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

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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 nerve1. 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 side1. 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 eminence2. CTS as a chronic and deteriorating problem might trigger physical, psychological, sociological and economic negative consequences3. 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 disease4. 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 nerves5. It might also be due to the fact that nerves are more susceptible to injury in diabetics6,7. 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.

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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. 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.9

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.10 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 spondylisis, 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. Electrophysiological 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 electrophysiological 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/m²) and overweight (BMI ≥24 kg/m²). 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 protocol12. 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 index13. Participants were seated with their shoulder abducted 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 protocol14. 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; KOH- DEN, 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 guidelines15. Conduction velocities were calculated automatically by the electromyography device.
CTS diagnosis and grading

CTS was diagnosed according to electrodiagnostic results following the recommendations of American Association of Neuro-muscular and Electrodiagnostic Medicine. 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. 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 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.

Excluded (n=36)
- Stroke (n=24)
- Other peripheral nerve injuries (n=1)
- Type I diabetes (n=4)
- Amputation (n=1)
- Connective tissue disease (n=1)
- Acute complications of diabetes (n=3)
- Malignant tumors (n=1)
- Severe organ failure (n=1)

Eligible for participation (n=164)

Physical examination and assessment

Electrodiagnostic testing and grouping

Excluded (n=3)
- Loss of electrodiagnostic data (n=3)

Grouping (n=161)

Patients without CTS and DPN (CTS-DPN-)
 n=42

Patients with CTS without DPN (CTS+DPN-)
 n=7

Patients with DPN without CTS (CTS-DPN+)
 n=76

Patients with CTS and DPN (CTS+DPN+)
 n=36

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Excluded (n=36)
- Stroke (n=24)
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- Connective tissue disease (n=1)
- Acute complications of diabetes (n=3)
- Malignant tumors (n=1)
- Severe organ failure (n=1)
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 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 $\chi^2$-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/m² 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 1.543–14.3%, $P = 0.009$) 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 in 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

| Characteristics                      | Univariate models | Adjusted models |
|--------------------------------------|-------------------|-----------------|
|                                     | Odds ratio (95% CI) | Wald $\chi^2$ | Odds ratio (95% CI) | Wald $\chi^2$
| 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.

| Characteristics                      | 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/m²)                          | 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+), 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.
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CLINICAL TRIAL
Overweight
Age
Duration of diabetes
CTS status

CTS group, Bonferroni-adjusted correlated with Purdue pegboard test scores (Table 5).

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             | Median (IQR) | P-value |
| Sex            |                       |                     |        |        |
| Male           | 8.2 ± 3.0            | <0.001              | 2.83 (2.44–3.61) | 0.086 |
| Female         | 6.2 ± 2.5            |                     | 2.83 (2.44–3.61) | 0.413 |
| Duration of diabetes | 7.5 ± 3.0 | 0.210              | 2.83 (2.44–3.61) | 0.004 |
| <10 years      | 6.8 ± 2.8            |                     | 3.22 (2.83–3.61) | 0.001 |
| >10 years      | 7.8 ± 3.1            | <0.001              | 2.8 (2.4–3.2) | 0.002 |
| Present        | 6.6 ± 2.7            |                     | 2.8 (2.4–3.2) | 0.085 |
| CTs status     |                       |                     |        |        |
| Absent         | 7.5 ± 2.9            | 0.026               | 2.8 (2.4–3.6) | 0.185 |
| Present        | 6.3 ± 2.6            |                     | 2.8 (2.4–3.6) | 0.001 |
| DPN status     |                       |                     |        |        |
| Absent         | 7.1 ± 3.1            | 0.744               | 2.4 (2.4–2.8) | <0.001 |
| Present        | 7.3 ± 2.8            |                     | 2.8 (2.4–2.8) | <0.001 |
| CTS and DPN status | 7.5 ± 3.0 | 0.053              | 2.4 (2.4–2.8) | 0.001 |
| CTS+DPN       | 7.5 ± 2.9            |                     | 2.8 (2.4–3.6) | 0.001 |
| CTS+DPN+      | 7.5 ± 2.1            |                     | 2.8 (2.4–2.8) | 0.001 |
| CTS+DPN+      | 6.6 ± 2.5            |                     | 3.2 (2.8–3.6) | 0.001 |

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.

