Evaluation of different physical examination methods for the diagnosis of carpal tunnel syndrome

JINJIN CAO[1-4*], TINGSONG JIA[1,3*], JIE LAO[1-3], AILIN LIU[5] and JING RUI[1-3]

[1]Department of Hand Surgery, Huashan Hospital, Fudan University; [2]NHC Key Laboratory of Hand Reconstruction (Fudan University); [3]Shanghai Key Laboratory of Peripheral Nerve and Microsurgery, Shanghai 200040; [4]Department of Gynecology and Obstetrics, Xijing Hospital, The Fourth Military Medical University, Xi'an, Shaanxi 710032; [5]Department of Medical Ultrasound, Huashan Hospital, Fudan University, Shanghai 200040, P.R. China

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Abstract. In the present study, to evaluate the diagnostic value of different physical examination methods for diagnosing carpal tunnel syndrome (CTS), the scratch collapse test (SCT) and hand elevation test were compared with other traditional tests, such as Tinel's, Phalen's and reverse Phalen's tests, in an aim to improve the current diagnostic standards for CTS. The present study examined 236 (465 hands) patients with CTS and 96 (170 hands) controls who were enrolled in the study from December, 2019 to January, 2021. The participants in both groups were of the same age range, with equal male-to-female ratios. An examiner who was familiar with all maneuvers performed the Tinel's, Phalen's and reverse Phalen's tests, as well as the SCT and the hand elevation test in the two groups. The examiner was blinded to the patient histories and diagnoses. The sensitivities and specificities of all the tests were as follows: Tinel's test, 0.4194 and 0.7706; Phalen's test, 0.5613 and 0.7353; reverse Phalen's test, 0.5527 and 0.7882; SCT, 0.6774 and 0.7176; and hand elevation test, 0.7548 and 0.6059, respectively. The sensitivities of the SCT and hand elevation test were significantly higher than those of the other three tests. The areas under the receiver operating characteristic curve of the SCT and hand elevation test were 0.6975 and 0.6804, respectively, both of which were higher than those of Tinel's (0.5950), Phalen's (0.6483) and reverse Phalen's (0.6705) tests. On the whole, the present study demonstrates that the SCT is objective, reliable and has a high sensitivity. Furthermore, the hand elevation test is easy to perform, reproducible and has a high sensitivity. These newer tests are valuable for the diagnosis of CTS and can improve the current diagnostic standard system.

Correspondence to: Dr Jing Rui, Department of Hand Surgery, Huashan Hospital, Fudan University, 12 Wulumuqizhong Road, Shanghai 200040, P.R. China
E-mail: ruijing@fudan.edu.cn

*Contributed equally

Abbreviations: CTS, carpal tunnel syndrome; SCT, scratch collapse test; ROC, area under the receiver operating characteristic curve; SD, standard deviation; LR^+, positive likelihood ratio; LR^-, negative likelihood ratio; AUC, area under the curve; CI, confidence interval

Key words: carpal tunnel syndrome, hand elevation test, Phalen's test, scratch collapse test, Tinel's test

Introduction

Carpal tunnel syndrome (CTS) is the most common type of nerve compression (1-3), with a reported incidence of ~3.8-5% (4-6). CTS is characterized by the compression of the median nerve within the carpal canal of the wrist, resulting in pain and numbness in the thumb, index, and middle and radial half of the ring fingers, as well as the weakness and subsequent atrophy of the thenar muscles (3). Nighttime wakefulness, pain and insomnia can severely affect the quality of life of patients with CTS.

Since Paget first described the disease in 1854, several studies on CTS have been conducted (7). However, controversies related to the pathogenesis, diagnosis and treatment of CTS remain. Currently, the diagnosis of CTS is mainly based on the clinical symptoms and characteristic physical examination findings. While electrophysiological studies provide an objective measurement of the nerve conduction abnormalities in CTS, it is argued that these studies often have varied sensitivities and specificities, as they are affected by factors such as height, age and finger circumference (8-12). Tinel's and Phalen's tests are the most common methods used for the diagnosis of CTS. Both tests are categorized as sensory evoked tests that use various methods, such as increased carpal tunnel pressure, to induce paresthesia in the area innervated by the median nerve. Although these methods are widely used as they are easy to perform, their sensitivities and specificities are still widely under debate. As per previous literature, the sensitivities and specificities of Tinel's and Phalen's tests are 38-100% and 42-85%, and 54-98% and 55-100%, respectively (13).

