JDI Journal of Diabetes Investigation Open access
Official Journal of the Asian Association for the Study of Diabetes
CLINICAL TRIAL

Diabetic polyneuropathy and carpal tunnel syndrome together affect hand strength, tactile sensation and dexterity in diabetes patients

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Keywords
Carpal tunnel syndrome, Diabetic polyneuropathy, Hand dexterity

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J Diabetes Investig 2021; 12: 2010–2018

doi: 10.1111/jdi.13580

Clinical Trial Registry
Chinese Clinical Trial Registry
ChiCTR1900025602, Establishment of comprehensive rehabilitation system for elderly diabetic peripheral neuropathy; ChiCTR1900025358, Effectiveness of full-cycle rehabilitation program for elderly patients with diabetic peripheral neuropathy

ABSTRACT

Aims/Introduction: Carpal tunnel syndrome (CTS) and diabetic polyneuropathy (DPN) can occur together, and this concomitance is thought to be higher in diabetes patients. We aimed to examine and compare hand function in type 2 diabetes mellitus patients without CTS and DPN (CTS–DPN–), patients with CTS without DPN (CTS+DPN–), patients with DPN without CTS (CTS–DPN+), and patients with CTS and DPN (CTS+DPN+).

Materials and Methods: A total of 161 type 2 diabetes mellitus patients underwent physical examination and electrodiagnostic tests. Grip and pinch strengths, tactile sensory thresholds were measured for each participant. Purdue pegboard test was used in evaluating the hand dexterity of the participants.

Results: Of the 161 type 2 diabetes mellitus participants, 36 (22.4%) had both CTS and DPN. CTS participants had lower grip (26.6 ± 10.6 vs 35.2 ± 14.3, $P < 0.001$) and pinch (6.3 ± 2.6 vs 7.5 ± 2.9, $P = 0.026$) strengths compared with non-CTS participants, whereas DPN participants had elevated tactile sensory thresholds of both the second (2.8 [2.8–3.6] vs 2.4 [2.4–2.8], $P < 0.001$) and the fifth (2.8 [2.8–3.6] vs 2.4 [2.4–2.8], $P < 0.001$) fingers compared with non-DPN participants. The CTS+DPN+ group had lower Purdue pegboard test scores than other groups. Grip ($r = 0.482$, 0.530, 0.467, 0.498, all $P < 0.001$) and pinch ($r = 0.246$, $P = 0.003$; $r = 0.265$, $P = 0.001$; $r = 0.264$, $P = 0.001$; $r = 0.235$, $P = 0.005$) strengths were positively correlated with Purdue pegboard test scores, whereas tactile sensory thresholds were negatively correlated with Purdue pegboard test scores ($r = –0.447$ to $–0.359$, all $P < 0.001$).

Conclusion: Type 2 diabetes mellitus patients with both DPN and CTS had lower grip and pinch strengths and decreased tactile sensation, both of which were correlated with poorer hand dexterity.

INTRODUCTION

Diabetes mellitus, characterized by hyperglycemia, is a worldwide major health problem. A series of long-term complications of diabetes have a direct impact on the quality of life and life expectancy of patients, resulting in higher healthcare cost.

Carpal tunnel syndrome (CTS) is the most common peripheral nerve entrapment syndrome, caused by increased pressure in the carpal tunnel with regard to gradual ischemia and damage of the median nerve[1]. CTS is characterized by paresthesia, numbness and pain in the territory innervated by the median nerve, often involving the three and a half fingers on the radial side[1]. In some patients, CTS worsens and motor dysfunctions in the hand develop, mainly manifested as weakness of thumb abduction, and opposition and atrophy of the thenar eminence[2]. CTS as a chronic and deteriorating problem might trigger physical, psychological, sociological and economic negative consequences[3]. Studies have reported that diabetes was among the most significant risk factors for CTS, and the prevalence of CTS was proportional to the duration of disease[4]. The underlying basis of increased incidence of CTS in diabetes is unknown. Contributory mechanisms might arise from the various metabolic abnormalities in diabetes patients that cause edema and congestion of tendons, synovium, ligaments and nerves[5]. It might also be due to the fact that nerves are more susceptible

Received 29 January 2021; revised 28 April 2021; accepted 11 May 2021

to compression because of microangiopathy, hypoxia and abnormal metabolism in diabetes patients[6–8].

Diabetic polyneuropathy (DPN) is among the most common long-term complications of diabetes. Studies have reported that 27.4–81.6% of diabetes patients are affected by DPN[9]. Distal symmetric sensorimotor polyneuropathy is the most common and widely recognized form of diabetic neuropathy, typically presenting with a distal symmetric decrease of sensory and motor function in the limbs. The onset and progression of DPN are relatively insidious. In the early stage of DPN, patients might present with manifestations of small fiber dysfunction, such as pain, hypersensitivity and elevated thermal sensory thresholds, as well as elevated tactile sensory and pain thresholds. If large fibers are involved, there might be decreased sensation of vibration and position, and decreased motor function[10].

