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Early Diagnosis of Carpal Tunnel Syndrome: Comparison of Digit 1 with Wrist and Distoproximal Ratio

■ Our objective in this study was to compare the sensitivity and specificity of the median sensory nerve conduction velocity (SNCV) from digit 1 to wrist with those of the distoproximal (D/P) ratio of the median SNCV from palm to digit 3/palm to wrist in the diagnosis of mild carpal tunnel syndrome (CTS) by using a receiver operating characteristic (ROC) curve. To achieve this objective, we studied prospectively (January 1997–October 1998) 370 patients referred for CTS. One hundred forty-two patients (38.4%) with moderate to severe CTS and 15 patients (4.1%) with multiple ($\geq$3) compressive neuropathies in upper limbs with subclinical peripheral neuropathy were excluded. The remaining 213 patients (302 hands with mild CTS; 167 women; mean age, 50 y $\pm$12 y) and 38 controls (71 hands; 25 women; mean age, 47 y $\pm$13 y) had median and ulnar nerve conduction studies. ROC curves were constructed for median SNCV digit 1 to wrist and median SNCV D/P ratio from the patients' and controls' data. The median SNCV at $\leq$45.9 m/s, corresponding to an optimal cutoff point on ROC curve, discriminated 89.5% of mild CTS from controls with specificity of 98.6%. The median D/P ratio at $\geq$1.12, corresponding to an optimal cutoff point on ROC curve, discriminated 67.2% of mild CTS from controls with specificity of 97.2%. Of the 10.3% (31/302) of hands in which digit 1 to wrist was within normal limits at the selected optimal cutoff value ($\leq$45.9 ms), 7% (21/302) had an abnormal D/P ratio ($\geq$1.12), and 3.3% (10/302) had a normal electrophysiologic examination. The likelihood ratio (true-positive ratio to false-positive ratio, assessing the discriminative power of a test) of the median SNCV digit 1 to wrist, at an optimal point on ROC curve (63.9), was higher than that of the median SNCV D/P ratio (23.9, χ^2 = 36.9, P < .001). These findings suggest that the median SNCV digit 1 to wrist is more sensitive than the median SNCV D/P ratio in the diagnosis of mild CTS. ■

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Compression of the median nerve at the wrist (carpal tunnel) is the most common entrapment neuropathy. Several electrophysiologic procedures are available to confirm the clinical impression of carpal tunnel syndrome (CTS). The Quality Assurance Committee of the American Association of Electrodiagnostic Medicine (1993) critically reviewed the literature, reported sensitivities of electrodiagnostic studies ranging from 49% to 84% and specificities of ≥95%, and proposed guidelines to improve sensitivities and specificity for future research.

With increased awareness of CTS, patients are referred earlier in the course of disease, and up to 40% of patients with typical CTS symptoms may lack electrodiagnostic abnormalities when using standard diagnostic criteria (Buchthal and Rosenfalck, 1971; Kimura and Ayyar, 1985; Stevens, 1997; Cioni et al, 1989; Pease et al, 1989; Charles et al, 1990; MacDonell et al, 1990). When diagnosing mild CTS (Stevens, 1997), it is important to exclude other conditions that may mimic CTS in order to avoid costly diagnostic procedures such as magnetic resonance imaging (Spinner et al, 1989) and to establish the most suitable treatment. Recent studies (Kothari et al, 1995; Trojaborg et al, 1996) have shown highest sensitivity (93%–94%) for median sensory nerve conduction from digit 1 to wrist for detection of early CTS, whereas other investigators (Padua et al, 1996) have shown highest sensitivity with the use of the distoproximal (D/P) ratio (palm to digit 3/palm to wrist) of median sensory nerve conduction velocity (SNCV). Our aim in this study was to compare the sensitivity and specificity of these two electrodiagnostic procedures (digit 1 to wrist vs D/P ratio) in the detection of early CTS by using receiver operating characteristic (ROC) curves. ROC curves are an ideal method for tests with a continuous scale of values. They provide optimal diagnostic efficacy of a test by affording equal status to both false-negative (FN) and false-positive (FP) test outcomes—unlike the traditional method (mean ± 2 SD), in which special status is given to FP test results, usually P(FP) = .05 or .001, to maximize P, true-positive (McNeil et al, 1975; Campbell and Machin, 1993; Eisen et al, 1993; Rivner, 1994; Schulzer, 1994; Gunnarsson et al, 1997).

