Chapter 5

Electrodiagnostic confirmation of carpal tunnel syndrome and especially the value of motor nerve conduction tests

Submitted
Abstract

Objective - For the preoperatively often required confirmation of clinically defined carpal tunnel syndrome (CTS) sensory as well as motor nerve conduction studies may be applied. The aim of this study was to test the sensitivity of specific motor nerve conduction tests in comparison with, as well as in addition to sensory nerve conduction tests.

Design - In 162 patients with clinically defined CTS, sensory and motor nerve conduction tests were performed prospectively and sensitivity of all tests was computed.

Results - Sensitivity for all sensory tests was at least 79.4 % (DIG1), but for motor conduction tests this was significantly lower, except for the TLI-APB, which was 81.3%.

Conclusions - In the electrophysiological confirmation of CTS, sensory nerve conduction tests and terminal latency index have a high sensitivity. If however, no sensory nerve action potentials can be recorded, all motor nerve conduction tests have a high sensitivity.
Introduction

Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy.\textsuperscript{1,2} Usually, diagnosis can be reliably made, based on clinical signs and symptoms. However, as in the Netherlands it is common that many (neuro-)surgeons require the clinical diagnosis confirmed electrodiagnostically prior to surgical treatment, reliable electrodiagnostic tests are an important issue.\textsuperscript{3}

Hitherto, it was well established that sensory nerve conduction studies are the most sensitive electrodiagnostic tests to confirm the diagnosis of CTS. Motor nerve conduction studies are important in the documentation of motor fiber involvement in CTS. In more severe cases sensory nerve action potentials (SNAP) may not be recordable\textsuperscript{4} and in that case, motor nerve conduction studies are the only means to confirm the clinically defined diagnosis of CTS.\textsuperscript{5}

Therefore, in the present study we prospectively tested the sensitivity of sensory and motor nerve conduction tests in a group of patients with clinically defined CTS.

We particularly focused on the group of CTS patients in whom no sensory nerve action potentials were recordable and tried to evaluate which motor nerve conduction showed would be the best alternative in these specific cases in terms of sensitivity.

Materials and Methods

Subjects

162 patients with clinically defined carpal tunnel syndrome were included. Data were prospectively collected. Carpal tunnel syndrome was considered to be present clinically in case of pain and/or paresthesias in the sensory distribution of the median nerve distribution. Two or more of the following criteria also needed to be present: (1) nocturnal paresthesias; (2) reproduction or aggravation of paresthesias or pain by provocative tests (Tinel or Phalen signs); (3) aggravation of paresthesias by activities such as driving, riding a bike, holding a book or a telephone; or (4) relief of symptoms by shaking the hand. These clinical criteria have previously been used in other studies.\textsuperscript{4,6,7} In case of clinical signs of polyneuropathy or known hereditary neuropathy with liability to pressure palsy, history of trauma or any previous surgery of the symptomatic wrist, pregnancy, severe atrophy of the abductor pollicis brevis muscle, history of rheumatoid arthritis or arthrosis of the wrist, known diabetes, thyroid disease, or alcoholism, patients were excluded from this study. Only the most symptomatic hand was
All candidates gave written informed consent, and the local medical ethics committee approved the study.

**Control subjects**

Reference values were derived from 47 healthy, asymptomatic volunteers, who were recruited from the hospital personnel. All were tested in the same laboratory according to the same electrodiagnostic test protocol.

**Clinical examination**

All subjects underwent neurological examination, including inspection of the thenar, motor function tests of the hand muscles according to Medical Research Council, especially the abductor pollicis brevis and opponens pollicis muscle, and sensory testing using a monofilament (10g) and two-point discrimination.

**Electrodiagnostic evaluation**

All patients and healthy volunteers underwent standardized motor and sensory nerve conduction studies (NCS) in accordance with our laboratory’s standard procedure as recommended by the American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM) guidelines. NCS were performed using a Viking Myograph IV (Nicolet Biomedical Inc., Madison, WI, USA). Skin temperature of the hands was warmed and maintained at a minimum of 31.0°C by means of hot packs and was measured before and after each test. One examiner, who was not informed of the preceding history and physical examination results, performed all tests.