CTS and DPN can occur together in diabetes patients. CTS occurs in 14% of diabetes patients without DPN, and in 30% of diabetes patients with DPN[11]. DPN can mask the symptoms of CTS, resulting in the delay of diagnosis and treatment in CTS. In the present study, we aimed to examine hand function in type 2 diabetes mellitus patients, and to observe the correlation between hand function and the presence of DPN and/or CTS.

MATERIALS AND METHODS

Participants

The current study was carried out in People's Hospital of Jiaozuo City, Henan Province, China, from July 2019 to September 2019. We recruited 200 patients (93 women and 107 men) with diabetes mellitus who were hospitalized for hyperglycemia management during the study period. Eligible patients included men or women aged >18 years who had been diagnosed with type 2 diabetes. The exclusion criteria were as follows: acute complications of diabetes, long-term heavy drinking, other neuromuscular diseases (such as stroke, cervical spondylosis, long-term heavy drinking etc.), thyroid dysfunction, previous wrist trauma, malignant tumors, connective tissue diseases and severe organ failure. The flow diagram of study participants is presented in Figure 1. A total of 161 type 2 diabetes mellitus patients (76 women, 85 men) were included. The mean age of the patients was 58.4 ± 13.3 years, with a duration of diabetes of 8.0 years (interquartile range 3.0–15.0 years). Demographic and clinical information were obtained, and functional status and symptoms were measured. Electrodiagnostic tests were carried out for all participants. The experiment was carried out from 09.00 hours to 11.00 hours and from 14.00 hours to 17.00 hours. Complete evaluation took approximately an hour. Random fingertip capillary blood glucose was tested before the physical examination and electrodiagnostic testing. If the blood glucose was <6.0 or >11.1 mmol/L, the evaluation would be postponed to another day.

Informed consent was obtained for experimentation. The Ethics Committee of People's Hospital of Jiaozuo City approved the study on 28 June 2019 (Approval No.2019001). The trial was registered on the Chinese Clinical Trial Registry (ChiCTR1900025602, ChiCTR1900025358).

Physical examination

Weight, height, waist circumference and hip circumference were measured. Body mass index (BMI) was calculated as weight (kg) divided by the square of height (m). Participants were categorized into two BMI groups: normal weight (BMI <24 kg/m^2) and overweight (BMI ≥24 kg/m^2). The waist-to-hip ratio was calculated as the waist circumference divided by hip circumference.

Assessment of tactile sensation, grip strength and hand flexibility is shown in Figure 2. Tactile sensory thresholds were tested through Semmes–Weinstein monofilaments. The participant's eyes were covered and then tactile stimulation with a set of Semmes–Weinstein monofilaments (Touch Test Complete Hand Kit; North Coast Medical Inc., Morgan Hill, CA, USA) was delivered to median nerve innervated (second) and ulnar nerve innervated (fifth) digits following a standard testing protocol[12]. Filaments from thin to thick were applied sequentially to the pulps of the fingers until the participants could feel the tactile stimulation. Both the grip and pinch strength values were assessed following a standard testing protocol and expressed in grip/pinch strength index[13]. Participants were seated with their shoulder adducted and neutrally rotated, elbow flexed at 90°, forearm in neutral position. Each test was repeated three times, and the largest value was recorded. The grip strength index was calculated as grip strength divided by bodyweight, and the pinch strength index was calculated as pinch strength divided by bodyweight. We also evaluated fine motor skill performance using the previously validated Purdue pegboard test following a standard testing protocol[14]. Participants were instructed to fill the holes with pegs within 30 s initially with the dominant hand, then with the non-dominant hand and finally with both hands. Then, participants were instructed to assemble in sequence a peg, a washer, a collar and finally another washer within 60 s.

Electrodiagnostic testing

All participants underwent nerve conduction studies (NCS) using a standard electromyography device (MEB-9200K; KOHDEN, Tokyo, Japan). NCS were carried out by three experienced electromyography technicians who were blinded to the results of the physical examination. Standardized techniques for NCS with temperature control and fixed distances were applied. Skin temperature was maintained above 32°C. The median, ulnar, radial, tibial, peroneal and sural nerves were tested in the upper and lower limbs. Measurements of latencies, distances and amplitudes were carried out in a standard fashion following American Academy of Emergency Medicine guidelines[15]. Conduction velocities were calculated automatically by the electromyography device.