In recent years, scholars have reported few novel diagnostic physical examination methods, which include the scratch collapse test (SCT) and hand elevation test. The SCT is considered positive if the patient demonstrates a loss of resistance

with the affected side after 'scratching', which is more objective than the other provocative tests that rely on the patient's subjective feeling. The hand elevation test simply requires elevation of the patient's hands above the head. These newer tests require less of the examiner's skill or patient's compliance than traditional tests.

The present study evaluated different physical examination tests, including both the new diagnostic tests, such as the SCT and hand elevation test, as well as traditional tests, such as Tinel's, Phalen's and reverse Phalen's tests for the diagnosis of patients with CTS. The sensitivities and specificities of these tests were calculated and compared, and a receiver operating characteristic (ROC) curve was used to determine which test has the optimal diagnostic value.

Patients and methods

Study population. The present study analyzed 243 patients with CTS who were enrolled in the study (from Huashan Hospital, Fudan University, Shanghai, China) from December, 2019 to January, 2021. Patients aged 20 to 80 years who expressed willingness to participate in the study and who were able to perform the entire series of examinations were included in the study. Patients who refused to take part in the examination, pregnant women, patients with post-operative CTS, those with cerebrovascular or peripheral vascular disease, a history of severe trauma to the upper limbs and cervical spondylosis were excluded. In addition, 7 patients were excluded as they had concurrent peripheral nervous system diseases. Finally, 236 patients (465 hands) were enrolled. Furthermore, controls with the same age range and male-to-female ratio were selected as the patents with CTS [age range, 20-80 years; male-to-female ratio, 1:7.94; 96 controls (170 hands)] were enrolled. The participants were then divided into the experimental (CTS group) and control (non-CTS group) groups. The CTS-6 scale (14) (Table I) as the gold standard for diagnosis. A clinical diagnosis of CTS was made if the patient had a score of ≥12 on the CTS-6 scale. This instrument is used to estimate the probability of CTS based on the presence or absence of six items recorded as part of the clinical history or noted on physical examination that were weighted for their diagnostic importance. The point values for all positive findings were then added together; total scores ≥12 points were defined as positive for CTS.

The Human Research Committee of our hospital approved the study protocol (KY2022-641). Written informed consent was obtained from each of the participants.

Study protocol. After the assessment of clinical symptoms with a questionnaire, physical examination and diagnostic tests were performed by a single evaluator who underwent a 2-year hand surgery training and was unaware of the patient histories and diagnoses. The tests were performed in the following order: Tinel's, Phalen's, reverse Phalen's, SCT and hand elevation test. Tinel's test was performed by tapping the median nerve at the wrist, repeated four to six times. The presence or absence of radiating pain or paresthesia in the median nerve distribution was considered positive. Phalen's test was performed by having each participant position the wrist of the affected hand in complete palmar flexion with the elbow flexed and the forearm pronated. The test was considered positive if symptoms developed after 1 min (15). The reverse Phalen's test was performed while the wrist was extended instead of flexed. The SCT was performed by lightly scratching the patient's skin over the area of nerve compression while the patient resisted external rotation of the bilateral shoulders. This test was considered positive if there was loss of resistance on the affected side after 'scratching' (16). The hand elevation test was performed by elevating and maintaining both hands of the patients above the head. The test was considered positive if numbness and tingling in the thumb, index, and middle and the radial half of the ring fingers developed within 2 min (17).

Statistical and power analyses. The sensitivities and specificities of all tests were compared using the Chi-squared test. The baseline data of the participants are presented as the mean ± standard deviation (SD), or as the number and percentage. The ROC curve was plotted for all the physical examination results. $P<0.05$ was considered to indicate a statistically significant difference, and the power was set at 80%.