**Sensory nerve conduction studies**

Ring electrodes were applied for recording SNAPs. In all, the proximal electrode was placed at the first interphalangeal joint and the distal recording electrode at a distance of, preferably, 3 cm. The optimal stimulation site was determined carefully. Signal averaging was applied on all SNAPs in order to obtain a sharp potential take off from baseline.

Conduction distances were measured with a precision of 1 mm using a tape measure.
Three different antidromic sensory nerve conduction studies were performed: 2 comparison tests, 1 short segment study.

- **DIG1**: sensory median-radial comparison test: the median and radial nerves, were stimulated separately at the wrist and SNAPs were recorded from the index finger. Onset latency differences were computed. SNAP amplitudes were measured (peak to peak).

- **DIG4**: sensory median-ulnar comparison test: the median and ulnar nerves, were stimulated separately at the wrist and SNAPs were recorded from the ring finger. Onset latency differences were computed. SNAP amplitudes were measured (peak to peak).

- **PALM3**: sensory short segment forearm-wrist vs. wrist-to-palm segment. SNAPs were recorded from the third finger after stimulation of the median nerve at the palm, wrist, and elbow. Difference in sensory nerve conduction velocities between the wrist to palm segment and elbow to wrist segments (forearm) were calculated using onset latencies.

**Motor nerve conduction studies**

Compound muscle action potentials (CMAP) were recorded by means of surface electrodes. Recording position was chosen in a way that enabled recording a CMAP as maximal as possible with a sharp initial negative deflection.

Two motor nerve conduction studies were performed:

- **DML-APB**: distal motor latency (DML) to the abductor pollicis brevis muscle. The median nerve was stimulated at the wrist and at the elbow. CMAPs were recorded from the thenar eminence at a distance of 6 cm from the stimulation site. The reference electrode was positioned over the metacarpal-phalangeal joint of the thumb.

- **2L-INT**: Lumbrical-interosseous comparison study: the median and ulnar nerves were both stimulated at the wrist, with the same conduction distance. However, the value of the conduction distance varied per patient as the optimal stimulation site of the stimulus cathode was variable in order to be able to search for the optimal stimulation site (mostly between 6 and 7 cm). CMAPs were recorded from the second lumbrical (2L) and second interosseous muscle (INT), respectively, with the active recording electrode at the palm, between the second and third metacarpals. The reference electrode was placed at the distal phalanx of the index finger. Distal motor latency of the lumbrical (DML-LUMB) and interosseous (DML-INT) muscles...
were recorded and differences between the two latencies were computed. The optimal recording site was defined as the location at which the CMAP was as maximal as possible with a sharp initial negative deflection.

For both DML-APB and 2L-INT terminal latency indexes (TLI) and residual motor latency (RML) were calculated by means of the following equations:

- \( \text{TLI-APB} = \frac{\text{terminal distance}}{\text{motor NCV forearm} \times \text{DML-APB}} \)
- \( \text{TLI-LUMB} = \frac{\text{terminal distance}}{\text{motor NCV forearm} \times \text{DML-LUMB}} \)
- \( \text{RML-APB} = \frac{\text{DML-APB} \times \text{terminal distance}}{\text{motor NCV forearm}} \)
- \( \text{RML-LUMB} = \frac{\text{DML-LUMB} \times \text{terminal distance}}{\text{motor NCV forearm}} \)

**Statistical Analysis**

Data concerning clinical variables and nerve conduction studies were processed using Microsoft Office Excel and Access 2003 and all statistical analyses were performed using IBM SPSS Statistics 21.0.

Mean differences, standard deviations, and upper and lower limits of normal (ULN and LLN, respectively) were calculated for the reference group for all nerve conduction studies. ULN and LLN were defined as the mean plus or minus twice the standard deviation, respectively. The number of patients with an abnormal test result was determined using the ULN or LLN (TLI only). The sensitivity of each test was calculated as the number of patients meeting the criteria of clinical CTS and an abnormal electrodiagnostic test result, divided by the number of patients meeting the criteria of clinical CTS times 100%.

