Tenelectrodes: a New Stimulator for Inching Technique in the Diagnosis of Carpal Tunnel Syndrome

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This study was designed to evaluate the usefulness of a new multielectrode stimulator, TenElectrodes, in the diagnosis and localization of the compression site in the wrists of carpal tunnel syndrome (CTS) patients. Antidromic inching technique (IT) of the median nerve at the wrist was performed with the TenElectrodes, on 46 controls and 21 CTS patients. In controls, mean conduction delay per centimeter (CD/cm) was 0.21 milliseconds (ms), and maximal CD/cm was 0.27 ms in the segment 3 to 4 centimeters distal to the distal wrist crease. The abnormal cut-off value, calculated as the maximal CD/cm + 2SD, was 0.45 ms. In the CTS group, the maximal CD/cm was 0.56 ms in the segment 2 to 3 centimeters distal to the distal wrist crease, and the CD/cm values in all segments between the distal wrist crease and 4 cm distal to the distal wrist crease were greater than 0.45 ms. Antidromic IT using TenElectrodes may be an easy, fast and accurate method as the electrodes of the stimulator are aligned at 1-cm intervals and are adjustable to the wrist contour by springs.

Key Words: Carpal tunnel syndrome, inching technique, nerve conduction study, median nerve, multielectrode stimulator

INTRODUCTION

Since the focal slowing of median nerve conduction at the wrist in carpal tunnel syndrome (CTS) was first demonstrated in 1956 by Simpson,[1] nerve conduction studies have been used to assess the conduction status of the median nerve in suspected CTS. Many techniques have been developed to increase the sensitivity of CTS diagnosis.[2-7] However, most of the tests measured the conduction velocity over long nerve lengths and were unable to identify the precise site or sites of conduction delay, and were apt to miss a mild and localized delay.[8]

In contrast, the inching technique (IT), which is the segmental stimulation method described by Kimura, was reported to be more sensitive.[9] This technique measures the conduction status of the nerve centimeter-by-centimeter and has the advantage of providing information about the precise location of conduction delay, as well as assisting in detection of conduction delay when other test results are normal.[8,10]

However, IT was thought to have several shortcomings. Geiringer concluded that IT was not useful because of technical limitations, questionable data reliability and clinical relevance.[11] Kimura noted that the sources of error of IT include variability in nerve conduction measurement, excessive spread of stimulation current, temporal dispersion, and inaccuracy of surface measurement.[12] IT was also thought to be a more time-consuming test.[10]

To decrease surface measurement error and improve the ease of testing with IT, we have invented a new multi-electrode stimulator. The aim of this study was to evaluate the usefulness of this stimulator in the diagnosis and localization of the compression site in the wrist of CTS.

MATERIALS AND METHODS

Seventy-two wrists of 46 control subjects (28 females and 18 males) with a mean age of 42.9

years (range, 30-71) and 31 wrists of 21 CTS patients (17 females and 4 males) with a mean age of 47.4 years (range, 40-69) were examined. Diagnosis of CTS was based on the American Academy of Neurology clinical diagnostic criteria.[13] There was no significant difference in demographic parameters between the two groups.

Electrophysiologic studies of the median nerve were initially performed with conventional techniques. Compound muscle action potential (CMAP) of the median nerve was recorded in the abductor pollicis brevis (APB) muscle with stimulation at the wrist 8 cm proximal to the recording site. The distal motor latency (DML) and baseline-to-peak amplitude of the median CMAP was measured. The median sensory nerve was stimulated 7 cm and 14 cm proximal to the recording site of the middle finger. The peak latency and baseline-to-peak amplitude of median sensory nerve action potential (SNAP) were measured. CTS was diagnosed if one of the following 3 electrophysiologic criteria were met: DML to APB greater than 4.2 ms, peak latency of 14 cm median sensory response greater than 3.7 ms, or more than twofold peak latency difference of antidromic median sensory recording of 14 cm stimulation than that of 7 cm stimulation.