Results

The baseline characteristics of the study population are presented in Table II. The sensitivities, specificities, positive and negative predictive values, and positive and negative likelihood ratios of the Tinel's, Phalen's, reverse Phalen's, SCT and hand elevation tests are presented in Table III. It was observed that the sensitivities and specificities of the SCT and hand elevation test were higher and lower than those of the other tests, respectively. The positive likelihood ratio (LR^+) is the probability that an individual with the disease tested positive divided by the probability that an individual without the disease tested positive (i.e., LR^+=true positive/false positive). The negative likelihood ratio (LR^-) is the probability that an individual with the disease tested negative divided by the probability that an individual without the disease tested negative (i.e., LR^-=false negative/true negative). These tests in order of LR^+ were the reverse Phalen's test > SCT > Phalen's test > hand elevation test > Tinel's test, thus revealing a high diagnostic accuracy. The tests in order of LR, were the hand elevation test < SCT < reverse Phalen's test < Phalen's test < Tinel's test, which indicated that the hand elevation test and SCT had a high-level ability to correctly exclude individuals without CTS.

To compare the sensitivity and specificity of each test, the Chi-squared test was used between each pair of tests (Tables IV and V). The results revealed that all test pairs had significantly different sensitivities [$P<0.0001$ for all, apart from the reverse Phalen's vs. Phalen's tests ($P=0.79$); Table IV]. Based on the results depicted in Table III, the sensitivities of the SCT and hand elevation test were significantly higher than those of other traditional tests. Moreover, the specificities between the hand elevation test and the other tests were all significantly different ($P=0.001$ for the hand elevation test vs. Tinel's test, $P=0.0111$ for the hand elevation test vs. Phalen's test, $P=0.0002$ for the hand elevation test vs. reverse-Phalen's test and $P=0.0294$ for the hand elevation test vs. SCT); however, the specificities between the Tinel's test, Phalen's test, reverse Phalen's test and SCT did not differ significantly ($P=0.45$ for Tinel's test vs. Phalen's test, $P=0.69$ for Tinel's test vs. reverse-Phalen's

Table I. CTS-6 scoring system.

Finding		Points
Symptoms and history	Numbness in median nerve distribution: Sensory symptoms are mostly in the thumb, index, middle and/or ring fingers	3.5
	Nocturnal symptoms: Symptoms are prominent when patient sleeps; numbness wakes patient from sleep	4
Physical examination	Thenar atrophy or weakness: The bulk of the thenar area is reduced or manual motor testing shows strength of grade 4 or less	5
	Positive Phalen test: Flexion of the wrist reproduces or worsens symptoms of numbness in the median nerve territory	5
	Loss of 2-point discrimination: A failure to discriminate two points held 5 mm or less apart from one another, in the median nerve innervated digits, is a positive test suggestive of CTS.	4.5
	Positive Tinel sign: Light tapping over the median nerve at the level of the carpal tunnel causing radiating paresthesia into the median nerve innervated digits (not proximally) is a positive test	4

CTS, carpel tunnel syndrome.

Table II. Baseline characteristics of the patients with CTS and the control subjects who participated in the present study.

Characteristic	Patients with CTS	Non-CTS controls
Number of hands	465	170
Age (years): mean ± SD	51.92±10.90	48.91±12.82
Males, n (%)	52 (11.23)	19 (11.18)
Females, n (%)	413 (89.20)	151 (88.82)
Right hand, n (%)	233 (50.32)	87 (51.18)
Left hand, n (%)	232 (49.68)	83 (48.82)
Dominant side number, n (%)	234 (50.54)	81 (47.65)
Non-dominant side number, n (%)	231 (49.46)	89 (52.35)

CTS, carpel tunnel syndrome.

Table III. The sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood rate and negative likelihood rate of the physical tests.

Test	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	LR^+	LR^-
Tinel's test	41.94	77.06	83.33	32.67	1.83	0.75
Phalen's test	56.13	73.53	85.29	37.99	2.12	0.60
Reverse Phalen's test	55.27	78.82	87.71	39.18	2.61	0.57
SCT	67.74	71.76	86.78	44.85	2.40	0.45
Hand elevation test	75.48	60.59	83.97	47.47	1.92	0.40

LR^+, positive likelihood ratio [probability that an individual with the disease tested positive divided by the probability that an individual without the disease tested positive (i.e., LR^+=true positive/false positive)]; LR^-, negative likelihood ratio [probability that an individual with the disease tested negative divided by the probability that an individual without the disease tested negative (i.e., LR^-=false negative/true negative)]; SCT, scratch collapse test.

test, P=0.25 for Phalen's test vs. reverse-Phalen's test, P=0.26 for SCT vs. Tinel's test, P=0.72 for SCT vs. Phalen's test and P=0.13 for SCT vs. reverse-Phalen's test) (Table V). Based on the results depicted in Table III, the specificity of the SCT was

Table IV. P-values of the Chi-squared test and results of the sensitivity of the physical tests.