Comparison between patients and the reference group was performed with a \( t \)-test for continuous variables or a \( \chi^2 \) test for categorical variables, as appropriate.

Correlation between 2 tests was measured by means of the Pearson product-moment correlation for continuous variables or Spearman’s rho for ordinal variables.

\( P \)-values < 0.05 were considered as a statistically significant test result.

**Results**

**Clinical features**

One-hundred-and-sixty-two patients with clinical symptoms of CTS were included in this study, 35 men and 127 women. The mean age in this group was 48.7 (SD 13.6). The median duration of symptoms was 12 months. The mean
age and gender distribution were significantly different between patients and controls ($P < 0.01$ and $P < 0.05$, respectively) (Table 1).

### Electrophysiology

Details on electrophysiological features in patients and reference group are presented in Table 2; ULN and LLN of performed tests are presented in Table 2 as well.

The DML to the APB was $3.36 \pm 0.32$ ms and $5.23 \pm 1.86$ ms (mean ± SD) in the reference group and patients, respectively. 2L-INT was $0.08 \pm 0.54$ ms in the reference group vs. $1.86 \pm 1.79$ ms in patients. DML-APB was abnormal in 115 patients (70.6%), in 5 of whom the CMAP was not recordable. 2L-INT was abnormal in 92 of 158 (58.2%), in 4 of whom the lumbrical CMAP was not recordable. These differences were statistically significant ($P < 0.01$).

TLI-APB was abnormal in 130 of 160 patients (81.3%), TLI-LUMB in 101 of 154 (65.6%). RML-APB was abnormal in 118 of 160 patients (73.8%), RML-LUMB in 99 of 154 (64.3%) (Table 2, $P < 0.01$).

<table>
<thead>
<tr>
<th>Table 1. Clinical features in patients and reference group</th>
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<tbody>
<tr>
<td><strong>Patients</strong> $n = 162$</td>
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<tr>
<td><strong>Women</strong></td>
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<tr>
<td><strong>Age (mean ± SD, years)</strong></td>
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<td><strong>Median symptom duration (months)</strong></td>
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<tr>
<td><strong>Wrist included left/right</strong></td>
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<td><strong>Atrophy of APB</strong></td>
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<td><strong>Sensory loss</strong></td>
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<td><strong>Monofilament</strong></td>
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<td><strong>Two-point discrimination</strong></td>
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<td><strong>Weakness APB</strong></td>
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<td><strong>Weakness opponens pollicis muscle</strong></td>
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† $P \leq 0.05$; † $P \leq 0.01$; ‡ $n = 87$ (53.7%) bilateral complaints.

Sensory loss is defined as numbness reported by the patient at neurologic examination by means of two-point discrimination and/or monofilament.

APB = abductor pollicis brevis muscle
Sensitivity for all sensory tests was at least 79.4% (DIG1), but for motor conduction tests sensitivity was significantly lower, except for the TLI-APB, which was 81.3%.

In CTS patients without recordable SNAPs, i.e. no median nerve SNAP recordable from DIG1, DIG4, and PALM3 \((n = 27)\) with stimulation at the wrist, the percentage of abnormal motor nerve conduction tests was 100, which was significantly more abnormal than in patients with recordable SNAPs \((P < 0.01, \text{Table 3})\). DML-APB was abnormal in 100% of these patients; the APB CMAP was not recordable in 5 of these patients. 2L-INT was abnormal in 26 of 27 patients \((96.3\%)\); the lumbrical CMAP was not recordable in 4 patients, one patient had a normal test result. TLI-ABP, RML-APB, and RML-LUMB were abnormal in all

<table>
<thead>
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<th>Table 2. Electrophysiological features in patients and reference group</th>
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<tr>
<td><strong>Reference group</strong></td>
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<tr>
<td>((n = 47))</td>
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<tr>
<td></td>
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<tr>
<td>DIG1 (ms)</td>
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<tr>
<td>DIG4 (ms)</td>
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<tr>
<td>PALM3 (m/s)</td>
</tr>
<tr>
<td>DML-APB (ms)</td>
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<tr>
<td>2L-INT (ms)</td>
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<tr>
<td>TLI-APB</td>
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<tr>
<td>TLI-LUMB</td>
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<tr>
<td>RML-APB</td>
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<tr>
<td>RML-LUMB</td>
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</tbody>
</table>