METHODS

Patients

We studied prospectively 370 patients referred consecutively to our laboratory from January 1997 to October 1998 with signs and symptoms of sensorimotor CTS (Kimura, 1993). The clinical inclusion criteria for this study were the characteristic CTS symptoms of pain, sensory discomfort, or numbness in the hand; nocturnal awakening because of hand pain; and clumsiness and loss of dexterity of the affected hand—as well as the signs of motor deficit and sensory deficit in the median nerve distribution in keeping with a lesion at the wrist; positive Tinel's sign; and Phalen's sign. All the patients qualifying for this study had ≥2 of these characteristic symptoms and ≥1 of these signs. All patients had detailed electrophysiologic evaluation (to be described). The severity of CTS was graded using electrophysiologic criteria (Stevens, 1997). Mild CTS was characterized by only median sensory nerve abnormality (details to be described) with normal distal motor latency (DML) and compound muscle action potential (CMAP) amplitude; moderate CTS was characterized by abnormal median sensory nerve abnormality (as in mild CTS) and prolongation of DML; and severe CTS was characterized by prolonged median DML with either (a) absent sensory response or low amplitude or (b) absent thenar CMAP amplitude. Electrophysiologic criteria for the diagnosis of mild CTS included, in addition to DML to abductor pollicis brevis (APB) ≤4.2 ms, either (a) slowed median SNCV digit 1 to wrist ≤45.9 m/s (stimulating digit 1 and recording at wrist at a distance of 9–10 cm) or (b) D/P ratio of median SNCV ≥1.12 (calculated as palm to digit 3 CV/palm to wrist CV [m/s]).

Of these 370 patients, 142 patients (213 hands) with moderate to severe CTS and 15 patients (4.1%) with multiple (≥3) compressive neuropathies in upper limbs with underlying subclinical peripheral sensorimotor axonal neuropathy were excluded from consideration in this study of criteria for the earliest diagnosis of CTS. Two of the 213 hands (142 patients) with moderate to severe CTS had median DML to APB <4.2 ms but had reduced CMAP amplitude <3.4 mV (2.8 mV, 2.3 mV). Of the remaining 213 patients, 203 patients (292 hands; 138 women [208 hands]; mean age, 50 y ± 12 y [range, 21–80 y]; 190 right hand dominant) with mild CTS and 10 patients (10 hands; 9 women; mean age, 43.7 y ± 9 y [range, 29–56 y]) with normal electrophysiologic examination were selected for study. Patients who had mild to severe CTS and who had associated peripheral sensorimotor neuropathy were not included in this study.

Controls

Thirty-eight normal volunteers (71 hands; 26 women; mean age, 47 y ± 13 y [range, 28–86 y]; 34 right hand dominant) with no symptoms or signs of neuromuscular disorders were studied. The 71 control hands had electrophysiologic studies similar to those of the patients (to be discussed).

Electrophysiology

All the studies were performed using TECA Sapphire/Premier electromyograph (TECA Corp., Pleasantville, NY), standard recording stainless-steel disc electrode (10 mm), stainless-steel ground electrode (32 mm), ring electrode (Medelec Model E/DS-K 16639; Old Woking, Surrey, England), and a bipolar (prong) surface stimulator (Medelec DPNSP 15675). The standard filter settings for motor (2–10,000 Hz) and sensory (10–5,000 Hz) studies were used. Stimulus strength of supramaximal (10%–15% above maximal stimulation) intensity was used to ensure a supramaximal response. Skin temperature was maintained at ≥32°C.

Nerve Conduction Studies

Nerve conduction studies (sensory, motor, F waves) were performed in the symptomatic upper extremity using standard methods. In subjects with multiple compressive neuropathy (≥3 nerves) in upper extremities, sural nerve and tibial H-reflex were studied (dominant lower limb) to exclude asymptomatic peripheral neuropathy (Bertelsmann et al, 1986; Hendriksen et al, 1993). The following studies were performed on all hands (patients and controls):

1. *Median orthodromic SNCV palm to wrist*, stimulating in the midpalm with a bipolar prong (interelectrode distance, 2 cm) stimulator with the stimulating cathode 7 to 8 cm from the recording distal electrode at the wrist.
2. *Median orthodromic SNCV from digit 1 to wrist.* Active recording disc electrode (G1) was kept at the same position as that for median SNCV palm to wrist, and the active stimulating ring electrode was placed on digit 1 at metacarpophalangeal joint at a distance of 9 to 10 cm measured on a straight line with the thumb in the neutral position (neither abducted nor adducted) from the G1 at the wrist and the reference ring electrode distally at the interphalangeal joint.
3. *Median SNCV (antidromic) from palm to digit 3*, stimulating at the midpalm with a bipolar stimulator 6 to 8 cm from proximal recording ring electrode placed over the proximal interphalangeal joint of digit 3 with the reference electrode at distal phalange.

4. *Median DML.* The median motor nerves were stimulated supramaximally at the midwrist, 7 cm proximal to G1 placed over the muscle belly of APB and G2 over the distal tendinous insertion to obtain the CMAP amplitude from the APB muscle.

