

A handheld nerve conduction measuring device in carpal tunnel syndrome

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Objectives – The diagnostic utility and reliability of an easy-to-operate novel handheld nerve conduction tester in carpal tunnel syndrome (CTS) were evaluated. **Materials and methods** – Using the test device, the sensory nerve conduction (SNC) in the median and ulnar nerves were compared with each other in 194 patients with suspected CTS and 95 healthy controls. The test device results were compared with the results of nerve conduction studies (NCS) with traditional instrumentation. **Results** – The new device correctly classified 145 of the 149 hands (97.3%) without median nerve lesion and 171 of the 200 hands (85.5%) with median nerve lesions in traditional NCS. The specificity of the new tester compared with traditional instrumentation was 98%. The correlation coefficient for different technicians in different studies was 0.87. **Conclusions** – The findings obtained with the new tester in CTS were reliable and reproducible. This tester may increase availability of NCS in CTS.

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Key words: carpal tunnel syndrome; electrophysiological testing; ring finger stimulation; sensory nerve conduction velocity

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Introduction

The diagnosis of carpal tunnel syndrome (CTS) is primarily based on clinical symptoms and physical signs (1–3). Measuring nerve conduction (NC) velocity is a sensitive and specific adjunct technique in the examination of this syndrome (2). Nerve conduction studies (NCS) objectively determine the severity and pre-treatment baseline status of median nerve lesion in CTS and facilitates differential diagnosis (1, 4). Moreover, NCS are an objective and quick method of measurement, which supplement the clinical examination in the follow-up of patients with both untreated and treated CTS (5–8).

Efforts have been made to enhance the availability of NCS for suspected CTS by developing automated electrophysiological devices (9–13). AAEM concluded that the earliest versions of these devices were experimental and not substitutes for standard NCS, especially due to the low sensitivity of these NC measuring techniques (14). Due to their more advanced technology, the newer devices are more valid and reliable (12, 15).

In CTS, sensory nerve conduction (SNC) studies are more sensitive than motor nerve conduction (MNC) studies (2–3). In SNC examinations of patients with CTS the highest sensitivity and specificity values, around 0.90, have been achieved in median sensory and mixed NC from the wrist to palm segment and in comparison with median and ulnar sensory NC between the wrist and ring finger (2).

A new handheld NC device measures SNC in the median and ulnar nerves and uses the difference in these readings as an indicator of abnormality. This SNC index evoked by ring finger stimulation and supplemented with pure median nerve innervated forefinger stimulation have been earlier established as one of the most sensitive electrophysiological measures of median nerve lesion in CTS (16–22). This easy-to-operate new device and the method of measurement are meant for electrodiagnostic testing of median nerve lesion in CTS for occupational health and primary care settings. In the present multicentre study, the utility of the new device and method

was compared with that of traditional NCS in patients with suspected CTS.

Material and methods

The characteristics of the patients and control subjects are presented in Table 1. A series of 194 patients seen due to suspected CTS were referred for NCS at different study sites and included in the study. Two departments of hand surgery and one department of clinical neurophysiology in two university hospitals, a department of surgery in a district hospital and three study sites of a private clinical neurophysiology laboratory in three different towns participated in the study. The following exclusion criteria were used: patients with prior surgery for CTS, except if their non-operated hand was involved, history or NC findings of any other neurological disorder that may produce numbness or paraesthesias in the hand, such as polyneuropathy, radiculopathy, other peripheral distal local nerve lesion and myelopathy or stroke. The control group for both the traditional NC values as well as the new device NC values consisted of 95 healthy volunteers without diseases possibly affecting nerves or evident symptoms suggestive of CTS. They were mainly medical staff of the study sites and their relatives and acquaintances. The protocol was approved by the Ethics Committee of the University of Oulu.

The patients and controls completed both the Boston Carpal Tunnel Questionnaire (BCTQ) (23) and our own questionnaire with five questions including both primary and secondary symptoms: 1) distal numbness and tingling in the hand; 2) nocturnal complaints – mainly awakening due to numbness of the hand; 3) worsening of the symptoms upon use of the hand or certain types of provocation such as cycling; 4) pain in the hand; and 5) weakness and/or clumsiness of the hand. A careful neurological sensory examination, including touch with cotton wool, and motor examination of the hands, including strength evaluation of thumb abduction, Phalen’s and Tinel’s tests, were

performed on all patients. Specialists in hospital departments of hand surgery, surgery and clinical neurophysiology, including the authors UT, JR, TR, VH, UH and SK, and specialists in private departments, including the authors MK, PS, KH and TK, performed the clinical examination according to the structured study form. The controls had only Phalen’s test done.

