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USE OF NERVE CONDUCTION STUDIES AND THE PRESSURE-SPECIFIED SENSORY DEVICE IN THE DIAGNOSIS OF CARPAL TUNNEL SYNDROME

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Sixty-nine patients with signs of carpal tunnel syndrome (CTS) underwent nerve conduction studies (NCS) and testing with the Pressure-Specified Sensory Device (PSSD). A total of 102 tests were performed (28 bilateral). Twenty patients underwent a carpal tunnel release and were retested after 4 to 6 months. The Symptom Severity Score (SSS) was calculated before and after surgery. A control group of 20 hands in 10 asymptomatic volunteers underwent identical testing. The NCS sensitivity was 87% with a specificity of 90% whereas the PSSD sensitivity was 81% with a specificity of 65%. The combined sensitivity of the two tests was 93%. In the operative group the SSS improved from a mean of 3.34 pre-operatively to 1.95 postoperatively. The NCS improved in 19/21 hands whereas the PSSD improved in 16/19 hands. The non-invasive SSS and PSSD can increase the diagnostic yield in CTS, especially when the NCS are normal.

Keywords: carpal tunnel syndrome, testing

The diagnosis of carpal tunnel syndrome (CTS) is usually made on clinical criteria that include numbness and paraesthesia in a median nerve distribution along with provocative testing such as Phalen's test and the Durkan compression test. While repeatable signs and symptoms should dictate subsequent treatment, objective standardised testing can yield important information, especially when there is some form of secondary gain. Nerve conduction studies (NCS) have become the gold standard in objective testing of CTS, but critics cite poor sensitivity and specificity. The Pressure-Specified Sensory Device (PSSD: Sensory Management Services, LLC. Baltimore, MD) has been proposed as a non-invasive painless test that compares favourably to NCS (Weber et al., 2000). The PSSD quantifies the cutaneous threshold for moving and static touch. It is subjective and relies on cortical interpretation. NCS are more objective and require no patient cooperation, but they are dependent upon factors affecting conductivity such as limb temperature, skin resistance and digit circumference. The pressure threshold in PSSD testing has been likened to the distal sensory latency and the distance between two points is thought to reflect the number of viable axons, which correlates with the sensory nerve amplitude (Aszmann and Dellon, 1998). The purpose of this study was to compare the sensitivity and specificity of NCS and the PSSD in the diagnosis of CTS and to evaluate the utility of clinical tests individually and in combination for diagnosing CTS.

MATERIALS AND METHODS

A prospective study was performed between 2004 and 2006 on 69 consecutive patients with symptoms of CTS. Due to bilateral involvement, a total of 102 hands were tested. In addition, a control group consisting of 10 asymptomatic volunteers (20 hands) with no evidence of pre-existing compressive neuropathy underwent identical testing on both hands.

Age, occupation, duration of symptoms, presence of numbness or paraesthesia, worker's compensation status and previous treatments were recorded for every patient. Associated medical illnesses including diabetes, hypo- or hyperthyroidism or other potential cause of underlying peripheral neuropathy were documented. The patient demographic data are detailed in Table 1.

For this study, the diagnosis of CTS was made on clinical grounds, based on at least two of the following previously reported criteria (Dhong et al., 2000; Padua et al., 1997b):

1. *Subjective criteria*: history of nocturnal or activity-related paraesthesia and/or numbness in the median nerve distribution.
2. *Objective criteria*: positive Phalen's test and/or positive Durkan's compression test, weakness ± atrophy of the abductor pollicis brevis, abnormal two-point discrimination in the median nerve distribution.

Electrodiagnostic studies were performed on all hands. Twelve of the initial studies were performed by

Table 1—Formulae

Sensitivity % = true positive/(true positive + false negative) × 100
Specificity % = true negative/(true negative + false positive) × 100
Predictive value positive (%) = true positive/(true positive + false positive) × 100
Predictive value negative (%) = true negative/(true negative + false negative) × 100

	Carpal tunnel syndrome	No carpal tunnel syndrome
Test positive	True positive	False positive
Test negative	False negative	True negative

outside physicians. Electrodiagnostic testing was performed by the author in 57/69 patients according to the American Association of Electrodiagnostic Medicine guidelines (Stevens, 1997) with the skin temperature maintained above 30 °C:

1. comparative radial and median sensory latencies to the thumb (10 cm),
2. median sensory conduction to the index, middle and radial ring finger (14 cm),
3. ulnar sensory conduction to the ulnar ring finger and small finger (14 cm),
4. median and ulnar midpalmar orthodromic latency (8 cm),
5. median distal motor latencies (DML): wrist to thenar eminence (8 cm) and elbow to wrist,
6. ulnar motor latencies: wrist to thenar eminence (8 cm), forearm to wrist and across elbow (12 cm),
7. second lumbrical to second dorsal interosseous (L2–P2) latency differences (8 cm) (Preston and Logigian, 1992).