Test	Tinel's test	Phalen's test	Reverse Phalen's test	SCT	Hand elevation test
Tinel's test	/	<0.0001[a]	<0.0001[a]	<0.0001[a]	<0.0001[a]
Phalen's test	/	/	0.79	0.0003[a]	<0.0001[a]
Reverse Phalen's test	/	/	/	<0.0001[a]	<0.0001[a]
SCT	/	/	/	/	0.0088[a]
Hand elevation test	/	/	/	/	/

SCT, scratch collapse test; [a]P<0.05, indicates a statistically significant difference.

Table V. P-values of the Chi-squared test and results of the specificity of the physical tests.

Test	Tinel's test	Phalen's test	Reverse Phalen's test	SCT	Hand elevation test
Tinel's test	/	0.45	0.69	0.26	0.001[a]
Phalen's test	/	/	0.25	0.72	0.0111[a]
Reverse-Phalen's test	/	/	/	0.13	0.0002[a]
SCT	/	/	/	/	0.0294[a]
Hand elevation test	/	/	/	/	/

SCT, scratch collapse test; [a]P<0.05, indicates a statistically significant difference.

Table VI. The AUC of the ROC curve of the physical tests.

Test	AUC	95% CI	
Tinel's test	0.5950	0.5468	0.6432
Phalen's test	0.6483	0.6011	0.6955
Reverse Phalen's test	0.6705	0.6248	0.7161
SCT	0.6975	0.6513	0.7437
Hand elevation test	0.6804	0.6317	0.7290

AUC, area under curve; CI, confidence interval; SCT, scratch collapse test; ROC, receiver operating characteristic.

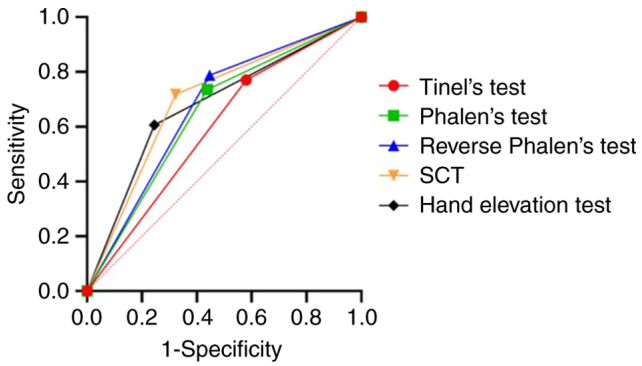

Figure 1. Receiver operating characteristic curve of the physical tests: Tinel's test, Phalen's test, reverse Phalen's test, SCT, and the hand elevation test. SCT, scratch collapse test.

lower than that of the other traditional tests, although no significant difference was observed. Furthermore, the specificity of the hand elevation test was significantly lower than that of the traditional tests.

The area under the curve (AUC) of the ROC and 95% confidence interval (CI) of the dichotomous physical tests are presented in Fig. 1 and Table VI, respectively. The order of the AUC was SCT > hand elevation test > reverse Phalen's test > Phalen's test > Tinel's test.

Discussion

In the present study, 236 patients with CTS (465 hands) and 96 controls (170 hands) were analyzed. Between these groups, the number of right and left hands, as well as the dominant and non-dominant sides were comparable. Therefore, the dominant side was not a confounder in the present study and did not need to be adjusted or set as a subgroup for analysis.

An ideal clinical diagnostic test should be easily performed, reliable, reproducible and have high sensitivity and specificity. Herein, five dichotomous tests used to diagnose CTS were conducted, and their sensitivities and specificities were compared. It was observed that the sensitivities of the SCT and hand elevation test were significantly higher than those of the traditional tests, and the specificity of the hand elevation test was significantly lower than that of the traditional tests. From the LR^+ result, the SCT exhibited the highest diagnostic accuracy, and from the LR^- result, the hand elevation test and SCT had high level ability to correctly exclude individuals without CTS. The ROC AUC of the SCT and hand elevation test were larger than those of the other tests, which shows that these tests are valuable for the diagnosis of CTS.