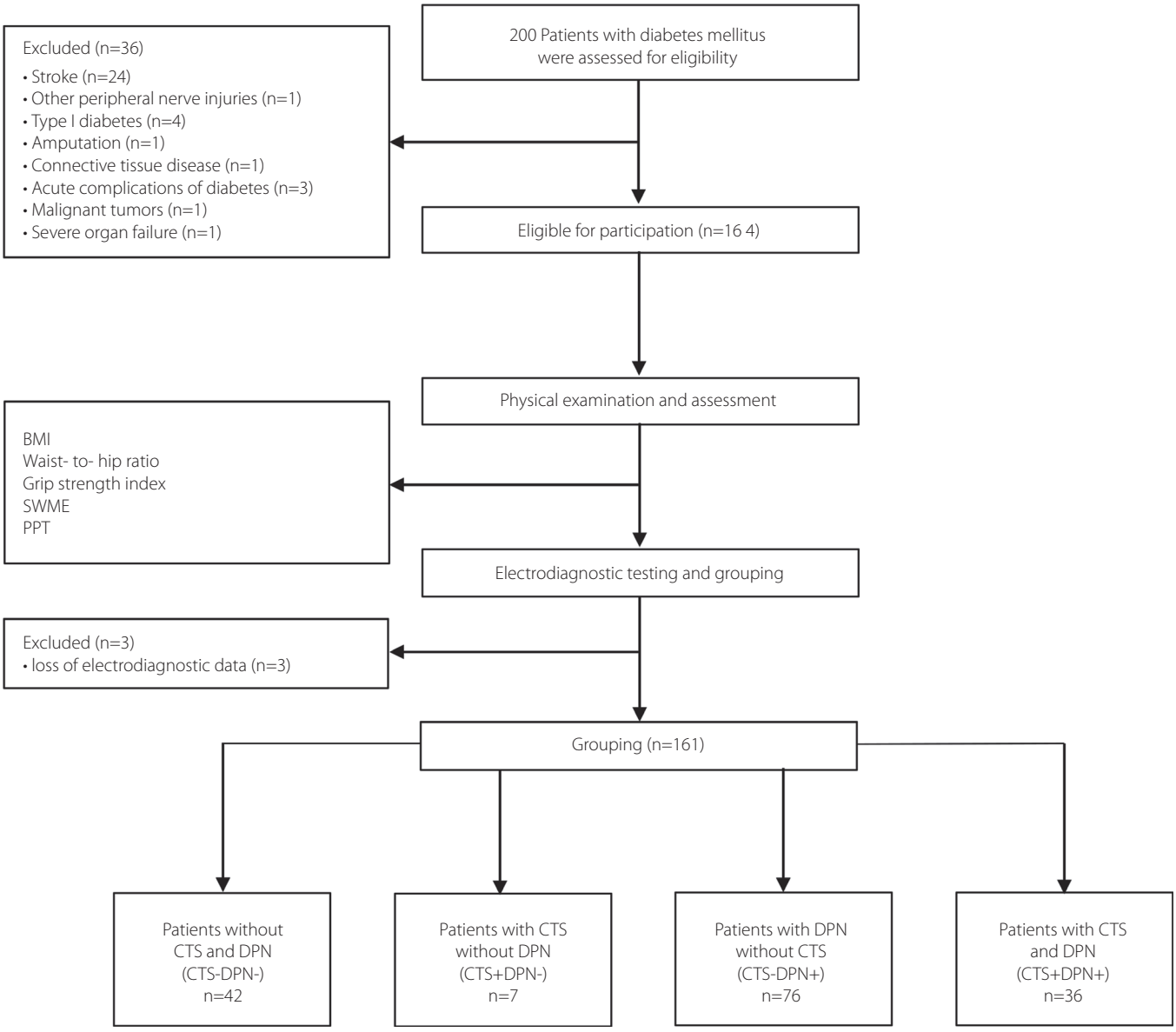

Figure 1 | The flow diagram. A total of 200 patients with diabetes were recruited. Of these, 36 were excluded according to the exclusion criteria, and three were excluded because of the loss of electrodiagnostic data. BMI, body mass index; CTS, carpal tunnel syndrome; DPN, diabetic polyneuropathy; PPT, Purdue Pegboard Test; SWME, Semmes–Weinstein monofilament examination.

CTS diagnosis and grading

CTS was diagnosed according to electrodiagnostic results following the recommendations of American Association of Neuromuscular and Electrodiagnostic Medicine[16,17]. Diagnosis of CTS in underlying DPN is usually complicated, because DPN can obscure the electrophysiological findings of CTS. Comparison of median NCS with those of the ulnar nerve of the same hand was used. When the data of the latter nerve show changes, then the diagnosis will no longer be CTS. Comparison of NCS with another upper extremity nerve was also used. Patients were categorized as having mild, moderate or severe CTS according to the electrodiagnostic results[18,19]. Mild CTS was defined by delayed distal latency of median sensory nerve conduction across the wrist (>3.7 ms and/or >0.5 ms compared with ulnar sensory nerve conduction) with normal motor nerve conduction; moderate CTS was defined by mild CTS and with delayed distal latency of median motor nerve conduction across the wrist (>4.2 ms), but with normal motor amplitudes; severe CTS was defined by prolonged median sensory and motor latencies with either absent sensory nerve action potentials and/or reduced (50%) median motor amplitudes. For patients with bilateral CTS, the CTS severity is graded based on the more severe hand.