The newly developed IT stimulator, TenElec-trodes, has 10 electrodes aligned at 1-cm intervals. The electrodes are adjustable to the irregular contour of the wrist and palm by various springs attached to each electrode (Fig. 1 and 2). The cathodal and anodal electrodes were paired in the electrical circuit within the switch box and were set to stimulate with an interelectrode distance of 2 cm. The stimulating electrode was selected by pressing a button in the switch box and altered

sequentially at 1-cm intervals along the median nerve. TenElectrodes was held and placed between the flexor carpi radialis and palmaris longus tendons, in alignment with the third digit. The hand to be examined was put on a flat board with the fingers extended. During the examination, TenElectrodes was secured to the hand to prevent slippage. The median sensory nerve was excited at one centimeter intervals from a point 1 cm proximal to the distal wrist crease (stimulation point 1, SP-1) to a point 6 cm distal to the distal wrist crease (stimulation point 8, SP-8), thereby providing 8 measurements, by sequentially pressing the buttons of the switch box. The median sensory response by IT was recorded in the third digit. The stimulation intensity was set at a level which evoked a sensory potential over the point 3 cm distal to the distal wrist crease.

A Nicolet Viking IV Electrodiagnostic System (Nicolet Instrument Corp., Madison) was used. The sensitivity range was 10-50 uV/division and
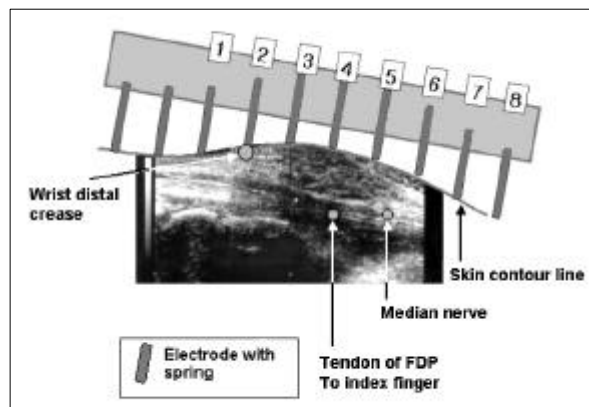

Fig. 2. Schematic drawing of longitudinal ultrasonographic finding from TenElectrodes of the median nerve within the carpal tunnel. FDP=flexor digitorum profundus.
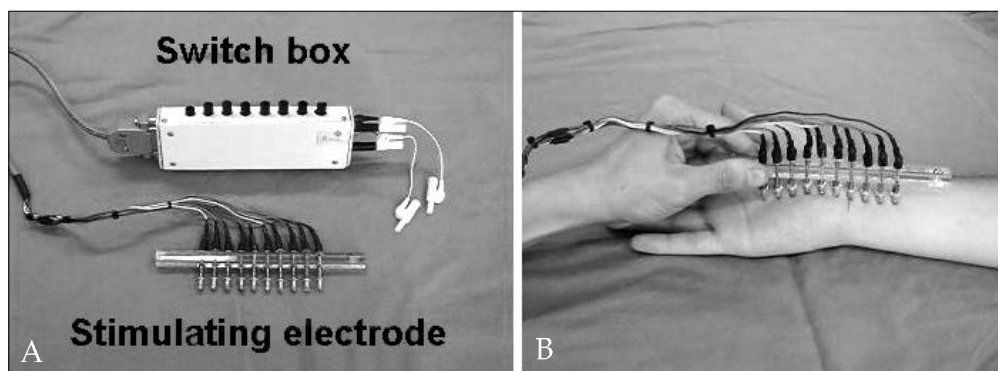

Fig. 1. TenElectrodes: (A) Switch box and stimulating electrodes, and (B) Stimulating electrodes of TenElectrodes applied on

the sweep speed was 1 ms/division. The low frequency filter was set at 20 Hz, and the high frequency filter at 2 kHz. The skin temperature was maintained above 34℃.

The latency was measured at the negative peak of SNAP on the screen, with an accuracy of 0.1 ms. The conduction delay per centimeter (CD/cm), the time necessary for the nerve impulse to travel 1 cm, was measured in 7 segments. The segment between SP-1 and SP-2 was called 1-cm segment I (Seg I), the segment between SP-2 and SP-3 was called 1-cm segment II (Seg II), and so on. The segments between the distal wrist crease and 4 cm distal to the distal wrist crease, Seg II through Seg V, were considered to be carpal tunnel segments because the length of the transverse carpal ligament is about 2.5 - 3 cm from the distal wrist crease.[14] The mean CD/cm was obtained at each 1-cm segment. The CD/cm of the control group was compared with that of the patients. The segment with the largest CD/cm was called the maximal CD/cm.