In patients with normal absolute median sensory and motor latencies, the Carpal Sensory Index (CSI) was calculated (Robinson et al., 1998). The CSI consists of the sum of the radial-thumb comparative latency difference, the median-ring to ulnar-ring comparative latency difference and the median to ulnar midpalmar orthodromic latency difference. An abnormal CSI (i.e. > 1.0 ms) is indicative of a minimal CTS. Mild CTS was graded as a prolonged median sensory latency (normal < 3.5 ms), moderate CTS was graded as prolonged sensory latencies and a prolonged distal motor latency (DML: normal < 4.2 ms) but with normal amplitudes (normal > 4.0 MV), severe CTS was graded as prolonged to absent sensory latencies and a prolonged DML with a drop in amplitude (i.e. < 4.0 MV).

Quantitative sensory testing using the Pressure-Specific Sensitised Device was performed by the author on each patient. It comprised static one-point (1PS) and static two-point (2PS) testings of the distal pad of the index (median nerve/C6 dermatome). The index finger was tested five times. The sensory threshold values were measured in g/mm^2 and averaged by the PSSD software. Normal pressure threshold values are a 1PS = 0.5 g/mm^2 (range 0.1–0.9) for adults younger than 45 years and 0.7 gm/mm^2 (range 0.2–1.5) for adults 45 years of age or older and a 2PS = 2.6 gm/mm^2 (range 2.5–4.0) for adults younger than 45 years and a 2PS = 2.9 gm/mm^2 (range 2.5–3.1) for adults 45 years of age or older (Aszmann and Dellon, 1998). Patients were classified as normal, grade 1 (abnormal 2PS with increased pressure ± distance but normal 1 PS) or grade 2 (abnormal 1 PS/2PS).

In 55 patients both tests were performed on the same day by the author. The PSSD testing was performed within an average of 30 days (range 5–60 days) from the NCS in the remaining patients.

An open carpal tunnel release (CTR) was performed in 21 hands (20 patients). The patients who underwent surgery were selected based on their lack of response to non-operative treatment. In these patients the PSSD and NCS were repeated at an average of 4 months (range 4–6 months) by the author. The Symptom Severity Scale Carpal Tunnel Questionnaire (Levine et al., 1993) was administered before and after the surgery along with a history and repeat physical examination. The distal motor and sensory latencies were compared before and after surgery. PSSD testing was repeated at the same visit. The surgical patients who did not consent to or were unavailable for pre- and postoperative testing were not included in this study.

Statistical analysis

A comparison was made on the pattern of concordances and discordances among test results using the McNemar test. Student's *T*-test was used to compare the Symptom Severity Scale Carpal Tunnel scores before and after CTR in the 20 patients (21 hands). Table 1 lists the formulae for calculating sensitivity, specificity and predictive value (Szabo et al., 1999).

RESULTS

The demographics for both groups are listed in Table 2. The average age for the study group was 52 years (35–77) and duration of symptoms was 32 months (4 months to 10 years). Regarding the clinical diagnosis, the symptoms of paraesthesia or numbness in the median nerve distribution were present in all 102 hands of the 69 patients. Tinel's sign was positive in 25/102 hands. Two-point discrimination was abnormal in 22/102 hands (i.e. > 5 mm in the median nerve distribution). Only three patients had any thenar weakness (4+ power in one hand, 0+ power in two hands). There was a positive Phalen's test and/or Durkan's test in 77/102 hands with equivocal tests in six hands (five patients) due to subjective numbness in the median nerve

Table 2—Demographic data

Characteristics	*Clinical patients*	*Normal control subjects*
Age, yr: Mean ± SD	52 ± 10	37 ± 13
No. of men	13/69	1/10
Occupation		
Manual work	10	0
Clerical/data entry	20	5
Managerial	14	0
White-collar professional	14	5
None	11	0
Diabetes ± thyroid dysfunction	15 (22 hands)	0
Totals	69	10

SD = standard deviation.

Table 3—Patients with symptoms of CTS

Test	*Sensitivity (symptoms of CTS) (%)*	*Specificity (control group) (%)*	*Positive predictive value (%)*	*Negative predictive value (%)*
Tinel's	25	100	100	21
Phalen's/ Durkan's	74	100	100	43
Two-point discrimination	22	100	100	20
PSSD	81	65	91	29
NCS	87	90	97	59

distribution. The NCS was positive in 90/102 hands. The PSSD was positive in 70/102 hands (Table 3). The electrophysiological data for the clinical group are presented in Table 4.