SCT was considered positive if the patient demonstrated a loss of resistance on the affected side after 'scratching',

which is a more objective measure than the results of the other four provocative tests (Tinel's, Phalen's, reverse Phalen's and hand elevation tests) that rely on the patient's subjective feeling. Scratching to stimulate the skin around the area of nerve damage results in a short period of inhibition of voluntary muscle activity, termed the 'silent period'. This 'silent period' can be tested by resisting the external rotation of the shoulder (usually a weak movement), and if the movement is suppressed, the examiner can break the external rotation ('arm collapse') (16,18). This is probably mediated mainly by the small-diameter slow-conducting A-δ fibers and could be an inhibitory spinal reflex, possibly playing a protective role (19,20). Therefore, the SCT is applied not only to diagnose CTS, but also other nerve compression syndromes; it can be used to indicate the location of nerve entrapment.

In previous studies on the application of SCT for the diagnosis pf CTS, Cheng *et al* (16) reported a sensitivity and specificity of 0.69 and 0.99 in 228 cases, Gillenwater *et al* (21) reported 0.77 and 0.99 in 24 cases, Huynh *et al* (22) performed a meta-analysis of Blok *et al* (23), Makanji *et al* (24) and Simon (25) *et al* who reported a sensitivity and specificity of 0.32 and 1.00 in 37 cases, 0.34 and 0.61 in 88 cases, and 0.28 and 0.38 in 40 cases, respectively . The sensitivity and specificity reported by Montgomery *et al* (26) were 0.07-0.15 and 0.78-0.87 in 92 cases, respectively. Simon *et al* (25) reported a sensitivity and specificity of 0.24 and 0.6 in a study comprising 40 cases. The sensitivities and specificities of the aforementioned studies were not consistent with those of the present study, which revealed higher values. While the SCT provides an objective assessment, performing it is more complex than the other tests, and the result can be influenced by different operators (27). In the present study, all the tests were conducted by the same evaluator who underwent a 2-year training for hand surgery and was blinded to the patient histories and diagnoses. On the other hand, the specificity observed in previous studies may be overestimated.

Performing the hand elevation test is simple compared to the SCT. Therefore, it is less dependent on the skills of the examiners or compliance of the patients. Ischemia of the median nerve has been recognized as one of the primary causes of spontaneous compression neuropathy. Thickening of the flexor synovialis leads to ischemia, which worsens median nerve edema. The hand elevation test further reduces the blood supply to the already compromised median nerve by transient ischemia, and thus, reproduces the symptoms of CTS. From the comparison of the sensitivity and specificity (0.7548 and 0.6059) of the hand elevation test with that was observed in previous studies [Ahn (17), 0.755 and 0.985 in 400 cases; Ma and Kim (28), 0.867 and 0.889 in 90 cases; and Amirfeyz *et al* (29), 0.88 and 0.98 in 60 cases, respectively], it was found that the sensitivity was highly consistent with that of the present study, although the specificity was not. This indicates that the hand elevation test is reproducible as a primary screening test. However, the small sample size may affect the specificity.

Considering that the sensitivities of the SCT and hand elevation test were significantly higher than those of the other three tests, whereas the specificities were not, these two examinations could be used as a primary screening test. Tinel's test, reverse Phalen's test could be conducted subsequently for exclusion.

The present study has some limitations which should be mentioned: As there is no universally acknowledged diagnostic reference standard for CTS, the present study used CTS-6 as gold standard, which used the symptoms, history and physical examinations to comprehensively evaluate CTS. As the CTS-6 contains the Phalen's and Tinel's tests, the sensitivities and specificities of these two tests would become higher due to the inner confounder. Regardless, the sensitivity and specificity of SCT and the sensitivity of the hand elevation test were still high, whereas the specificity of hand elevation test was still acceptable.

In conclusion, SCT is an objective assessment of CTS that is reliable and has a high sensitivity. Furthermore, the hand elevation test is easy to perform, is reproducible, and has a high sensitivity. Both tests may be valuable for the diagnosis of CTS.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

JC collected and analyzed the patient data. TJ performed the physical tests. JL and JR designed the study and JR was a major contributor to the writing of the manuscript. AL assisted in the analysis of the results. JC and JR confirm the authenticity of all the raw data. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

All procedures performed involving human participants were in accordance with the ethical standards of The Human Research Committee of Huashan hospital Fudan University (KY2022-641) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Written informed consent was obtained from all individual participants included in the study.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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