Traditional NCS, based on the recommendations of AAEM, AAN and AAPMR (2), was performed on all patients. Previously operated hands and some of the asymptomatic hands were not examined. Median antidromic measurements of SCV on the digits II and IV and that of ulnar on the digits IV and V, SCV of the median and ulnar palm-to-wrist segment as well as median and ulnar MCV were examined. In addition, SCV measurements with the techniques used in the test device were performed on all patients in traditional NCS.

The test device (Mediracer CTS Test Device[®]; EMG Technologies, Oulu, Finland) is a small handheld battery-powered instrument, including adhesive surface electrodes specially manufactured for the device (Fig. 1). The main technical data are: stimulus output (0–50 mA, 0.2 ms duration square wave pulse maximum 163 V), resolution 10 bit, sampling frequency 29.2 kHz, high-pass filter 20 Hz, low-pass filter 3 kHz, stimulation frequency 2 Hz and measuring window 10 ms. Before the electrodes are inserted, the skin is cleaned with a suitable solvent for medical use and, if very rough,

Table 1 Descriptive statistics of the patients and control subjects. The figures are mean values and range in parentheses

Patients	<i>n</i>	Age, years	Height, cm	Weight, kg
All	194	49 (17–85)	165 (150–192)	75 (45–120)
Women	148	49 (17–85)	162 (150–180)	73 (45–120)
Men	46	49 (19–79)	174 (157–192)	84 (53–120)
<i>Control subjects</i>				
All	95	41 (16–80)	171 (153–192)	71 (42–125)
Women	51	40 (19–80)	165 (153–178)	62 (42–88)
Men	44	41 (16–80)	179 (162–192)	80 (60–125)

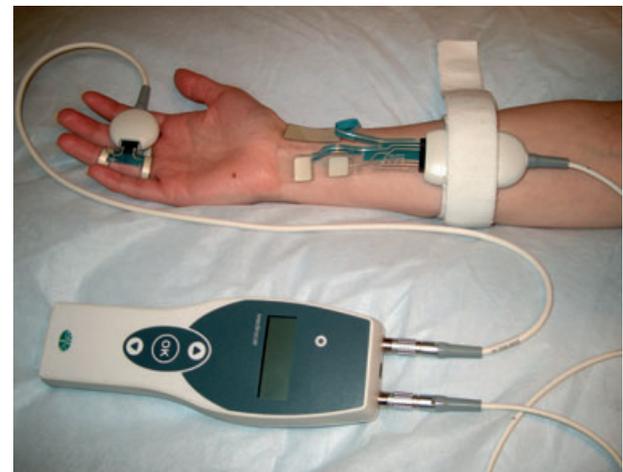


Figure 1. Placement of the stimulating (ring finger), recording (wrist, medial side) and ground (wrist, lateral side) electrodes in the ring finger examination. The distance between the cathode and the anode is 25 mm in both the stimulation and the recording areas. The device consists of control, stimulation and analysis units inside the device and a preamplifier, which is located at the end of the recording cable near the recording electrode.

softened by sand paper. After electrode insertion, the device first checks the battery charge level and thereafter the average noise level coming from both skin contact of electrodes and biological noise, such as poor relaxation. The test cannot be started before the noise level is below the set limit. First, ring finger responses are measured by stimulating the fourth digit nerves with ring electrodes placed 25 mm apart and recording the response from the wrist 10 mm above the distal wrist groove with electrodes 25 mm apart between the median and ulnar nerves (Fig. 1). The sensory threshold level of the study subject is defined, and stimulus intensity is adjusted automatically at 2.5 times the sensory threshold. A total of 64 stimuli are delivered and averaged. However, during stimulation, the tester checks the noise level from each response signal separately and rejects the signals recorded when the noise level is above the set limit. The same procedure is then applied to the forefinger. The automatic algorithm detects and marks the peaks coming later than 1.6 ms after the stimulus and exceeding 2 μ V. The device has three types of display on its own screen: 1) one peak x.x ms, 2) two peaks x.x ms, x.x ms and 3) no peaks. The signals are transferred to a PC through an infrared link. On the PC screen, the averaged signals can be viewed, and the peak latency values marked by the test device can be checked (Figs 2 and 3). The whole process of examining both hands takes 15 min. The temperature measurement was performed halfway between the stimulation and recording areas on the palm.

