (**a**), internal carpal tunnel ratio (**b**), numbers of hours/day of repeated hand movement (**c**), and median nerve parameters sonographically (**d**) for studied subjects to differentiate between patients and controls

depth and dorsopalmar diameter, they approached significance. These parameters were also correlated with CTS severity where dorsopalmar diameter as measured by US was the only significant factor, and wrist ratio was approaching significance. All these parameters point to increased risk of CTS in individuals with more squaring of their wrist shape. These results were supported by many investigators [6, 10, 16] who found that square-shaped wrist was associated with slower impulse traveling along the sensory and motor fibers of the MN through the carpal tunnel. In a trial to figure out the optimal cut-off values for wrist ratio to detect patients with CTS, a ROC curve was constructed and found a ratio > 0.68 to have a sensitivity of 77.53%, specificity of 63.0%, PPV of 65.1%, NPV of 75.0%, and total accuracy of 82.4%. This ratio was comparable to another study where patients with a ratio > 0.69 were 8.195 times more likely to have CTS than those with a ratio < 0.69 [16]. On the other hand, another study found that cut-off point to be > 0.46 [6], which might be less accurate because wrist measurements in this study were taken by the measuring tape. Whether it is the depth or width of the wrist which impacts this ratio of square wrists is still a matter of unresolved debate. A study found that wrist depths were not different between healthy controls and CTS patients, thus concluding that square wrists were rather affected by wrist width [17]. This was then contradicted by others who found wrist widths were also not different between controls and patients, thus concluding that it is rather the CSA or volume of the carpal tunnel that is important in CTS pathogenesis [18]. For better assessment of the tunnel volume in relation to the median nerve and other structures passing within, US could do a better job and help resolve this debate. This was evident where dorsopalmar diameter as measured by US was the only wrist factor significantly correlated with the electrophysiological severity of CTS.

Regarding the second model, several work-related stresses were found significantly associated with risk of CTS including number of hours per day engaged in

Table 4 Univariate and multivariate logistic regression analysis for parameters affecting carpal tunnel syndrome (89 patients' hands vs 100 controls' hands)

	Univariate		#Multivariate	
	p	OR (95% *CI*)	*p*	OR (95% *CI*)
Females©	0.330	1.848 (0.537–6.359)		
Age (years)$^{(n)}$	0.147	1.020 (0.993–1.049)		
Hands dominance©	0.075	1.697 (0.948–3.037)		
Smoking©	0.999	-		
Sport©	0.999	-		
Family history©	**0.001***	2.858* (1.572–5.197)	**0.007***	4.985* (1.558–15.950)
Previous job©	0.204	1.983 (0.690–5.698)		
Current job©	**0.001***	0.356* (0.197–0.644)	0.780	1.157 (0.416–3.213)
Overall current duration repeated movement of hand and wrist (h/day)$^{(n)}$	0.999	-		
Height (m)$^{(n)}$	0.060	0.008 (0.000–1.224)		
Weight (kg)$^{(n)}$	**< 0.001***	1.070* (1.043–1.098)	0.153	0.918 (0.816–1.032)
BMI (kg/m^2)$^{(n)}$	**< 0.001***	1.222* (1.137–1.313)	**0.042***	1.382* (1.012–1.888)
Wrist depth (AP) (cm)$^{(n)}$	**< 0.001***	4.385* (2.250–8.548)	**0.052**	3.711 (0.989–13.918)
Wrist width (ML) (cm)$^{(n)}$	0.187	1.351 (0.864–2.110)		
Wrist ratio (AP/ML) (× 10^2)$^{(n)}$	**< 0.001***	1.658* (1.411–1.949)	**< 0.001***	1.553* (1.269–1.901)
Pinch strength (kg)$^{(n)}$	**< 0.001***	0.537* (0.435–0.664)	0.613	0.908 (0.625–1.319)
Grip strength (kg)$^{(n)}$	**< 0.001***	0.852* (0.809–0.897)	**0.003***	0.851* (0.766–0.946)
Radioulnar diameter (cm)$^{(n)}$	0.626	0.758 (0.248–2.311)		
Dorsopalmar diameter (cm)$^{(n)}$	**< 0.001***	40.74* (5.94–279.37)	0.069	45.753 (0.744–2812.75)
Internal carpal tunnel ratio$^{(n)}$	**< 0.001***	0.162* (0.058–0.457)	0.886	0.854 (0.100–7.303)
Bifid median nerve©	**0.459**	1.384 (0.586–3.268)		