In addition to having these studies, all the patients underwent determination of the median motor nerve CV by stimulation at the elbow as well as 10 F-wave responses. They also had ulnar motor nerve conduction studies (DML, 7 cm from stimulating site at the wrist to G1 placed over the abductor digiti minimi, CV below the elbow, across the elbow, and 10 F-wave responses; and orthodromic ulnar SNCV D5 to W (11–12 cm).

The latency of the sensory nerve action potential (SNAP) was measured from the takeoff of the negative response or from the base of the positivity if it preceded the negative component of SNAP. The onset latency of SNAP, which is less affected by temporal dispersion of the potential than is the peak latency of the potential, was used to calculate the CV (Mills, 1985). The CV of the median nerve SNAP at the wrist and D3 was preferred to the latency, as this measure compensates for different hand sizes (MacDonell et al, 1990). The amplitude of the SNAP was measured from the baseline to the negative peak or from the base of the positivity if it preceded the negative component of the SNAP. All sensory responses were averaged 4 to 8 times to obtain clear onset latencies. The motor onset latency was measured at the takeoff of the negative component of the CMAP response, and the CMAP amplitude was measured from the baseline to peak. All distances were measured to the nearest 1 mm and were measured from cathode to active electrode or from cathode to cathode sites, depending on each study. CVs were calculated using onset latencies and were expressed as meters/second (m/s). All the nerve conduction study parameters were rounded to the integers or to one decimal place.

Electromyography
All patients had electromyography of APB and first dorsal interosseous (FDI) muscles with concentric disposable needle electrode. Selected patients had studies of proximal ulnar, median innervated muscles, and radial innervated proximal and distal muscles. The control subjects did not have the needle electrode examination.

Data Analysis
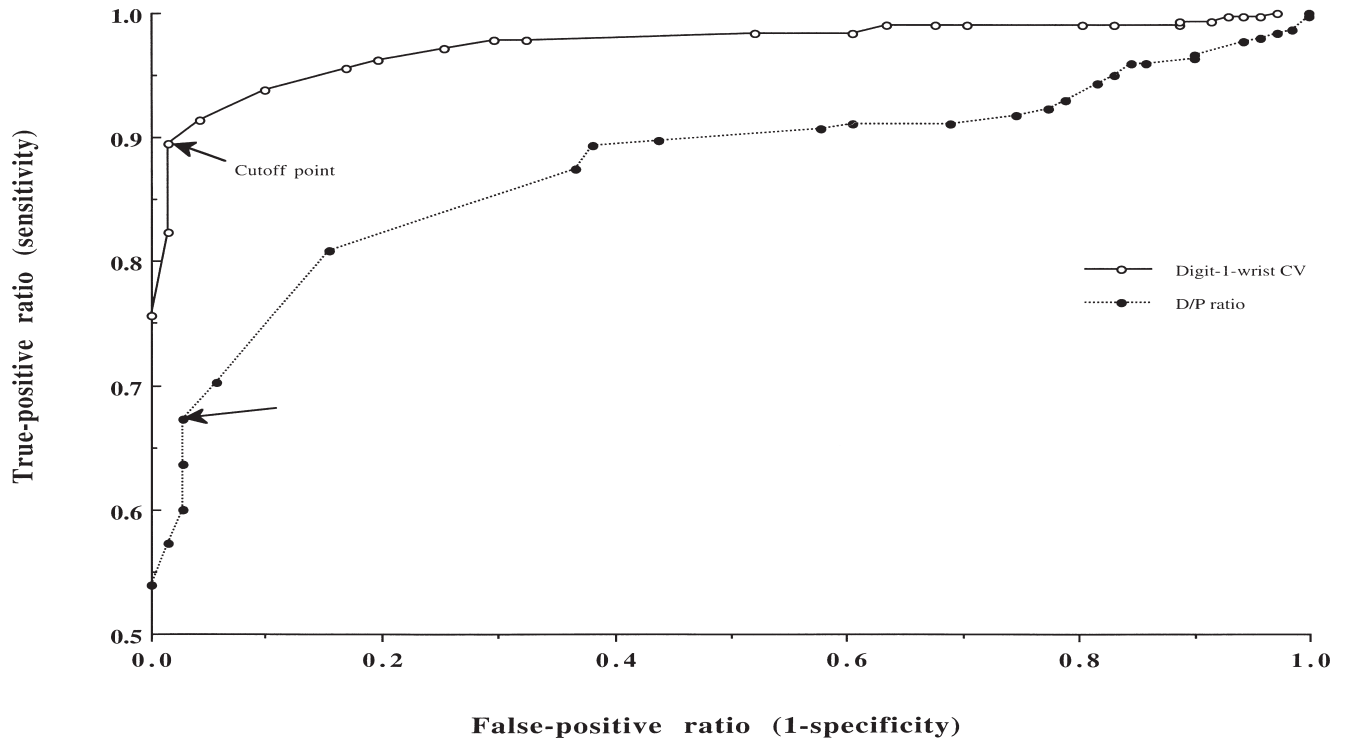
Receiver Operating Characteristic Curve
We examined the ability of median SNCV digit 1 to wrist and median SNCV D/P ratio to identify