Number of patients may vary due to missing values or not recordable SNAPs or CMAPs
<sup>‡</sup>ULN, upper limit of normal; LLN= lower limit of normal; DIG1, sensory median-radial comparison test; DIG4, sensory median-ulnar comparison test; PALM3, sensory short segment forearm-wrist vs. wrist-to-palm segment; DML-APB, distal motor latency to the abductor pollicis brevis muscle; 2L-INT, lumbrical-interosseous comparison study; TLI-APB, terminal latency index abductor pollicis brevis muscle; TLI-LUMB, terminal latency index lumbrical muscle; RML-APB, residual motor latency abductor pollicis brevis muscle; RML-LUMB, residual motor latency lumbrical muscle.

Sensitivity for all sensory tests was at least 79.4% (DIG1), but for motor conduction tests sensitivity was significantly lower, except for the TLI-APB, which was 81.3%.
Table 3. Electrophysiological features in patients with SNAPs recordable vs. patients with SNAPs not recordable

<table>
<thead>
<tr>
<th></th>
<th>SNAPs recordable n = 135</th>
<th></th>
<th>SNAPs not recordable n = 27</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Mean ± SD #Abnormal tests/#tests(%)</td>
<td>Mean ± SD #Abnormal tests/#tests(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DML-APB (ms)</td>
<td>4.76 ± 1.33’ 88/133 (66.2)“</td>
<td>8.08 ± 2.09’ 27/27 (100)“</td>
<td></td>
<td></td>
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<tr>
<td>DML increased</td>
<td></td>
<td>22/27</td>
<td></td>
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<tr>
<td>2L-INT (ms)</td>
<td>1.39 ± 1.20’ 66/131 (50.4)“</td>
<td>4.56 ± 2.16’ 26/27 (96.3)“</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2L-INT increased</td>
<td></td>
<td>22/27</td>
<td></td>
<td></td>
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<tr>
<td>TLI-APB</td>
<td>0.22 ± 0.05’ 103/133 (77.4)“</td>
<td>0.15 ± 0.03’ 27/27 (100)“</td>
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<tr>
<td>TLI-LUMB</td>
<td>0.29 ± 0.08’ 78/130 (60.0)“</td>
<td>0.20 ± 0.05’ 23/24 (95.8)“</td>
<td></td>
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<tr>
<td>RML-APB</td>
<td>3.66 ± 1.28’ 91/133 (68.4)“</td>
<td>6.85 ± 2.04’ 27/27 (100)“</td>
<td></td>
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<tr>
<td>RML-LUMB</td>
<td>3.24 ± 1.21’ 75/130 (57.7)“</td>
<td>6.18 ± 2.00’ 24/24 (100)“</td>
<td></td>
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</tr>
</tbody>
</table>

Number of patients may vary due to missing values or not recordable SNAPs or CMAPs.

*D M L-APB, distal motor latency to the abductor pollicis brevis muscle; 2L-INT, lumbrical-interosseous comparison study; TLI-APB, terminal latency index abductor pollicis brevis muscle; TLI-LUMB, terminal latency index lumbrical muscle; RML-APB, residual motor latency abductor pollicis brevis muscle; RML-LUMB, residual motor latency lumbrical muscle.