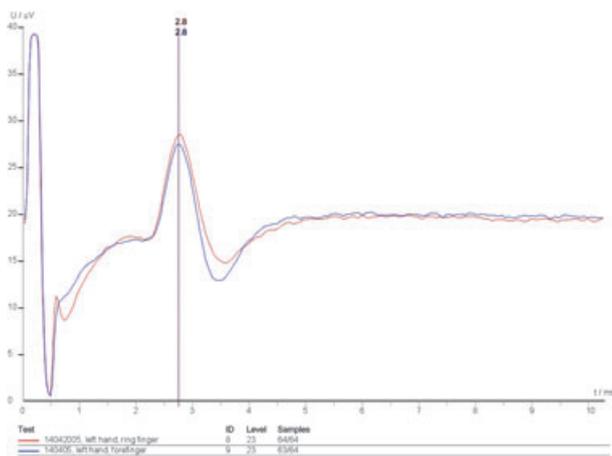


Figure 2. Normal median and ulnar sensory nerve responses measured with the new nerve conduction device. The superimposed sensory nerve responses were evoked separately by stimulation of the ring finger and forefinger. There is a single peak in the ring finger examination (i.e. no nerve conduction difference in the median and ulnar nerves), and the latencies of the ring finger and forefinger evoked peaks are equal.

Eight technicians (seven nurses and one MHSc) performed the new tester studies. Three were nurses working in clinical teams, who had not made neurophysiologic measurements earlier. Only two examiners were accustomed to performing NC measurements. With the exception of these two, the other technicians were working blindly, i.e. without knowledge of the traditional NC results. The reproducibility of the tester study was assessed in the subgroup of patients, i.e. 56 patients for inter-technician reproducibility.

According to traditional NCS the neurophysiologic severity of CTS was classified with a modified system of Padua et al. (24) as follows: 1) normal, no electrophysiological evidence of CTS; 2) mild CTS, slowed median SNC either absolutely or relative to ulnar SCV but normal median motor distal latency; 3) moderate CTS, moderately slowed median SNC (>4 SD) and prolonged median motor distal latency; 4) severe, prolonged median motor distal latency and either absent or profoundly decreased (2 μ V or less) median sensory response or reduced median motor amplitude. A total of 129 out of 194 patients had NCS abnormality suggestive of CTS, 78 of them in both hands. The patient was considered to have CTS without abnormal NCS if he/she had all three primary symptoms and two secondary symptoms or a positive Phalen's test. The neurophysiological severity of CTS was also graded in the new device study. The limits of this classification were determined using the above described classification in traditional NCS.

Statistical analysis

Multiple regression analysis was used to calculate control values for the median and ulnar nerve SNC and MNC parameters in traditional NCS. SNC and MNC were adjusted for age, height and skin temperature, and the level of 2.5 SD was used as the limit of abnormality. Confidence interval analysis was used to determine the control values at the level of 97.5%. The reproducibility of the inter-technician values and the reproducibility of the peak latencies of the test device and traditional NCS were tested using both Spearman's and Pearson's correlation analyses and linear regression curve fit. The latency differences between the groups were compared using the Mann-Whitney *U*-test.

Results

In the test device examination, both ring finger and forefinger stimulation usually evoked a single peak

response in the control subjects (Fig. 2). However, after ring finger stimulation, the evoked response included two peaks in one hand of five control subjects (as shown by the patient's data in Fig. 3), indicating slower SNC in the median nerve than in the ulnar nerve. In three of them this peak latency difference was 0.7 ms and in two of them 0.9 ms. Thus, at about a 97.5% confidence level, the abnormal latency difference between the peak latencies was 0.8 ms or more.

In the controls, the upper limit at the 2.5 SD level for the peak latency difference between the responses evoked by forefinger stimulation and ring finger stimulation (the first peak in those who had two peaks) was 0.6 ms. A peak latency difference of this size or more, i.e. up to 0.8 ms, occurred in four hands of the healthy controls. In two of these four hands ring finger stimulation also produced two peaks with an abnormal latency difference of 0.9 ms.

The clinical and questionnaire data are presented in Tables 1 and 2. In the test device study, the mean peak latency differences of a forefinger stimulated peak and a ring finger stimulated first or the only peak were equal in the patients without median nerve lesion in traditional NCS and in the controls (data: mean \pm SEM): patients (0.07 \pm 0.02 ms, $n = 148$, $P = 0.194$) and controls (0.06 \pm 0.01 ms, $n = 189$). On the contrary, this latency difference between the forefinger and ring finger peaks differed significantly between all the patient groups with median nerve lesion in traditional NCS and the controls: mild (0.68 \pm 0.04 ms,

$n = 58$, $P < 0.000$), moderate (1.19 \pm 0.04 ms, $n = 65$, $P < 0.000$) and severe (2.04 \pm 0.12 ms, $n = 14$, $P < 0.000$).