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 men20–23. Previous studies have also found that CTS is related to the degree of wrist usage24. 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 CTS25–27. 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,
C T S a n D P N s t a t u s

Overweight

SWME-2

DPN status

SWME-1

Age

SWME-1 - Pinch strength index 0.246 0.003 0.265 0.001 0.264 0.001 0.235 0.005

Duration of diabetes

<10 years

120 (10.0–14.0) <0.001 110 (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 (7.0–11.0) <0.001 6.0 (4.0–7.0) <0.001 17.0 (14.0–20.0)

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

| Sex          | Median (IQR) | P-value | Median (IQR) | P-value | Median (IQR) | P-value | Median (IQR) | P-value |
|--------------|--------------|---------|--------------|---------|--------------|---------|--------------|---------|
| 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) | 0.001   | 10.0 (8.0–12.0) | 0.003   | 5.0 (4.0–6.0) | 0.001   | 19.0 (14.0–24.0) | 0.001   |
| 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)  | <0.001       | 9 (7–10)  | <0.001       | 5 (4–7)  | <0.001       | 16 (13–18) | <0.001   |
| Overweight   | Absent       | 12 (9.3–13) | 0.016       | 11 (9–12)  | 0.244       | 7 (6–8)  | 0.261       | 22 (17–28) | 0.068    |
|              | Present      | 10 (8.5–12) | <0.001      | 10 (9–12)  | 0.010       | 6 (5–8)  | 0.024       | 18 (15–25) | 0.001    |
| 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)   | 0.001       | 10 (7.5–11)| 0.001       | 6 (4.5–7) | 0.001       | 17 (14–20) | 0.005    |
| DPN status   | Absent       | 12 (10.8–14) | <0.001     | 12 (10–13) | <0.001     | 7.5 (6–9) | <0.001     | 24 (19.5–30) | 0.001   |
|              | Present      | 10 (9–12)  | 0.001       | 10 (8–11)  | 0.001       | 6 (5–7)  | 0.001       | 18 (15–23) | 0.001    |
| CTS and DPN  | status       | CTS–DPN−  | 13 (11–14)  | <0.001     | 12 (10–13) | 0.001   | 8 (6–9)    | <0.001     | 24 (20.5–32.3) | <0.001 |
|              | CTS–DPN+  3 | 11 (9–13)  | 0.001       | 10 (8.8–12) | 0.001     | 6 (5–8)  | <0.001     | 20 (16–25) | 0.001    |
|              | CTS+DPN−  3  | 10.5 (8.8–12.3) | 0.001 | 11 (9.5–12.8) | 0.001 | 6 (5.8–7.8) | 0.001 | 19 (14.5–25.3) | 0.001 |
|              | CTS+DPN+  3  | 9 (8–11)  | 0.001       | 9 (7–11)  | 0.001       | 6 (4–7)  | 0.001       | 16 (14–20) | 0.001    |

Data are median (interquartile range [IQR]). CTS, carpal tunnel syndrome; DPN, diabetic polyneuropathy; PPT, Purdue pegboard test scores. 3 CTS–DPN+ group vs CT–DPN− group, Bonferroni-adjusted P value <0.05. 2 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

|                  | CTS (dominant hand) | PPT (dominant hand) | CTS (non-dominant hand) | PPT (non-dominant hand) | CTS (both hands) | PPT (both hands) | CTS (assembly) | PPT (assembly) |
|------------------|----------------------|---------------------|------------------------|------------------------|------------------|------------------|----------------|----------------|
| Grip strength    | 0.482                | 0.001               | 0.530                  | <0.001                 | 0.467            | <0.001           | 0.498          | <0.001         |
| Pinch strength   | 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. 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.

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. Some patients had clinical CTS on one side and subclinical CTS on the other side. 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.

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\textsuperscript{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.

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**DISCLOSURE**

The authors declare no conflict of interest.

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