correctly normal and symptomatically mild CTS subjects by means of an ROC curve for each of these tests (Metz, 1978). ROC curves were designed during World War II to assess the ability of the receiver to distinguish radar signals embedded in noise (Egan, 1975). ROC curves have been successfully used by radiologists to analyze information designed from imaging techniques (Hanley and McNeil, 1982) and by others to evaluate the performance of various laboratory tests (Beck and Shultz, 1986; Hermann et al, 1986). In their application to the study of sensitivity and specificity of diagnostic tests, ROC curves consisted of plots of true-positive (TP) ratio (sensitivity) versus false-positive (FP) ratio (1.0 specificity) of a diagnostic test. The plots are derived by varying the level of the cutpoint used to divide the range of observations into "positive" and "negative" diagnostic portions (Fig. 1). A perfect diagnostic test would be one with no FP or false-negative (FN) results and would be represented by a line that starts at the origin and goes up the *y*-axis to a sensitivity of 1.0, and then across to an FP ratio of 0 (Fig. 1). The closer a given curve courses the ideal curve, the better its discriminating ability. A test with no discriminating ability would produce equal TP ratio and FP ratio at every cutpoint and would produce an ROC curve on the diagonal line $y = x$ (Fig. 1). Any reasonable diagnostic test will display an ROC curve in the upper left triangle (above the diagonal line, as seen in this study—Fig. 1). When more than one laboratory test is available for the same clinical problem, one can compare ROC curves by plotting both on the same figure (Fig. 1).

Test Selection. Tests can be selected by comparing their ROC curves. A good diagnostic test has a high TP ratio (ie, optimal sensitivity) and a low FP ratio; it correctly identifies a large portion of diseased patients without incorrectly including patients without disease. The ratio of the TP ratio to the FP ratio is known as the *likelihood ratio.* Tests with a high likelihood ratio are better discriminators of disease than are tests with a low likelihood ratio. The chi-square test was used to compare the likelihood ratios of the two ROC curves at various cutoff points for their sensitivity and specificity in the diagnosis of mild CTS.

Selecting Cutoff Points. With the use of an ROC curve, a test may be developed by selecting different cutoff points according to desired sensitivity and specificity or by selecting the overall features of its ROC curve. A common "omnibus" criterion for optimality is a larger area under the curve. An ROC curve can be adapted to reflect variation in the true prevalence rate of the disease in the test population (Bayes's theorem), representing the predictive values of the test—and also for nongaussian distributions of the test scores (Tosteson and Begg, 1988). When

Figure 1. Receiver operating characteristic (ROC) curves for median sensory nerve conduction velocity (SNCV) from digit 1 to wrist (open circle with solid line), median SNCV distoproximal (D/P) ratio (closed circle with dotted line), and diagonal line (solid line) ROC curve. ROC curve for median SNCV digit 1 to wrist at selected optimal cutoff point (shown by closed arrow), with corresponding reference value at $\leq$45.9 m/s, provides sensitivity of 89.5% and specificity of 98.6%; ROC curve for median SNCV D/P ratio at its optimal cutoff point (shown by open arrow), with corresponding reference value at $\geq$1.12, provides sensitivity of 66.9% and specificity of 97.2%. Diagonal-line ROC curve *y = x* corresponds to a totally uninformative test; at every cutpoint, the test will produce equal true-positive and false-positive ratios.

there is too much overlap between normal and abnormal values, it is not possible to devise a test sensitive enough to select all abnormal values but specific enough to exclude normal values. Usually, the normal value for a test is set where the ROC curve flattens. This optimizes the number of TPs detected while limiting the number of FPs.

ROC Curve Limitations. Some of the several drawbacks of ROC analysis should be acknowledged. First, the technique requires the ability to establish, independent of the analytic system being evaluated, the true condition of many cases. This may prove difficult, time-consuming, and expensive. In this study, we did not assess the ability of either test literally to distinguish normal from symptomatic CTS patients. What we did was assess the ability of these tests to separate two groups of subjects preclassified as symptomatic (patients) or asymptomatic (controls). Second, as in other investigations, reasonable unbiased population samples must be obtained. But these may not be obtained if verification of the underlying conditions is influenced by the test results themselves.

Descriptive Statistics
Stat View II (Abacus Concepts, Inc., Berkeley, CA) was used for data analysis. Descriptive statistics including mean, maximum, minimum, standard deviation, and 95% confidence intervals were determined for each of the nerve conduction study parameters for controls and patients. An unpaired two-tailed Student's *t*test was used for comparative statistics. The chi-square test was used to compare the likelihood ratio of the two ROC curves at various cutoff points for their sensitivity and specificity in the diagnosis of mild CTS. The sensitivity of each test was calculated as number of hands with positive test and mild CTS (as defined) / total number of hands with mild CTS × 100. The specificity of each test was calculated as number of asymptomatic hands (controls) with negative test / total number of asymptomatic hands (controls) × 100. Statistical significance for all analyses was defined as *P* < .05. Data were adjusted for multiple comparisons using Bonferroni's multiple comparisons.