OR odd's ratio, *CI* confidence interval

All variables with $p < 0.05$ was included in the multivariate

* Statistically significant at $p \leq 0.05$

C category, *N* numeric

Table 5 Univariate and multivariate analysis for the parameters affecting carpal tunnel syndrome (cases vs controls)

Carpal tunnel syndrome	Univariate		#Multivariate	
	p	OR (95% *CI*)	*p*	OR (95% *CI*)
Repeated movement of hand and wrist (h/day)$^{(N)}$	**< 0.001***	1.595* (1.353–1.879)	**0.691**	0.730 (0.155–3.447)
Total hours/duration (years)$^{(N)}$	**< 0.001***	1.000* (1.000–1.000)	**0.547**	1.000 (1.000–1.000)
Manual hand loads©	**0.009***	2.216* (1.219–4.029)	**0.703**	1.201 (0.469–3.075)
Working with high force©	**0.001***	2.958* (1.538–5.689)	**0.021***	0.228* (0.065–0.802)
Awkward hand position©	**< 0.001***	13.606* (6.265–29.548)	**< 0.001***	9.742* (3.314–28.632)
Pressure on base of palm hours/day©	**0.107**	1.248 (0.954–1.633)		
Thump pressure hours/day©	**< 0.001***	2.190* (1.627–2.948)	**0.210**	1.358 (0.842–2.191)
Forearm rotation hours/day©	**< 0.001***	2.276* (1.649–3.141)	**0.123**	0.643 (0.367–1.127)
Wrist bending hours/day©	**< 0.001***	1.882* (1.449–2.443)	**0.815**	1.075 (0.586–1.973)
Forced position of wrist hours/day©	**< 0.001***	2.646* (1.828–3.829)	**0.331**	1.404 (0.708–2.783)
Working with vibration tools hours/day©	**0.998**	-		
Cold exposure hours/day©	**< 0.001***	2.802* (1.962–3.999)	**< 0.001***	3.329* (1.862–5.954)

OR odd's ratio, *CI* confidence interval

All variables with $p < 0.05$ were included in the multivariate

* Statistically significant at $p \leq 0.05$

C category, *N* numeric

repetitive hand and wrist movement, manual hand loads, working with high force or awkward hand position, tasks with thumb pressure, forearm rotation, wrist bending, or cold exposure. These factors could lead to increased interstitial fluid pressure within the carpal tunnel and subsequent compression of its contents, which may lead to poor blood circulation in the flexor synovial cells and MN. Prolonged ischemia causes synovial thickening, intraneural fibrosis, and demyelination of MN [19, 20]. After multiple regression analysis, the only predictors found were working with awkward hand position and cold exposure, where the risk of CTS increased by 9.7 times for the former and 3.3 times for the latter. Some studies that have assessed carpal tunnel pressure indicate that the greatest increase in canal pressure occurs with wrist flexion or extension. As a matter of fact, the position of the forearm, hand, and fingers clearly participates in CTS development [21]. On the contrary, another study found no significant association between work entailing awkward hand position and CTS development [22].