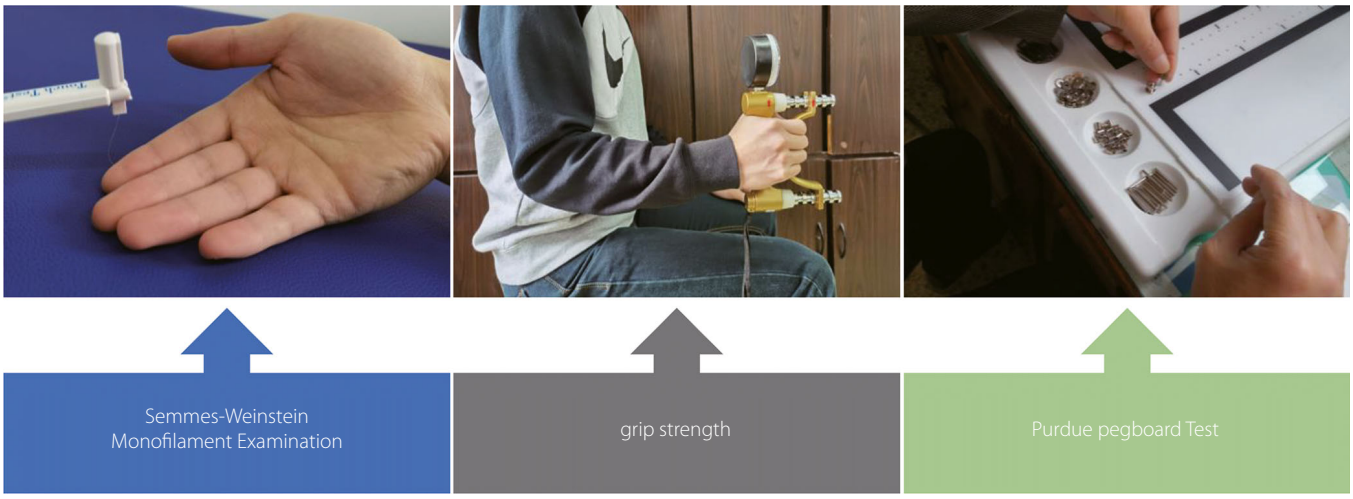

Figure 2 | Assessment of tactile sensation, grip strength and hand flexibility. (a) Tactile sensory thresholds of the fingers were tested through Semmes–Weinstein monofilaments. (b) Grip strength was measured with a Jamar Dynamometer. (c) Hand flexibility was assessed through Purdue pegboard test.

DPN diagnosis

We used the NCS for diagnosis of DPN. Both upper and lower extremities were assessed. Bilateral nerve conduction studies of media, ulnar, superficial peroneal, sural sensory nerves, and median, ulnar, tibial and peroneal motor nerves with F waves were carried out. The criteria for electrodiagnostic confirmation of distal symmetric polyneuropathy is an abnormality (median or ulnar NCV <45 m/s; peroneal, sural or tibial NCV <40 m/s) of any attribute of nerve conduction in two separate nerves, one of which must be in lower extremities. In those with normal NCV, sympathetic skin response (SSR) in the upper and lower limbs was tested. Patients with normal NCV and abnormal SSR (SSR amplitude <1 mV, SSR latency >1,500 ms in the upper limbs or SSR amplitude <0.5 mV, SSR latency >2,000 ms in the lower limbs) were diagnosed as early DPN.

Statistical analysis

Statistical analysis was carried out using SPSS version 18.0 software. Normally distributed continuous variables were represented as $x \pm s$. Non-parametric continuous variables are represented as the median (upper and lower quartile). Categorical variables are represented as the number and percentages (%). Normally distributed continuous variables between two independent groups were compared using the *t*-test. Non-parametric continuous variables between two independent groups were compared using the Mann–Whitney *U*-test. Normally distributed continuous variables were compared among multiple groups using the one-way ANOVA. Non-parametric continuous variables were compared using the Kruskal–Wallis test. Post-hoc comparisons were carried out with the Bonferroni test. Categorical variables were compared using the χ^2-test. The Kolmogorov–Smirnov test was used to analyze the normal distribution of the variables. Logistic regression models were used to assess the association between risk factors, DPN and the presence of CTS. Spearman's coefficient (r) was used to correlate variables. $P < 0.05$ was considered statistically significant.

RESULTS

Of the 161 (76 women, 85 men) participants included in the current study, the average age was 58.4 ± 12.8 years, and the duration of diabetes was 8.0 years (interquartile range 3.0–15.0 years). The BMI was 25.4 ± 3.6 kg/m^2 and the waist-to-hip ratio was 0.92 ± 0.06. Hypertension was reported in 74 (46.0%) of these diabetes patients. Also reported were coronary heart disease in 31 patients (19.3%). A total of 95 (59.0%) of the participants were receiving insulin therapy. The average age of women was lower compared with men (61.4 ± 12.5 vs 55.7 ± 12.6, $P = 0.005$). The average waist-to-hip ratio was higher in men than in women (0.94 ± 0.06 vs 0.90 ± 0.06, $P < 0.001$). No significant difference was found in the duration of diabetes and BMI between men and women. CTS was more likely to occur in women than in men (34.2% vs 20.0%, $P = 0.042$). There was no difference in the frequency of hypertension, coronary heart disease or DPN between men and women.