Results

Demographic and Nerve Conduction Parameters

There were no significant differences between the demographic data (age, height, male:female ratio, dominant hand) of patients and controls. The skew deviation of both parameters (median SNCV digit 1 to wrist, median SNCV D/P ratio) and demographic data (age, height) in patients and controls was close to 0 (−.05 to −.12) and did not require transformation.

Results for the calculated median SNCV (digit 1 to wrist, palm to wrist, palm to digit 3), amplitude, and D/P ratio are shown in Table 1. Mean values for median SNCV (digit 1 to wrist, palm to wrist) in controls were significantly higher ($P < .001$) than in patients with mild CTS. Median SNCV D/P ratio in controls was lower than in patients with mild CTS ($P < .0001$). Median SNAP amplitude (digit 1 to wrist, palm to wrist) in controls was significantly higher ($P < .009$) than in patients. Median SNCV and SNAP amplitude in the distal segment (palm to digit 3) in controls and patients with mild CTS were similar ($P = .8$).

Sensitivity and Specificity of Nerve Conduction Parameters

The ability of median SNCV digit 1 to wrist and median SNCV D/P ratio to distinguish between normal controls and patients with mild CTS was studied in greater depth using ROC curve analysis (Fig. 1). The median SNCV digit 1 to wrist ROC curve is closer to the ideal curve (0 FP, 1 TP) and more left to the diagonal line (no discriminating ability—equal TP and FP rates at every cutpoint) than is the median SNCV D/P ratio ROC curve (Fig. 1). Also, ROC curves for both tests do not intersect (in abnormal range), implying that diagnostic performance of median SNCV digit 1 to wrist is superior to that of median SNCV D/P ratio throughout the region of interest. Further, to delineate the discriminating ability of these two

parameters, we used the likelihood ratio (ratio of TP rate to FP rate) at selected cutoff points of these two curves rather than the area under the curves. The likelihood ratios of these two curves at various operating points on these curves, with corresponding abnormal cutoff values for these two parameters, are shown in Table 2. Compared with the likelihood ratio of the median SNCV D/P ratio, the likelihood ratio of the median SNCV digit 1 to wrist was higher ($P < .001$, Table 2) at each operating point (from starting point of the curve to the end). This suggests that, of these two tests, the median SNCV digit 1 to wrist better discriminates patients with mild CTS from controls than the median SNCV D/P ratio does. We selected optimal (higher sensitivity with acceptable specificity) cutoff values for median SNCV at ≤ 45.9 ms and median SNCV D/P ratio at ≥ 1.12. At these optimal cutoff values for each parameter, the median SNCV digit 1 to wrist sensitivity (89.5% with specificity of 98.6%) was higher than that of the median SNCV D/P ratio (66.9% with specificity of 97.2%, $P < .001$).

Clinical CTS With or Without Abnormal Electrophysiologic Examination

In 59.9% (181/302) of hands, both tests (median SNCV digit 1 to wrist, median SNCV D/P ratio) were abnormal at selected optimal cutoff values for the respective tests. Of the 10.3% (31/302) of hands in which median SNCV digit 1 to wrist was within normal limits at the selected optimal cutoff value (≤ 45.9 ms), 7% (21/302) had an abnormal median SNCV D/P ratio (≥ 1.12), and 3.3% (10/302) had normal electrophysiologic examination.

Multiple Testing

In this study, mild CTS was diagnosed when one or both tests (median SNCV digit 1 to wrist, median SNCV D/P ratio) were positive. Given this duplicate test program, in a symptomatic patient, an FN (1.0 TP ratio) diagnosis would occur with a probability of

Table 1 Details of Median Sensory Nerve Conduction Study Parameters of Controls and Patients

		D1–W CV m/s	D1–W Amp μV	P–W CV m/s	P–W Amp μV	P–D3 CV m/s	P–D3 Amp μV	D/P Ratio
Controls[a]	Mean	50.6 ± 3	18.0 ± 6.5	53.5 ± 3.7	47.2 ± 16.8	53.3 ± 3.3	20.1 ± 7.7	0.99 ± 0.06
	Range	44.0–58.8	4.5–49.6	45.7–66.5	11.6–80.3	47.4–61.2	4.9–79.3	0.86–1.16
Patients[b]	Mean	40.0 ± 5.6	15.2 ± 8.5	43.8 ± 6.7	32.2 ± 17.0	52.9 ± 5.7	20.0 ± 9.9	1.26 ± 0.2
	Range	25.5–57.4	1.8–49.0	20.3–62.0	5.0–99.3	34.3–69.5	2.3–74.4	0.87–2.03
	P value	.0001	.009	.0001	.0001	.7	.8	.0001

Data are expressed as means ± SD. D1 = digit 1; W = wrist; CV = conduction velocity; Amp = amplitude; P = palm; D3 = digit 3; D/P = distoproximal; m/s = meters per second.
[a]N = 71. [b]N = 302.