Unfortunately, no validated criteria have been previously established to determine the acceptable limit for each individual exposure. Thus, we attempted a ROC curve to quantitatively estimate the magnitude of ergonomic load to discriminate between hazardous and safe number of daily hours of repeated hand movement whether at work or household chores especially that the majority of patients were housewives. Exceeding 3 h daily of repeated hand movement was the calculated limit beyond which the risk for CTS increased. This estimated cut-off value could help set protective regulations to decrease risk of CTS whether at workplace or in household chores, which could guide practitioners who have confusion in clarifying impact of risky factors (occupational, nonoccupational) to CTS, in determining the compensability of a CTS case.

Conclusion

Occupational risk assessment by clinical, anthropometric, and ultrasonographic measurement should be utilized in professions requiring repetitive or awkward hand movements. Greater concern is directed towards overweight persons with square wrists, where appropriate workplace setup measures or assistive technology at work or home could be taken to prevent or decrease the impact of work hazards or help choose individuals with low risk for appropriate jobs.

Strength and limitations

The current case–control study design cannot ascertain temporal relationship between predictor variables and CTS especially with the self-reported data as opposed to direct observation regarding the occupational risk factors. Despite this, it has explored both occupational and nonoccupational factors combined, predicting CTS development using electrophysiological and sonographic assessment, and has also addressed the relationship of these factors with the different grades of CTS severity, which adds to the credibility of the results. Nevertheless, the model developed has not been externally validated; thus, the generalizability of the results may be limited. A larger group of participants should be recruited for better statistical power and generalization of the models.

Abbreviations

CTS Carpal tunnel syndrome
MN Median nerve
BMI Body mass index
CSA Cross-sectional areas
ICR Internal carpal tunnel ratio
ROC Receiver operating characteristic
OR Odds ratio
CI Confidence interval
PPV Positive predictive value
NPV Negative predictive value

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Authors' contributions

SMS, corresponding author (MD), sonographic examination of the studied patients, and writing the first draft of manuscript. NMH, shared in the study design, carried out the clinical examination, collection of data, statistical analysis, and shared in writing and revision of the manuscript. GAY, the topic of the research was her idea, shared in the study design, and revision of the manuscript. YHA, shared in electrodiagnostic and sonographic examinations of the studied patients and shared in revision of the manuscript.

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Availability of data and materials

Data are available upon reasonable request from the reviewers.

Declarations

Ethics approval and consent to participate

The study was approved by the local Ethics Committee for Human Research, Faculty of Medicine, Alexandria University (IRB No.: 00012098), and a written informed consent was obtained from all participants in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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References

1. Alimohammadi E, Bagheri SR, Hadidi H, Rizevandi P, Abdi A (2020) Carpal tunnel surgery: predictors of clinical outcomes and patients' satisfaction.