The NCS sensitivity was 87% (95% confidence interval [CI]: 79–93%) whereas the PSSD sensitivity was 81% (95% CI: 73–88%). These CIs overlap by about 9%. The difference in sensitivity between methods is 5.9% (95% CI from −2.9% to 14.7%). The NCS was slightly better than PSSD but this difference was not statistically different. The combined sensitivity of the two tests however was 93%. The NCS specificity based on the testing of the asymptomatic control group was 90% whereas the PSSD specificity was 65%. 19/102 hands had a negative Tinel's and a negative Phalen's test/Durkan's compression test (six were bilateral). In those patients with negative physical signs, either the PSSD and/or the NCS were positive in every instance.

Table 5 summarises the electrophysiologic and PSSD data and symptom severity scores (SSS) in the surgical group. The patients are arranged from minimal to severe CTS based on the NCS findings. Note that even patients with severe CTS showed improvement in the DML and/or the sensory nerve conduction. The SSS was unavailable in one patient who nevertheless experienced improvement in the CTS symptoms as well as both the

Table 4—Neurophysiologic findings

CTS grade	*No. of hands tested*	*Normal PSSD*	*Abnormal PSSD*	*False negative studies*
I. Negative	12	5 (1 bilateral)	7 (3 bilateral)	PSSD = 5 NCS = 12
II. Minimal: normal absolute latencies, increased CSI	8	2	6 (1 bilateral)	PSSD = 2
III. Mild: prolonged SNAP, normal DML	28	8 (1 bilateral)	20 (1 bilateral)	PSSD = 8
IV. Moderate: prolonged SNAP, prolonged DML but normal amplitudes	26	2	24 (3 bilateral)	PSSD = 2
V. Severe: prolonged to absent SNAP ±, prolonged DML with low amplitude	28	2	26(5 bilateral)	PSSD = 2
Totals	102	19	83	31

Table 5—Patients with negative physical findings

Group	*Improved PSSD*	*Improved NCS*	*Improved SSS*
Minimal = 1	1/1	1/1	1.73
Mild = 6	4/4 (PSSD normal in 2)	3/6	6/6 improved avg 1.45 (range 0.09–2.09)
Moderate = 6	6/6	6/6	5/5 improved[1] avg 1.83 (range 1.09–2.71)
Severe = 8	3/8	8/8	7/8[2] avg 1.36 (range 0.28–2.27)

PSSD = pressure-specified sensory device testing, NCS = nerve conduction studies, SSS = symptom severity score.
[1]SSS available for 5/6 patients.
[2]Both NCS and PSSD improved.

PSSD and the NCS parameters. The SSS improved in the 20/21 hands of the remaining patients, from an average of 3.34 pre-operatively (range 2.9–5.72) to 1.95 postoperatively (range 1.0–3.57). This did not reach statistical significance ($P > 0.05$). Patient 21 (WR, left hand) also had resolution of his CTS symptoms but his SSS remained high due to functional impairment from trapeziometacarpal osteoarthritis. The median NCS improved in 19/21 hands whereas the PSSD improved in 18/21 hands.

DISCUSSION

Szabo et al. (1999) tested the validity of a combination of tests for the diagnosis of CTS. They defined CTS as a clinical picture consistent with CTS and amelioration of symptoms following surgical decompression. Their findings supported the use of clinical history and physical examination as the primary method of diag-

nosing CTS. They did note however that a combination of tests provides predictors for determining the probability of correctly diagnosing CTS. In other words, ancillary diagnostic testing does have some value.

In the present study, both the Tinel's sign and two-point discrimination were quite specific but generally not helpful in making the diagnosis of CTS, with sensitivities of 23% and 22%, respectively. Two-point discrimination correlates poorly with the median nerve conduction parameters (Marlowe et al., 1999). Thenar weakness and atrophy contributed to the diagnosis of CTS in only three patients even though 28 patients were graded as severe by electrophysiologic parameters. Recent studies have also substantiated that these physical signs are often lacking since patients with CTS usually present early (Agabegi et al., 2007; Mallette et al., 2007).

Provocative manoeuvres such as the Phalen's and Durkan's compression tests have reported degrees of sensitivity and specificity ranging from 23% to 100% (Dhong et al., 2000). In the current study, a positive Phalen's test and/or Durkan's compression test were reliable indicators of CTS but they were helpful in making the diagnosis in only 74% of the symptomatic patients.