Table 2 Likelihood Ratio with Corresponding Cutoff Values

Parameter	Cutoff Value	Likelihood Ratio	Sensitivity	Specificity	P Value
D1–W CV (m/s)	<44.0	75.5	75.5	100	
vs					
D/P ratio	>1.161	54	54	100	<.0001
D1–W CV (m/s)	<45.0	58.8	82.4	98.6	
vs					
D/P ratio	>1.15	40.7	57.3	98.6	<.0001
D1–W CV (m/s)	<46.0	63.9	89.5	98.6	
vs					
D/P ratio	>1.12	23.8	66.9	97.2	<.0001
D1–W CV (m/s)	<46.5	21.6	91.3	95.8	
vs					
D/P ratio	>1.11	12.5	70.2	94.4	<.001
D1–W CV (m/s)	<47.0	9.5	93.8	90.1	
vs					
D/P ratio	>1.05	5.2	84.5	84.5	<.001
D1–W CV (m/s)	<47.5	5.7	95.6	83.1	
vs					
D/P ratio	>1.0	2.4	87.4	63.4	<.001

Comparison of likelihood ratio of receiver operating characteristic (ROC) curve of median sensory nerve conduction velocity (SNCV) from digit 1 to wrist (D1–W) and median SNCV distoproximal (D/P) ratio (palm to digit 3/palm to wrist) at selected points on each ROC curve and their corresponding abnormal cutoff values on respective parameters.

$0.105 \times 0.328 = 3.4\%$ (Schulzer, 1994), and resultant combined sensitivity would be 96.6%, which would be higher than the individual tests (89.5%, 67.2%). However, in a normal person, a true-negative diagnosis (1.0 FP ratio) would occur with probability of $0.986 \times 0.972 = 95.8\%$ (Schulzer, 1994), which would be lower than the individual tests (98.6%, 97.2%). To increase combined sensitivity from 96.6% to 97.4%, with the corresponding cutoff value for median SNCV digit 1 at ≤46.5 ms and D/P ratio at ≥1.11, would decrease the specificity from 95.8% to 90.4%. Similarly, to increase the sensitivity to 99.04% with corresponding cutoff value of median SNCV digit 1 to wrist at ≤47.5 ms and D/P ratio of ≥1.05 would further decrease the specificity from 90.1% to 74.9%. Therefore, we selected optimal (higher sensitivity with acceptable specificity) cutoff values for median SNCV at ≤45.9 ms and median SNCV D/P ratio (≥1.12). At these values, the combined sensitivity was 96.6%, and specificity was 95.8%.

Although all the study subjects (patients, controls) had palm to wrist median SNCV as part of D/P ratio determination, we did not use this measurement as the third electrophysiologic test for diagnosis of mild CTS (ie, in addition to median SNCV digit 1 to wrist and median SNCV D/P ratio). The reason was twofold: The aims of this study were (a) to compare the sensitivity and specificity of the median SNCV from digit l to wrist with that of D/P ratio of median SNCV from palm to digit 3/palm to wrist in the diagnosis of mild CTS and (b) to minimize type I error (normal subject is mistakenly called abnormal) to ≤5% (Rivner, 1994). Addition of each test increases type I error by 2.5% (Rivner, 1994). As no two tests for a single condition are completely independent, the total error is less than the sum of the individual errors for each test. Even after accounting for interdependency, the total error of combined tests may be unacceptably high. Further, if a single, highly discriminating test is not available, and multiple tests are used, abnormalities in two or more tests are needed to distinguish between normal and abnormal subjects (Rivner, 1994).

Sensitivity With Traditional Method

If we had analyzed data by traditional methods for determining the reference values (mean ± 2 SD for each parameter), then the median SNCV digit 1 to wrist would have diagnosed 77.5% of mild CTS with specificity of 97.5%, and median SNCV D/P ratio would have diagnosed 66.7% with specificity of 97.5%. As reported earlier (Eisen et al, 1993; Rivner, 1994; Schulzer, 1994), this underdiagnosis of mild CTS and overdiagnosis of FPs with traditional methods are due to significant overlapping of data of controls and patients, whose condition could not be diagnosed even with correction for other factors like

age, height, temperature, and transformation of data for correction of skew deviation. With the use of ROC curves, sensitivity for median SNCV digit 1 to wrist was significantly increased from 77.5% to 89.5% with optimal specificity of 98.6%.