Electrophysiologically confirmed CTS was present in 43 of 161 diabetes patients (prevalence, 26.7%). The higher prevalence of CTS among female diabetes patients was more significant than male diabetes patients (34.2% [$n = 26$] vs 20.0% [$n = 17$], $\chi^2 = 4.139$, $P = 0.042$). Of the 43 diabetes patients with CTS, 11 (25.6%) had mild CTS, 29 (67.4%) had moderate CTS and three (6.9%) had severe CTS. Among the 43 diabetes patients with CTS, eight (18.4%) had only the dominant hand affected,

two (4.6%) had only the non-dominant hand affected and 33 (76.7%) of them had both hands affected.

Of these 161 diabetes patients, 112 (69.6%) had DPN, and 36 (22.4%) had both CTS and DPN. The prevalence of CTS was higher in DPN patients than in non-DPN patients (32.1% vs 14.3%, $\chi^2 = 5.553$, $P = 0.018$). However, there is no demonstrable correlation between the presence of DPN and the severity of CTS. Table 3 presents the odds of CTS for various risk factors and DPN. Using logistic regression analysis, patients with DPN reported elevated risk for CTS. The odds of CTS were 4.755-fold higher (95% CI 1.543–14.651, $P = 0.007$) for patients with DPN after adjusting for age, sex, duration of diabetes and the presence of overweight. In addition, in diabetes patients, overweight (OR = 6.367, 95% CI 2.278–17.802, $P < 0.001$) and female sex (OR = 3.453, 95% CI: 1.365–8.733, $P = 0.009$) were also observed to be risk factors for CTS (Table 1).

On the basis of the results of the NCS, patients were divided into four subgroups: patients without CTS or DPN (CTS–DPN–); patients with CTS without DPN (CTS+DPN–); patients with DPN without CTS (CTS–DPN+), and patients with both CTS and DPN (CTS+DPN+). There was no significant difference in BMI, waist-to-hip ratio and prevalence of hypertension and coronary heart disease among these groups. The CTS+DPN+ group and the CTS–DPN+ group have older age, longer duration of diabetes and higher proportion of insulin treatment compared with the CTS–DPN– group. Analyses were limited by the relatively small number of patients with CTS without DPN ($n = 7$; Table 2).

The dynamometer measurements showed greater grip and pinch strength in men than in women, whereas Semmes–Weinstein monofilament measurements showed no significant difference in tactile sensory thresholds between men and women (Table 3). The presence of CTS was associated with lower grip and pinch strength. However, the magnitude of the difference of tactile sensory thresholds of the second finger between CTS and non-CTS patients was too small to be clinically meaningful. The presence of DPN was associated with

Table 1 | Modeling associations among risk factors, diabetic polyneuropathy and the presence of carpal tunnel syndrome

Characteristics	Univariate models		Adjusted models	
	Odds ratio (95% CI)	Wald χ^2	Odds ratio (95% CI)	Wald χ^2
Sex (female vs male)	2.080 (1.021–4.239)	4.064	3.453 (1.365–8.733)	6.853
Age (per 1 year)	1.031 (1.002–1.061)	4.351	1.001 (0.961–1.043)	0.004
Duration of diabetes (per 1 year)	1.029 (0.987–1.074)	1.816	0.999 (0.939–1.062)	0.002
Overweight (yes vs no)	4.508 (1.749–11.620)	9.718	6.367 (2.278–17.802)	12.455
DPN (yes vs no)	1.688 (1.152–2.473)	7.224	4.755 (1.543–14.651)	7.375

95% CI, 95% confidence interval; DPN, diabetic polyneuropathy.

Table 2 | Clinical characteristics of the without carpal tunnel syndrome and without diabetic polyneuropathy group, without carpal tunnel syndrome and with diabetic polyneuropathy group, with carpal tunnel syndrome and without diabetic polyneuropathy group, and with carpal tunnel syndrome and with diabetic polyneuropathy group

	CTS–DPN– ($n = 42$)	CTS+DPN– ($n = 7$)	CTS–DPN+ ($n = 76$)	CTS+DPN+ ($n = 36$)	*P*-value
Female/male	23/19	5/2	27/49[†]	21/15[§]	0.035
Age (years)	51.6 ± 13.0	59.3 ± 11.1	60.0 ± 12.7[†]	61.8 ± 12.1[‡]	0.001
Duration of diabetes (years)	5 (1.75–9)	5 (0–5)	10 (4–17)[†]	11 (4.25–18.5)[‡]	0.004
BMI (kg/m^2)	25.3 ± 3.7	27.5 ± 2.0	24.9 ± 3.7	26.3 ± 3.1	0.166
Waist-to-hip ratio	0.92 ± 0.07	0.94 ± 0.04	0.92 ± 0.06	0.93 ± 0.06	0.792
Insulin treatment	18 (42.9%)	2 (28.6%)	48 (64.9%)[†]	27 (75.0%)[‡]	0.006
Mecobalamin treatment	6 (14.3%)	1 (14.3%)	15 (19.7%)	6 (16.7%)	0.709
Hypertension	14 (33.3%)	3 (42.9%)	38 (50.7%)	19 (52.8%)	0.252
Coronary heart disease	4 (9.5%)	1 (14.3%)	17 (22.7%)	9 (25.0%)	0.241