Electrodiagnostic studies and CTS

Approximately 7% to 10% of patients with CTS symptoms have normal electrodiagnostic findings (Dhong et al., 2000; Stevens, 1997), which is in agreement with the present study where the sensitivity of NCS was 88% and specificity 90%. Twelve per cent had normal studies. The addition of a painless diagnostic test such as the PSSD was especially useful in those patients with symptoms of CTS but normal electrodiagnostic studies since seven of the 12 patients with a negative NCS had abnormal PSSD findings, which increased the diagnostic yield of CTS.

Electrodiagnostic studies versus PSSD

Electrodiagnostic studies were more sensitive than the PSSD testing in the current study but the differences were not statistically different. Weber et al. (2000) performed a prospective study comparing NCS and PSSD in 54 hands (42 patients) and also tested 37 patients who did not have CTS, including 26 control subjects. They retested nine patients at 6 months after CTR and found that NCS had a sensitivity of 80% and a specificity of 77%, whereas the PSSD had a sensitivity of 91% and a specificity of 82%. In the present study, the PSSD had a sensitivity of 81% whereas the specificity was only 65%. The electrodiagnostic tests in Weber's series included median and ulnar compound motor action potentials, as well as median and ulnar sensory action potentials and transpalmar studies. The electrodiagnostic testing in the present study was much more rigorous since it included differential latency testing as well as the use of the CSI, which have been shown to improve the diagnostic classification over the use of the single test (Padua et al., 1999; Robinson et al., 1998). An abnormal CSI established the diagnosis in eight hands in the current study.

Symptom severity scale after CTR

A validated carpal tunnel questionnaire is another non-invasive method that can aid in the diagnosis of CTS, especially when it is used as an outcome tool post-operatively. There is a significant correlation between the Symptom Severity Scale and the NCS data (Dhong et al., 2000). Mondelli et al. (2002) demonstrated that Q1 the SSS was responsive to changes in clinical status for 6 months following a CTR. Although the improvement in the SSS did not reach statistical significance, there was a clinically important change. Ozyurekoglu et al. (2006) showed that the decrease of 1.04 in the SSS was the minimally important clinical difference for CTS. In the present study, all of the patients who underwent a CTR had clinical improvement in their symptoms, with 17/21 hands showing a decrease of the SSS of 1.04 or greater. The SSS did not improve as much in the remaining four due to coexisting trapeziometacarpal disease.

Electrodiagnostic studies following CTR

It appears intuitive that if the patient showed a clinical improvement after CTR then there was a high likelihood that CTS was present, although a placebo effect cannot be completely ruled out. One would, however, expect an improvement in the NCS and/or PSSD if this was a true finding. The postoperative median NCS improved in 19/21 cases. This was similar to the overall sensitivity in the clinical group, which confirms the reliability of electrodiagnostic studies in CTS. Nolan et al. (1992) confirmed that a marked improvement can be observed in severe cases. Although the nerve conduction values did not return to normal in all patients, residual conduction abnormalities following a CTR have been well documented in the literature. Surgical decompression can however provide improvement of clinical symptoms and electrophysiologic finding even in cases with longstanding nerve impairment that have an absence of the sensory response but complete nerve recovery is likely only if surgery is performed at a very early stage of compression (Aulisa et al., 1998). Q2

The postoperative PSSD testing was normal in two patients and improved in 16/19 hands with abnormal pre-operative PSSD, which is more in keeping with Weber's pre-operative results.

One criticism of the present study is the short postoperative follow-up period. The patients were retested at 4 to 6 months since many studies have

shown this to be sufficient to demonstrate both clinical and electrophysiological improvement. Several studies have confirmed that grip strength and SSS plateau by 3 to 6 months (Aulisa et al., 1998; Burke et al., 2006; Gellman et al., 1989; Guyette and Wilgis, 2004; Naidu et al., 2003; Padua et al., 1997a). Another limitation of this study is the small size of the control group and the younger mean age. Although it might be expected that younger, asymptomatic patients would have normal studies, which would lead to a falsely high test specificity, this was not the case. Since all of the PSSD testing and the majority of the NCS were performed by the same examiner, methodological testing errors might introduce bias. The clinical improvement in symptoms of the patients who underwent CTR as well as the subsequent improvement in the NCS and PSSD however serve as control and support the findings of this study.

In summary, the diagnosis of CTS starts with a thorough history and complete physical exam. Electrodiagnostic studies are not mandatory but may be helpful in patients with negative physical findings and secondary gain. The addition of a validated test questionnaire such as the SSS and a non-invasive painless test such as the PSSD can increase the diagnostic yield in CTS, especially when the electrodiagnostic studies are normal.

Q3 UNCITED REFERENCE

Rempel et al. (1998).

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