The conduction delay per 2 centimeters (CD/2 cm), the time necessary for the nerve impulse to travel a distance of 2 cm, was applied if a response was unobtainable. The segment between SP-1 and SP-3 was called 2-cm segment I (2-Seg I), the segment between SP-2 and SP-4 was called 2-Seg II, and so forth. Thus, CD/2 cm was performed in a total of 6 segments in all subjects. The segment with the largest CD/2 cm was called the maximal CD/2 cm.

Statistical analysis

All statistical analyses were performed using the statistical package SPSS version 10.0. The data were recorded as mean ± standard deviation. In the 1-cm segment and 2-cm segment studies, values of each segment from control subjects and CTS patients were compared with independent t-tests. The level of significance was set at $p < 0.05$.

RESULTS

Control group

The mean DML was 3.3 ± 0.4 ms, the mean

CMAP amplitude 10.2 ± 2.9 mV, the mean 14 cm SNAP latency 3.1 ± 0.3 ms, the mean 7 cm SNAP latency 1.8 ± 0.2 ms, and the mean SNAP amplitude 46.1 ± 18.6 uV (Table 1).

The mean CD/cm was 0.21 ms (range, 0.17 - 0.27 ms). The maximal CD/cm was at Seg V (i.e., the segment 3 to 4 cm distal to the distal wrist crease) in controls, with a value of 0.27 ± 0.09 ms (Table 2). The abnormal cut-off value was considered as the maximal CD/cm + 2SD, i.e., 0.27 + 2 × 0.09=0.45 ms. All the CD/cm in each segment of controls were less than this value, with the largest latency difference being 0.4 ms. The segments with smallest mean CD/cm were Seg-I and Seg-VII (0.17 ms each), both of which were located outside the carpal tunnel.

The mean CD/2 cm was 0.42 ms (range, 0.34 - 0.52 ms). The maximal CD/2 cm was at 2-Seg IV (the segment 2 to 4 cm distal to the distal wrist crease), which was 0.52 ± 0.11 ms (Table 3). Abnormal criterion in the 2-cm segment study was calculated as the maximal CD/2 cm + 2SD, which was 0.74 ms.

CTS group

The mean DML was 4.4 ± 0.9 ms, the mean CMAP amplitude 7.4 ± 2.3 mV, the mean 14 cm SNAP latency 4.1 ± 0.7 ms, the mean 7 cm SNAP latency 1.9 ± 0.3 ms, and the mean of SNAP amplitude 29.2 ± 13.0 uV (Table 1).

The mean CD/cm was 0.31 ms (range, 0.17 - 0.56 ms). The maximal CD/cm was at Seg IV (0.56

Table 1. Routine Median Motor and Sensory Conduction Study for Control and CTS Groups

		Control	CTS
Motor			
	DML (ms)	3.3 ± 0.4	4.4 ± 0.9
	Amplitude (mV)	10.2 ± 2.9	7.4 ± 2.3
Sensory			
	14 cm amplitude (uV)	46.1 ± 18.6	29.2 ± 13.0
	14 cm peak latency (ms)	3.1 ± 0.3	4.1 ± 0.7
	7 cm peak latency (ms)	1.8 ± 0.2	1.9 ± 0.3

DML, distal motor latency.
CTS, carpal tunnel syndrome.

Table 2. Conduction Delay Value of 1-cm Segment Study for Control and CTS Groups

1-cm Segment	Control	CTS
Seg I	0.17 ± 0.08	0.16 ± 0.06
Seg II	0.18 ± 0.07	0.21 ± 0.14
Seg III	0.19 ± 0.08	0.32 ± 0.21*
Seg IV	0.25 ± 0.09	0.55 ± 0.29*
Seg V	0.27 ± 0.09	0.50 ± 0.46*
Seg VI	0.20 ± 0.08	0.21 ± 0.09
Seg VII	0.18 ± 0.06	0.19 ± 0.07
Mean	0.21 ± 0.04	0.31 ± 0.16

Values are mean ± standard deviation, in milliseconds.
*$p < 0.05$.
CTS, carpal tunnel syndrome.

Table 3. Conduction Delay Value of 2-cm Segment Study for Control and CTS Groups

2-cm Segment	Control	CTS
2-Seg I	0.34 ± 0.11	0.38 ± 0.14
2-Seg II	0.37 ± 0.10	0.54 ± 0.21*
2-Seg III	0.44 ± 0.10	0.87 ± 0.34*
2-Seg IV	0.52 ± 0.11	1.04 ± 0.41*
2-Seg V	0.47 ± 0.11	0.71 ± 0.46*
2-Seg VI	0.38 ± 0.09	0.44 ± 0.10
Mean	0.42 ± 0.07	0.66 ± 0.26

Values are mean ± standard deviation, in milliseconds.
*$p < 0.05$.
CTS, carpal tunnel syndrome.