Data are mean ± standard deviation, median (interquartile range) or *n* (%). The *P*-value evaluates the differences among the without carpal tunnel syndrome and without diabetic polyneuropathy (CTS–DPN–) group, without carpal tunnel syndrome and with diabetic polyneuropathy (CTS–DPN+) group, with carpal tunnel syndrome and without diabetic polyneuropathy (CTS+DPN–) group, and with carpal tunnel syndrome and with diabetic polyneuropathy (CTS+DPN+) group. The presence of hypertension or coronary heart disease was determined by the history provided by the patient without further testing. BMI, body mass index. [†]CTS–DPN+ group vs CT–DPN– group, Bonferroni-adjusted *P*-value <0.05. [‡]CTS+DPN+ group vs CT–DPN– group, Bonferroni-adjusted *P*-value <0.05. [§]CTS–DPN+ group vs CTS+DPN+ group, Bonferroni-adjusted *P*-value <0.05.

Table 3 | Grip and pinch strength and tactile sensory threshold by selected characters of diabetes

	Pinch strength index		Grip strength index		SWME-1		SWME-2	
	Mean ± SD	*P*-value	Mean ± SD	*P*-value	Median (IQR)	*P*-value	Median (IQR)	*P*-value
Sex								
Male	8.2 ± 3.0	<0.001	39.7 ± 13.0	<0.001	2.83 (2.44–3.61)	0.086	2.83 (2.64–3.61)	0.413
Female	6.2 ± 2.5		25.7 ± 11.0		2.83 (2.44–3.61)		2.83 (2.44–3.41)	
Duration of diabetes								
<10 years	7.5 ± 3.0	0.210	36.2 ± 14.0	0.001	2.83 (2.44–3.22)	0.004	2.83 (2.44–3.22)	0.001
>10 years	6.8 ± 2.8		28.3 ± 13.0		3.22 (2.83–3.61)		3.22 (2.83–3.61)	
Age								
<65 years	7.8 ± 3.1	<0.001	37.6 ± 13.2	<0.001	2.8 (2.4–3.2)	0.003	2.8 (2.4–3.2)	0.002
>65 years	6.0 ± 2.0		23.2 ± 10.0		3.2 (2.8–3.6)		3.2 (2.8–3.6)	
Overweight								
Absent	8.3 ± 3.0	0.001	37.7 ± 15.4	0.002	2.8 (2.4–3.2)	0.026	2.8 (2.4–3.2)	0.085
Present	6.6 ± 2.7		30.4 ± 12.4		2.8 (2.4–3.6)		2.8 (2.4–3.6)	
CTS status								
Absent	7.5 ± 2.9	0.026	35.2 ± 14.3	<0.001	2.8 (2.4–3.6)	0.025	2.8 (2.4–3.5)	0.185
Present	6.3 ± 2.6		26.6 ± 10.6		2.8 (2.8–3.8)		2.8 (2.8–3.6)	
DPN status								
Absent	7.1 ± 3.1	0.744	35.9 ± 13.0	0.094	2.4 (2.4–2.8)	<0.001	2.4 (2.4–2.8)	<0.001
Present	7.3 ± 2.8		31.7 ± 14.2		2.8 (2.8–3.6)		2.8 (2.8–3.6)	
CTS and DPN status								
CTS–DPN–	7.5 ± 3.0	0.053	36.8 ± 13.1	0.006	2.4 (2.4–2.8)	0.001	2.4 (2.4–2.8)	<0.001
CTS–DPN+	7.5 ± 2.9		34.4 ± 15.0[§]		2.8 (2.4–3.6)[†]		2.8 (2.8–3.6)[†]	
CTS+DPN–	4.5 ± 2.1		30.1 ± 12.5		2.8 (2.4–2.9)		2.4 (2.4–2.8)[¶]	
CTS+DPN+	6.6 ± 2.5		25.9 ± 10.4[‡]		3.2 (2.8–3.8)[‡]		3.2 (2.8–3.6)[‡]	

Data are mean ± SD or median (interquartile range [IQR]). CTS, carpal tunnel syndrome; DPN, diabetic polyneuropathy; SWME-1, tactile sensory thresholds in the second finger measured with Semmes–Weinstein monofilaments; SWME-2, tactile sensory thresholds in the fifth finger measured with Semmes–Weinstein monofilaments. [†]CTS–DPN+ group vs CT–DPN– group, Bonferroni-adjusted *P*-value <0.05. [‡]CTS+DPN+ group vs CT–DPN– group, Bonferroni-adjusted *P*-value <0.05. [§]CTS–DPN+ group vs CTS+DPN+ group, Bonferroni-adjusted *P*-value <0.05. [¶]CTS+DPN– group vs CTS+DPN+ group, Bonferroni-adjusted *P*-value <0.05

elevated tactile sensory thresholds of both the second and the fifth fingers. However, the grip and pinch strength did not differ significantly between those with and without DPN. The CTS+DPN+ group had significantly reduced grip strength, as well as increased tactile detection threshold when compared with the other groups. Not all of the differences in the analysis were statistically significant, because of the small number of cases and reduced power (Table 3).