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Table 4. Lumbrical-interosseous (2L-INT) vs. DML-APB in patients

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Abnormal</th>
<th>Not recordable</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>DML-APB</td>
<td>45</td>
<td>2</td>
<td>0</td>
<td>47 (29.4%)</td>
</tr>
<tr>
<td>Abnormal</td>
<td>23</td>
<td>85</td>
<td>0</td>
<td>108 (67.5%)</td>
</tr>
<tr>
<td>CMAP not recordable</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>5 (3.1%)</td>
</tr>
<tr>
<td>Total</td>
<td>68 (42.5%)</td>
<td>88 (55.0%)</td>
<td>4 (2.5%)</td>
<td>160 (100%)</td>
</tr>
</tbody>
</table>

2L-INT = lumbrical-interosseous comparison study; DML-APB = distal motor latency to abductor pollicis brevis muscle; CMAP = compound muscle action potential.
cases and TLI-LUMB in 95.8% (Table 3). Numbers of normal and abnormal tests according to 2L-INT and DML-APB are presented in Table 4. Of 47 CTS patients with normal DML-APB test results, only 2 patients had an abnormal 2L-INT test result. In contrast, 23 of 68 patients with normal 2L-INT test results had an abnormal DML-APB test result (Table 4).

Discussion

Our results confirm that out of all available electrodiagnostic tests to confirm the clinical diagnosis of CTS, the sensory conduction studies are the most sensitive.\(^1\,^5\)

In severe CTS, however, sensory nerve action potentials often cannot be recorded and several types of motor conduction studies can then be applied to show the presence of conduction slowing in the median nerve across the wrist. Most often the distal motor latency of the median nerve is used, defined as the onset latency of the APB CMAP, obtained with stimulation of the median nerve at the crease of the wrist. A cut-off value of 4.0 ms without taking conduction distance into account has a reported sensitivity of 60 to 65\%.\(^1\) This cut-off value has been used in other studies; this is in accordance with reference values of our laboratory acquired in healthy individuals, however with applied conduction distance of 60 mm.\(^10\) However, as the DML varies approximately linearly with conduction distance, normograms can be used to compensate for this. Alternatively, one can choose for a fixed conduction distance of for instance 6 cm. However, for both methods, it is true that the measured distance of the recording electrode on the belly of the APB to the stimulus cathode is not an accurate representation of the length of the nerve as can be inferred from the anatomical course of the nerve through the wrist and carpal tunnel.\(^11,12\) Moreover, choosing a predetermined conduction distance of for instance 6 cm will often result in a rather awkward position of the cathode relatively proximal of the wrist where the median nerve lies deeply. This will need higher stimulus strength than necessary to meet the supramaximal demands and will result in discomfort, co-stimulation, and an uncertain position of the virtual cathode with inherent uncertainties of the true conduction distance. Moreover, the motor nerve conduction in the median nerve in healthy subjects may show a large variation as is obvious from normative data.\(^13,14\) For instance in our own normal data the motor nerve conduction velocity varies between 49 and 63 m/s (mean 55.4 ± 3.08 m/s), which obviously is reflected in the variance of the DML-APB, i.e. between 2.50 and 3.90 ms (3.36 ± 0.32). Values may be influenced by age,
temperature, and comorbidity. Therefore reference values in this test, even if concomitant variables are taken into account, are relatively uncertain and may be misleading.

A better alternative seems to be the lumbrical-interosseous comparison test as described in the methods. The comparative aspect of this test is advantageous as the motor conduction of the ulnar nerve is its reference. One may expect that, normally, nerve conduction velocities in distal segments of median and ulnar nerve do not differ much.\textsuperscript{15} In our data, however, the sensitivity of this test is even less than that of the classic DML-APB test in the whole group of patients. Moreover, 23 of 68 patients with a normal lumbrical interosseous comparison test result showed an abnormal DML-APB. In the subgroup of patients with severe CTS, i.e. in which no SNAPs are recordable and the motor tests could therefore be particularly useful, we found that all specific motor nerve conduction tests show a high sensitivity up to 100%. In only one patient the CMAP to the APB was not recordable while the lumbrical test showed abnormal results, which proved a distal median neuropathy. The sensitivity of the lumbrical interosseous comparison test in this study is considerably lower compared to reported sensitivities in the literature.\textsuperscript{16,17} This difference can be explained by the different cut-off value used. Preston et al.\textsuperscript{16} used a cut-off of 0.4 ms, and Chang et al.\textsuperscript{17} 0.6 ms but according to our reference population the cut-off value is 1.16 ms. We do not have a satisfying explanation for this difference.