Median DML and CMAP Amplitude
Median DML was within the upper limit of the normal range (4.2 ms) in patients and controls combined. However, median DML was significantly prolonged ($P < .0l$) in patients (3.7 ± 0.4 ms) versus controls (3.4 ± 0.4 ms). Median CMAP amplitude was similar ($P = .09$) in patients (9.7 ± 3.8 mV) and controls (10.6 ± 3.6 mV). None of the patients had CMAP amplitude below the lower limit of normal (3.4 mV). Median motor CV in the forearm was similar ($P = .07$) in patients (55.6 ± 3.4 m/s) and controls (56.6 ± 3.0 m/s).

Ulnar Nerve: DML, CMAP Amplitude, SNAP, and CV
Details of ulnar nerve parameters are not shown, as they were not the focus of this study. In brief, though, there was no difference between the ulnar nerve parameters of patients and controls except in 68 of 302 hands (22.5%) that had ulnar nerve dysfunction at the elbow. Details of median F waves, ulnar F waves, and needle electrode examination of the upper extremities are not shown for similar reason.

CTS With Peripheral Neuropathy
Of all 370 patients (547 hands), 68 patients (18.4%) had multiple (≥3) compressive neuropathies in both upper extremities. Among these 68 patients with multiple compressive neuropathies, 15 patients (22.1%) had underlying subclinical peripheral sensorimotor axonal neuropathy. This emphasizes the importance of studying the sural sensory nerve and tibial H-reflex in detecting subclinical generalized peripheral neuropathy in patients with multiple compressive neuropathies in upper extremities.

DISCUSSION
The main findings from this study were:

1. Median SNCV digit 1 to wrist is more sensitive in discriminating patients with mild CTS from controls (89.5%) than is median SNCV D/P ratio (67.2%).
2. Specificity of these two tests at these sensitivities was similar (98.6% vs 97.2%).
3. Compared with the traditional method of mean ± 2 SD (sensitivity, 77.5%; specificity, 97.5%), ROC curve was the more sensitive (89.5% with specificity of 98.6%) and appropriate method in determining normative cutoff values that would discriminate patients with mild CTS from asymptomatic subjects (controls).
4. Mean median DML was significantly prolonged in patients (3.7 ± 0.4 ms) versus controls (3.4 ± 0.4 ms).
5. Median CMAP amplitudes were similar in patients and controls.

These findings suggest that median SNCV digit 1 to wrist is more sensitive than D/P ratio for the diagnosis of mild CTS. Similarly, other investigators (Kothari et al, 1995; Trojaborg et al, 1996) have noted higher sensitivity (86%–94%) for median SNCV digit 1 to wrist in comparison to the SNCV in other digits in the diagnosis of mild to moderate CTS. Padua et al (1996) observed highest sensitivity for median SNCV D/P ratio (98%) in diagnosis of 43 patients (50 hands) with mild to moderate CTS—when compared to other techniques (palm to wrist, 76%; radial–median ratio, 74%; digit 1 to wrist, 66%; digit 3 to wrist, 64%; DML, 44%). In their study, the median nerve was stimulated via ring electrodes placed at digit 3, and SNAPs were recorded at the palm (digit 3 to palm) and at the wrist (digit 3 to wrist). Median SNCV palm to wrist was calculated with a subtraction formula: palm – wrist distance (mm) / (digit 3 to wrist latency) (–) (digit 3 to palm latency in ms). D/P ratio was calculated as: median SNCV digit 3 to palm / median SNCV palm to wrist (m/s). D/P ratio sensitivity was 67.2% in the present study, 98% in Padua et al's study, and 69% in Kuntzer's (1994) study (in which D/P ratio was obtained at digit 2 rather than digit 3). Controls' D/P ratio in Padua et al's study was lower (0.82 ± 0.08) compared with that in the present study (0.99 ± 0.06), in Kimura's (1979) study (0.98 ± 0.02), in Buchthal et al's (1974) study (0.97 ± 0.06), and in Kuntzer's (1994) study (0.98 ± 0.17). Similarly Tackmann et al (1981) calculated median SNCV palm to wrist and palm to digit 3 in 32 normal subjects by stimulating the median sensory nerve in the palm (needle electrode) and recorded SNAP at the wrist and digit 3 simultaneously (surface electrode). In 9 subjects (28%), CV in the proximal segment (palm to wrist) was slower (0.3–6.3 m/s) compared with the distal segment (palm to digit 3). In the present study, 8 of the 71 controls (11%) had D/P ratio of >1 compared to 0 in Padua et al's (1996) study. Also, 18 (6.2%) of the patients in the present study had D/P ratio <1 compared with only 1 patient (2%) in Padua et al's study. Therefore, the most likely reason for higher sensitivity of D/P ratio versus digit 1 to wrist was due to lower D/P ratio in controls in Padua et al's study as compared with that in other studies (Buchthal et al, 1974; Tackmann et al, 1981; Charles et al, 1990; Kuntzer, 1994), including the present study. The reasons for low D/P ratio in controls in Padua et al's study are not clear, but they did use a technique different from that used in the present study and in

other studies (Buchthal et al, 1974; Tackmann et al, 1981; Charles et al, 1990; Kuntzer, 1994).