Table 4 showed that the presence of either CTS or DPN was associated with lower Purdue pegboard test scores, reflecting poorer dexterity in both dominant and non-dominant hands. Participants in the CTS+DPN+ group had lower Purdue pegboard test scores than those in other groups. Purdue pegboard test scores were also associated with other factors: those with diabetes for >10 years and those aged ≥65 years had lower scores. There was no difference in Purdue pegboard test scores between men and women.

Furthermore, grip and pinch strength were positively correlated with Purdue pegboard test scores. Tactile detection thresholds of the second and the fifth fingers were negatively correlated with Purdue pegboard test scores (Table 5).

DISCUSSION

CTS is a common disease. The estimated prevalence of CTS in the general population is 1–5%. Most studies have reported a female predominance in the frequency of CTS. The female-to-male ratio for CTS prevalence is approximately 3:1. In the present study, women were more affected by CTS compared with men, which is concordant with previous studies. One possible explanation is that the cross-sectional area of the proximal carpal tunnel is smaller in women than in men[20–23]. Previous studies have also found that CTS is related to the degree of wrist usage[24]. So another possible explanation is that women do more housework than men and their wrists are bent or pressed more frequently. Previous studies reported that diabetes was a major risk factor for the development of CTS[25–27]. The findings of the present study show CTS to be common in diabetes patients. Therefore, the high prevalence of CTS in diabetes patients should be borne in mind when managing diabetes patients. The underlying basis of the increased prevalence of CTS in diabetes patients is not yet clear. It might be related to the various metabolic abnormalities in diabetes patients that cause edema and congestion of tendons,

Table 4 | Results of the Purdue pegboard test by selected characters of diabetes

	PPT (dominant hand)		PPT (non-dominant hand)		PPT (both hands)		PPT (assembly)	
	Median (IQR)	*P*-value	Median (IQR)	*P*-value	Median (IQR)	*P*-value	Median (IQR)	*P*-value
Sex								
Male	11.0 (9.0–13.0)	0.092	11.0 (9.0–12.0)	0.208	5.0 (4.0–7.0)	0.103	22.5 (16.0–27.0)	0.053
Female	11.0 (9.0–13.0)		10.0 (8.0–12.0)		5.0 (4.0–6.0)		19.0 (14.0–24.0)	
Duration of diabetes								
<10 years	12.0 (10.0–14.0)	<0.001	11.0 (10.0–13.0)	<0.001	7.0 (6.0–9.0)	<0.001	23.0 (18.0–28.3)	<0.001
>10 years	9.0 (8.0–11.0)		9.0 (7.0–11.0)		6.0 (4.0–7.0)		17.0 (14.0–20.0)	
Age								
<65 years	12 (10–14)	<0.001	11 (10–13)	<0.001	7 (6–9)	<0.001	23 (18–29)	<0.001
>65 years	9 (8–11)		9 (7–10)		5 (4–7)		16 (13–18)	
Overweight								
Absent	12 (9.3–13)	0.016	11 (9–12.5)	0.244	7 (6–8)	0.261	22 (17–28)	0.068
Present	10 (8.5–12)		10 (9–12)		6 (5–8)		18 (15–25)	
CTS status								
Absent	11 (9–13)	0.001	11 (9–12)	0.010	7 (5–8)	0.024	22 (17–28)	0.001
Present	9 (8–11)		10 (7.5–11)		6 (4.5–7)		17 (14–20.5)	
DPN status								
Absent	12 (10.8–14)	<0.001	12 (10–13.3)	<0.001	7.5 (6–9)	<0.001	24 (19.5–30)	0.001
Present	10 (9–12)		10 (8–11)		6 (5–7)		18 (15–23)	
CTS and DPN status								
CTS–DPN–	13 (11–14)	<0.001	12 (10–13.8)	0.001	8 (6–9)	<0.001	24 (20.5–32.3)	<0.001
CTS–DPN+	11 (9–13)†		10 (8.8–12)†		6 (5–8)†		20 (16–25)	
CTS+DPN–	10.5 (8.8–12.3)		11 (9.5,12.8)		6 (5.8–7.8)		19 (14.5–25.3)	
CTS+DPN+	9 (8–11)‡		9 (7–11)‡		6 (4–7)‡		16 (14–20)‡	

Data are median (interquartile range [IQR]). CTS, carpal tunnel syndrome; DPN, diabetic polyneuropathy; PPT, Purdue pegboard test scores. †CTS–DPN+ group vs CT–DPN– group, Bonferroni-adjusted *P* value <0.05. ‡CTS+DPN+ group vs CT–DPN– group, Bonferroni-adjusted *P* value <0.05.