The great advantage of the lumbrical test over the other motor nerve conduction studies is, that a DML of ulnar muscles can be used as a reference for the thenar DML. However, since in only one patient the lumbrical test had additional value to the DML-APB, we could not confirm the hypothesis that motor fibres to the lumbrical muscle at the level of the carpal tunnel are less vulnerable due to their anatomical/topographical position in the median nerve, as has been suggested by others.\textsuperscript{16,18-20} Moreover, the association between 2L-INT and DML-APB is high ($r = 0.87; P < 0.001$), so the additional value of the 2L-INT to the traditionally performed DML is marginal. Values in the same order of magnitude were found in the subgroup of CTS patients whose SNAP could not be recorded.

As TLI gives a DML correction according to nerve conduction velocity in the proximal segment of the median nerve and the terminal distance, it is not very surprising that we found that the TLI of APB showed a high sensitivity, even nearly similar to sensory tests in the whole patient group and that it reached values of 100\% and 95.8\% for TLI-APB and TLI-LUMB, respectively, in the subgroup of
patients whose SNAPs are not recordable. This is in accordance with previous reports, although normative values may vary due to methodological differences and the electrophysiological techniques used. One may argue that, due to the tortuous course of the median nerve in the carpal tunnel, it is virtually impossible to measure the distal conduction distance precisely. As a consequence, the TLI value may be biased to lower values as it may be expected that measured distances are underestimated. However, as the same argument can be used for the TLI value acquired in healthy subjects, this is not an issue if reference values are collected in the same way as in the patients are tested, which is what we did. Therefore, the TLI test appears to be a robust electrodiagnostic test in CTS.

Recently, Seror et al. evaluated the electrodiagnostic pattern of severe CTS in a large patient population. They found the 2L-INT to be present in severe cases, defined as a DML > 6.0 ms. Moreover, they found that the percentage of preservation of the SNAP from digit 2 was equal to that of the APB CMAP. Differences may be explained by different recording techniques; Seror et al., performed orthodromic sensory nerve conduction studies and applied averaging up to 200 traces. It is obvious that in daily clinical practice this cumbersome test is not feasible and that the TLI-APB measurement is a more practical solution for this category of patients.

The conclusions of our study apply not to patients with thenar atrophy. That is not to say that we omitted severe CTS as 17% of patients had absent SNAPs and low amplitude thenar CMAPs. However, we excluded patients with severe thenar atrophy and with this group probably the group of patients with severe CTS. This is probably numerically not a very significant group of patients and according to the study of Yates et al., in which only 5% of the total carpal tunnel syndrome population tested in the laboratory over a 2 and a half year period had severe thenar wasting. It would therefore be very worthwhile to investigate the group of very severe CTS patients with the aforementioned tests in the future.

Because we used the clinical diagnosis as the standard and all patients in this study had clinical CTS, specificity could not be calculated. Knowledge of specificities of motor nerve conduction studies would have been, however, of additional value. Also, the reference group was not completely matched for age and sex with the patient group and this could have influenced the results. In conclusion, according to our findings it appears that in CTS patients without thenar atrophy but with recordable SNAPs, motor nerve conduction tests are less sensitive to confirm the clinical diagnosis of CTS. The TLI of the APB in this group of patients however, shows a sensitivity which is similar to those of the sensory nerve conduction tests and is therefore, in this respect, superior.
to the other motor nerve conduction tests in CTS patients. In contrast to this, in CTS patients whose SNAPs are not recordable, all discussed motor tests are very sensitive. If no APB CMAP can be recorded, we recommend using the 2L-INT. However, in our study the chance of recording a lumbrical CMAP in these specific cases is rather low. In case of not recordable median nerve SNAPs, but a recordable CMAP to the APB, the 2L-INT has no additional value.

In addition, since for confirmation of the clinical diagnosis of CTS in some electrodiagnostic test protocols at least two abnormal test results are required, the fourth finger test (DIG4) and the TLI of the APB are recommended as minimal tests to begin with.
References