It is possible that the technical factors that favor median SNCV digit 1 to wrist could explain in part its higher sensitivity (compared with that of median SNCV D/P ratio) in the present study's diagnosis of mild CTS. Each calculation used to obtain final values will increase the inherent error. Median SNCV digit 1 to wrist uses only one calculation (CV), whereas median SNCV D/P ratio uses three calculations (palm to wrist CV, palm to digit CV, and their ratio). Unfortunately, one needs two values to calculate a ratio. One could use absolute latencies obtained at fixed distances to reduce the number of calculations. CV of the median nerve SNAP at the wrist and D3 were preferred to the latency, as this measure compensates for different hand sizes (MacDonell et al, 1990).

Several investigators have attempted to determine the most sensitive test for early diagnosis of CTS. The precise comparison of interstudy sensitivities is not possible because of differences in study design, inclusion criteria, disease severity, and normative cutoff values. However, variable sensitivities have been reported for several electrodiagnostic tests (techniques) in mild CTS: median–ulnar palmar mixed latency difference, 51% to 97% (Jackson and Clifford, 1989; Uncini et al, 1993; Preston et al, 1994; Andary et al, 1996); digit 4 median–ulnar latency difference, 42% to 91% (Uncini et al, 1989, 1993; Preston et al, 1994; Andary et al, 1996; Terzis et al, 1998); median–radial sensory latency difference, 44% to 90% (Jackson and Clifford, 1989; Pease et al, 1989; Campbell and Machin, 1993; Andary et al, 1996); second lumbrical–interossei latency difference, 10% to 88% (Uncini et al, 1993; Preston et al, 1994); and the motor and sensory inching method, which is more laborious, limiting its clinical utility, 52% to 96% (Kimura, 1979; Seror, 1998). A higher sensitivity, >80%, has also been reported for median SNCV digit 3 versus 62% for digit 2 (Cioni et al, 1989); that higher sensitivity is similar to the 86% reported for digit 1 and digit 3 (Buchthal et al, 1974) and to the 88% reported for digit 4 versus 77% for digit 2 (Uncini et al, 1989), 56% for standard techniques (Valls and Llanas, 1988; Uncini et al, 1993), and 61% for digit 1, 22% for digit 2, and 50% for digit 3 (Terzis et al, 1998). However, except for Terzis et al (1998), all these studies did not study sensory conduction along median sensory fibers of the thumb. Also, they all studied mild to severe cases, except for Uncini et al (1989, 1993), who found 77% to 78% sensitivity, and Terzis et al, who found 88% sensitivity. Moreover, Lauritzen et al (1991) studied 38 patients with mild to moderately severe CTS by comparing ring finger with digit 1 and digit 3, concluded that the ring finger (74% sensitivity) was not superior to digit 1 or digit 3, and recommended that the ring finger should be tested for screening purposes because of its high specificity (double peak). Similarly, Trojaborg et al (1996) demonstrated low specificity of the double-peak (40%), and low sensitivity (50%) of ring finger compared with digit 1 (68%), in patients with mild to moderate CTS.

The higher sensitivity of median SNCV digit 1 to wrist observed in the present study and in other studies (Kothari et al, 1995; Trojaborg et al, 1996), compared with standard techniques using other digits, might be related to the fascicular topography of the median nerve in the distal portion of the carpal tunnel, where compression is usually more severe (Sunderland, 1945; Kimura, 1979). Sensory fibers from digit 1, digit 4, and the medial side of digit 3 lie more anterior in the nerve, just beneath the transverse carpal ligament, whereas sensory fibers from digit 2 lie more posterior in the distal median nerve. Therefore, the sensory fibers from digit 1 and digit 4 are more susceptible to injury than are the fibers from digit 2. This is suggested by a recent report of a case of partial anterior median nerve laceration, in which the sensory fibers to the thumb were destroyed, but those to digit 2 and digit 3 were relatively spared (Vennix and Glennon, 1994).

In summary, our findings suggest that median SNCV in digit 1 to wrist is more sensitive than median SNCV D/P ratio in the diagnosis of early CTS. It is advantageous to determine sensitivity and specificity of a test by using ROC curve than by using the traditional method (mean ± 2 SD) for early diagnosis of mild CTS. Determining median SNCV D/P ratio in patients who are suspected as having CTS and who have normal median SNCV digit 1 to wrist would significantly increase the sensitivity for early diagnosis of CTS.

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