Table 5 | Spearman correlation coefficients of grip and pinch strength, tactile detection thresholds with Purdue pegboard test scores

	PPT (dominant hand)		PPT (non-dominant hand)		PPT (both hands)		PPT (assembly)	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
Grip strength index	0.482	<0.001	0.530	<0.001	0.467	<0.001	0.498	<0.001
Pinch strength index	0.246	0.003	0.265	0.001	0.264	0.001	0.235	0.005
SWME-1	−0.381	<0.001	−0.430	<0.001	−0.385	<0.001	−0.427	<0.001
SWME-2	−0.359	<0.001	−0.447	<0.001	−0.369	<0.001	−0.428	<0.001

PPT, Purdue pegboard test scores; SWME-1, tactile sensory thresholds in the second finger measured with Semmes–Weinstein monofilaments; SWME-2, tactile sensory thresholds in the fifth finger measured with Semmes–Weinstein monofilaments.

synovium, ligaments and nerves[5]. It might also be due to the fact that nerves are more sensitive to compression in diabetes patients because of microangiopathy, hypoxia and abnormal metabolism[6–8].

Although clinical experience shows that the incidence of unilateral CTS is higher, bilateral CTS is actually very common. Previous studies found that 61% of the patients with CTS were bilateral, and 39% were unilateral[28]. Some patients had clinical CTS on one side and subclinical CTS on the other side[29]. Among the participants in the present study, the prevalence of bilateral CTS was 76.7%, higher than previously reported. This might be due to the small sample size of the present study. It might also be due to the fact that DPN can mask the symptoms of CTS, causing delayed diagnosis in CTS in the present participants with diabetes.

Carpal tunnel syndrome and DPN can occur together, and this concomitance is thought to be higher in diabetes patients[30]. In the present study, 22.4% diabetes patients had both DPN and CTS. Patients with DPN had a higher prevalence of CTS than those without DPN, which is concordant with previous

studies[11]. Logistic regression analysis showed that DPN was a risk factor for CTS in diabetes patients, and the risk of having CTS in DPN patients was 4.78-fold that in patients without DPN.

DPN and CTS can both reduce muscle strength or decrease tactile sensation in the hands of diabetes patients. In the present study, DPN patients had significantly higher tactile sensory thresholds than non-DPN patients, whereas the grip and pinch strength did not differ significantly between the two groups. At the same time, CTS patients had significantly lower grip and pinch strength than non-CTS patients. However, the magnitude of the differences in tactile sensory threshold was small between the CTS and non-CTS groups, and was of little clinical relevance. Diabetes patients with both CTS and DPN showed obviously decreased grip strength and hand tactile sensation. These results suggest that large diameter myelinated motor nerve fibers are more likely to be involved in diabetes patients with CTS, which is probably because large myelinated nerve fibers are more susceptible to compression. However, in DPN patients, small myelinated sensory nerve fibers are usually impaired earlier, leading to decreased tactile sensation in that hands. We used NCS for the diagnosis of DPN and CTS in the present study. However, diagnosis of CTS in underlying DPN is usually complicated, because DPN can obscure the electrophysiological findings of CTS, especially in those with much more advanced DPN. Median nerve ultrasound might help to better differentiate between DPN and CTS in future studies.

The present study showed that DPN patients had lower Purdue pegboard test scores compared with non-DPN patients, indicating poorer hand dexterity. CTS patients had lower Purdue pegboard test scores compared with non-CTS patients. Patients with both CTS and DPN had the lowest Purdue pegboard test scores. Higher grip and pinch strength had a positive effect on Purdue pegboard test scores. The tactile sensory threshold in the second and the fifth fingers were adversely related to the Purdue pegboard test scores, respectively. These results suggest that CTS and DPN together contribute to poor hand dexterity in diabetes patients.

The present study was a cross-sectional study with a relatively small sample size, and it lacks a normal control group. All of our participants were recruited from the Jiao People's Hospital of Jiaozuo City, Henan Province, China, potentially reducing generalizability. Therefore, the findings of the present study should be regarded as preliminary and need to be confirmed by more large-scale, prospective studies. We used electrodiagnostic tests to define the CTS and DPN, which might be questioned, because their accuracy might vary among laboratories and neurophysiologists. Previous studies have found that the severity of DPN and CTS might be related to the level of glycated hemoglobin in diabetes patients. However, the present study failed to collect the results of glycated hemoglobin, which is a study limitation.

Overall, these data show that CTS and DPN together contribute to poor hand dexterity in diabetes patients. Clinicians should pay more attention to early diagnosis and effective treatment of CTS and DPN in diabetes patients to prevent the exacerbation of hand dysfunction.

ACKNOWLEDGMENTS

This work was supported by the National Key R&D Program of China (grant numbers 2018YFC2002300, 2018YFC2002301).

DISCLOSURE

The authors declare no conflict of interest.

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