± 0.30 ms) (Table 2). In all CTS patients, a CD/cm value larger than 0.45 ms (the abnormal cut-off value in controls) was located in at least one of the 4 segments between Seg II and Seg V (carpal tunnel segments), with Seg IV, comprising 18 of 31 cases (58.1%), being the most common site of delay.

The maximal CD/2 cm, 1.10 ± 0.45 ms, was at 2-Seg IV (segment 2 to 4 cm distal to the wrist distal crease) (Table 3). In all CTS patients, CD/ 2 cm greater than 0.74 ms (the abnormal criterion in controls) was observed in at least one of the 4

segments between 2-Seg II and 2-Seg V. Conduction delay greater than this value in 2-Seg IV was noted in 22 of 31 cases (71.0%).

DISCUSSION

IT, first described in a short segment incremental study by Kimura, has proven useful in localizing the source of abnormality of median sensory conduction in most CTS patients.[9,15] This finding has been confirmed by Nathan[16] and White.[17] Nathan stimulated the median sensory nerve at 1-cm intervals across the carpal tunnel and recommended 0.4 ms as a criterion of abnormality which provided a specificity of 81%.[16] Seror demonstrated an overall specificity of 100% and sensitivity of 96% with orthodromic IT.[10,18]

Studies with longer segments tend to lower the sensitivity of the test because the inclusion of the unaffected segments in the calculations dilutes the effect of conduction delay at the site of the lesion. For example, assume a nerve impulse normally conducts at a rate of 0.2 ms/cm (50 m/s), but slows down to 0.5 ms/cm (20 m/s) in a 1-cm segment of demyelination. In a 10-cm segment, a 0.3 ms increase would constitute a 15% change, which is well within the normal range of variability. However, the same 0.3 ms increase represents a 150% change in latency if measured over a 1-cm segment. In the chronically compressed nerve, the most likely focal abnormality is the restricted slowing across the lesion without loss of amplitude or major changes in waveform configuration.[19,20] IT can accurately locate this focal nerve lesion.

This study confirmed Kimura's finding[9] and was similar with the results of orthodromic IT reported by Seror.[10] Kimura reported that, in patients with CTS, the location of the 1-cm segment having the maximal conduction time was usually 2 to 4 cm distal to the distal crease of the wrist.[9] According to Seror, the typical location of impaired conduction was located between 3 and 4 cm distal to the distal wrist crease.[10] In our results, maximal conduction delay was observed in the segment between 2 to 3 cm distal to the distal wrist crease (Seg IV) in the 1-cm segment study and in the segment between 2 to 4 cm distal
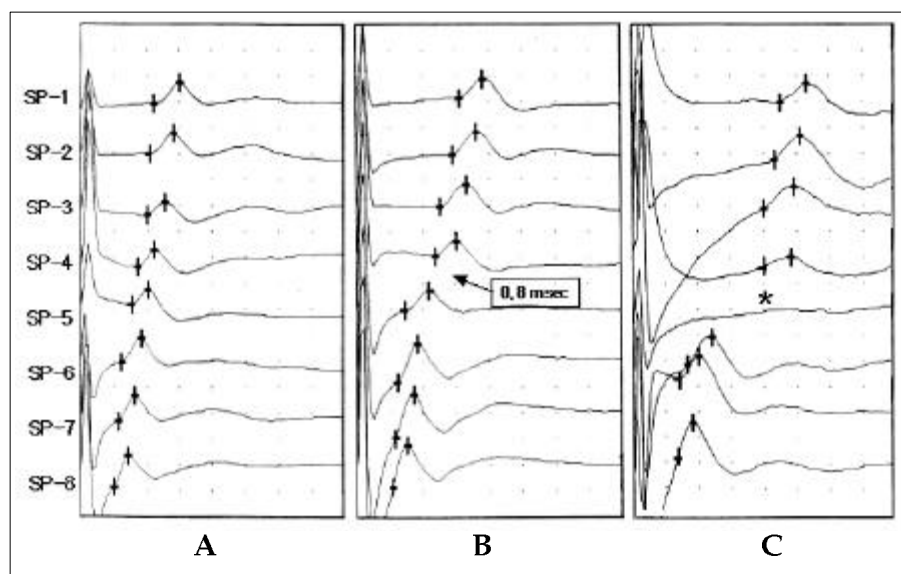
Fig. 3. Antidromic inching technique using TenElectrodes in: (A) control, (B) a carpal tunnel syndrome (CTS) patient with conduction delay (0.8 msec) between SP-4 and SP-5, and (C) a CTS patient with no response in SP- 5 which was 3 cm distal to the wrist distal crease (asterisk). (SP-1: Stimulation point 1, 1 cm proximal to wrist distal crease; SP-2, Stimulation point 2, wrist distal crease; SP-3: Stimulation point 3, 1 cm distal to wrist distal crease; and so on.)