BMC Musculoskelet Disord 21(1):51. https://doi.org/10.1186/s12891-020-3082-2.PMID:31992298;PMCID:PMC6988299
2. Mallouhi A, Pültzl P, Trieb T, Piza-Katzer H, Bodner G (2006) Predictors of carpal tunnel syndrome: accuracy of gray-scale and color Doppler sonography. AJR 186:1240–1245
3. Singjam A, Charoentanyarak K, Saengsuwan J (2021) Prevalence and predictive factors for bilateral carpal tunnel syndrome by electrodiagnosis: a retrospective study. PLOS ONE 16:e0260578. https://doi.org/10.1371/journal.pone.0260578
4. Zaki M, Ali M, Yousef W, Ezzat W, Basha W (2020) Age and body anthropometry as predicting factors for carpal tunnel syndrome among Egyptian obese women. Open Access Maced J Med Sci 8(B):930–934(Cited 2023 Oct. 31)
5. You H, Simmons Z, Freivalds A, Kothari MJ, Naidu SH, Young R (2004) The development of risk assessment models for carpal tunnel syndrome: a case-referent study. Ergonomics 47(6):688–709. https://doi.org/10.1080/0014013042000193291
6. Imam M, Hasan M, ELnemr R et al (2019) Body, wrist, and hand anthropometric measurements as risk factors for carpal tunnel syndrome. Egypt Rheumatol Rehabil 46:35–41. https://doi.org/10.4103/err.err_21_18
7. Preston D, Shapiro B (2013) Electromyography and neuromuscular disorders: clinical-electrophysiologic correlations, 3rd edn. Elsevier, London
8. Bland JD (2000) A neurophysiological grading scale for carpal tunnel syndrome. Muscle Nerve 23:1280–1283
9. Frankel HM, Staeheli JC (1992) Calculating body mass index. Ann Intern Med 117(8):698–699
10. Moghtaderi A, Izadi S, Sharafadinzadeh N (2005) An evaluation of gender, body mass index, wrist circumference and wrist ratio as independent risk factors for carpal tunnel syndrome. Acta NeurolScand 112(6):375–9
11. Fernandes CH, Meirelles LM, RaduanNeto J, Nakachima LR, Dos Santos JB, Faloppa F (2013) Carpal tunnel syndrome with thenar atrophy: evaluation of the pinch and grip strength in patients undergoing surgical treatment. Hand (N Y) 8(1):60–63
12. Chen YT, Williams L, Zak MJ, Fredericson M (2016) Review of ultrasonography in the diagnosis of carpal tunnel syndrome and a proposed scanning protocol. J Ultrasound Med 35(11):2311–2324(Epub 2016 Sep 14)
13. Greenland S (1989) Modeling and variable selection in epidemiologic analysis. Am J Public Health 79(3):340–349. https://doi.org/10.2105/ajph.79.3.340
14. Shiri R, Pourmemari MH, Falah-Hassani K, Viikari-Juntura E (2015) The effect of excess body mass on the risk of carpal tunnel syndrome: a metaanalysis of 58 studies. Obes Rev 16:1094–1104
15. Werner RA, Albers JW, Franzblau A, Armstrong TJ (1994) The relationship between body mass index and the diagnosis of carpal tunnel syndrome. Muscle Nerve 17(6):632–636. https://doi.org/10.1002/mus.880170610. (PMID: 8196706)
16. Ozcakir S, Sigirli D, Avsaroglu H (2018) High wrist ratio is a risk factor for carpal tunnel syndrome. Clin Anat 31(5):698–701. https://doi.org/10.1002/ca.23198. (Epub 2018 May 25 PMID: 29722064)
17. Kamolz LP, Beck H, Haslik W, Hogler R, Rab M, Schrogendorfer KF, Frey M (2004) Carpal tunnel syndrome: a question of hand and wrist configurations? J Hand Surg Br 29:321–324
18. Mondelli M, Aretini A, Ginanneschi F, Greco G, Mattioli S (2014) Waist circumference and waist-to-hip ratio in carpal tunnel syndrome: a case control study. J Neurol Sci 338:207–213
19. Shiri R, Miranda H, Heliövaara M, Viikari-Juntura E (2009) Physical work load factors and carpal tunnel syndrome: a population-based study. Occup Environ Med 66(6):368–373. https://doi.org/10.1136/oem.2008.039719.(PMID: 19451144)
20. Demissie B, Yenew C, Alemu A, Bantie B, Sume BW, Deml YA, Tegegne E (2023) Carpal tunnel syndrome and its associated factors among computer user bankers in South Gondar zone, northwest Ethiopia, 2021: a cross sectional study. BMC Musculoskelet Disord 24(1):828. https://doi.org/10.1186/s12891-023-06918-5.PMID:37858114;PMCID:PMC10585807
21. Rempel D, Bach JM, Gordon L et al (1998) Effects of forearm pronation/supination on carpal tunnel pressure. J Hand Surg Am 23(1):38–42
22. Romana U, Viera J, Oto O, Maria T, Jan J, Henrieta H (2022) Occupational risk factors for carpal tunnel syndrome among working population. Zdravotnicke listy 10(1):24–29

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