to the distal wrist crease of (2-Seg IV) in the 2-cm segment study. These findings place the site of median nerve compression at approximately 3 cm distal to the distal wrist crease, roughly corresponding to the distal edge of the transverse carpal ligament.

In this study the use of the segmental stimulation technique, with the criterion for abnormality of the median nerve set at 0.45 ms, produced a sensitivity of 100% and a specificity of 100% in the carpal tunnel segments (Seg II through Seg V). In all controls, the largest conduction delay for each 1-cm segment was 0.4 ms, i.e., less than the 0.45 ms which corresponded to the maximal CD + 2SD. In all CTS patients, the smallest CD/cm in the carpal tunnel segment was 0.5 ms, which was larger than 0.45 ms. Compared with other studies,[10,16,19,21] these results proved that IT using TenElectrodes may be a very sensitive and specific method in the diagnosis of CTS.

Unobtainable SNAP with supramaximal stimulation intensity over the transcarpal ligament (SP-3 or SP-4) in both the control and CTS groups was probably the result of the thicker subcutaneous tissue compared to the other segments (Fig. 2 and 3). In these cases, the 2-cm segment study was applied, with the conduction delay in the 2-cm segment able to be calculated from the results of the 1-cm segment study. For the criterion of abnormality for the 2-cm segment study, the value of 0.74 ms was calculated from the

maximal CD/2 cm + 2SD. As the use of this value also produced 100% sensitivity and specificity within the carpal tunnel, this technique may be very useful in cases with no response using IT. In Fig. 4, a CTS patient with no response at SP-5 (3 cm distal to the distal wrist crease) demonstrated 1.0 ms in the 2-cm segment between SP-4 and SP-6 (2-Seg IV), which was greater than the abnormal cut-off value of 0.74 ms.

One of the major problems in conventional IT is the inaccuracy of surface measurement as the surface contour over the carpal tunnel is not flat. However, in a preliminary study, we found that the median nerve was straight in the carpal tunnel on ultrasonographic examination (Fig. 2). Thus tape measurement over the wrist may not reflect the actual length of the median nerve. Another problem noted when using the conventional stimulator is the sliding of the stimulator over the distal forearm. These problems affect the latency of the median sensory response and may lead to false positive or false negative results. Also, most of the previous antidromic and orthodromic IT methods utilize processes such as tape measurement, skin marking and relocating the stimulator electrodes, all of which may lead to inaccurate results. We propose these problems could be overcome by using TenElectrodes with fixed distance.

When performing IT with TenElectrodes it is not necessary to relocated the stimulator at 1-cm

intervals, and tape measurement is not needed as the electrodes are set at 1-cm fixed intervals. The inching test with TenElectrodes was done in controls within 2 to 3 minutes including the time from electrode placement to data analysis. In addition, as TenElectrodes was adjusted to the irregular contour of the surface by springs under each electrode and applied to the skin simultaneously, sliding was minimal at the distal forearm and the accuracy of the test could be increased. Thus, IT using TenElectrodes reduced the measurement errors and was performed very easily and relatively rapidly.

This study demonstrated the usefulness of TenElectrodes, a new stimulator with multi-electrodes, for IT. The test had a sensitivity of 100% and a specificity of 100% in CTS patients. This method is reliable when applied carefully and locate the median nerve conduction abnormality within the carpal tunnel. Antidromic IT using TenElectrodes may be an easy, fast and accurate method because the electrodes are fixed at 1-cm intervals, and can be adjusted to the wrist contour, thereby overcoming the shortcomings of conventional IT.

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