In visual signal evaluation compared with traditional NCS, the sensitivity of the new device was 97.3%, i.e. the device correctly detected 145 of 149 of the hands without median nerve lesion in traditional NCS (Table 3). The corresponding correct detection rate in the hands with median nerve lesion in traditional NCS was 85.5% (171/200 hands, Table 3). In the groups of mild, moderate and severe CTS, the test device also correctly identified most cases (Table 3). Compared with traditional NCS, the specificity of the new tester was 98%: in the group of 149 hands with normal traditional NCS findings, the new device yielded three abnormal NC results (2.0%). However, after ring finger stimulation, two of these three hands had two peaks with a latency difference of 0.7 ms, and two fulfilled our clinical criteria of CTS.

In 200 hands with a median nerve lesion in traditional NCS, 18 measurements (9%) with the new tester either failed due to poor signal quality, evoked no peaks after ring finger stimulation or yielded a normal finding in cases with a pure motor abnormality in traditional NCS (two hands). When the 16 cases with either poor signal quality or missing responses after ring finger stimulation were excluded (had to be referred for traditional NCS), the new tester identified 87.1% of the 62 mild, 96.3% of the 81 moderate and 100% of the 39 severe cases of CTS (Table 3).

The automatic program of the test device correctly identified 128 of 139 (92.1%) of the hands without abnormalities in traditional NCS and 147 of 182 (80.8%) of the hands with abnormal NCS findings. The digital data of 15 patients were lost upon transfer from the different study units to the main server.

After ring finger stimulation, the mean latency difference of the median and ulnar nerve peaks (the number of hands with double peaks in parentheses) was 1.0 ms in the patients with mild CTS (double peaks in 35/70) and 1.23 ms in the patients with moderate CTS (double peaks in 34/91). None of the patients with severe CTS had double peaks. The mean latency difference between the second digit median response and the fourth digit ulnar response was 0.67 ms in mild CTS, 1.12 ms in moderate CTS and 1.68 ms in severe CTS in the six of 44 (13.6%) hands producing any response upon forefinger stimulation.

Ring finger stimulation in the traditional and new device measurements yielded the following correlation coefficients of the latency differences of

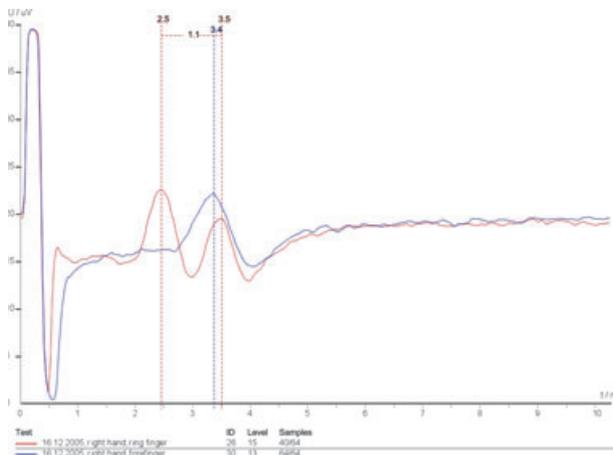


Figure 3. Mildly abnormal nerve responses evoked by the new nerve conduction tester in a patient with carpal tunnel syndrome. There are two peaks after ring finger stimulation at the wrist (i.e. conduction velocity is 1.1 ms slower in the median nerve than in the ulnar nerve). The latency of the wrist peak evoked by forefinger stimulation is also significantly longer (0.9 ms) than the first peak (ulnar peak) evoked by ring finger stimulation.

Table 2 Clinical data (mean values and range in parentheses) of the controls and the patients with normal nerve conduction findings as well as mildly, moderately or severely disturbed median nerve conduction in traditional nerve conduction measuring

	Normal NCS	Mild CTS	Moderate CTS	Severe CTS
Boston Carpal Tunnel Questionnaire results (scale 0–50)				
Patients	27.8 (12–43)	27.4 (12–43)	27.7 (12–42)	27.9 (15–43)
Controls	11.6 (10–34)			
5-Scale Questionnaire (scale 0–5)				
Patients	3.8 (1–5)	3.8 (2–5)	3.8 (1–5)	3.9 (5–2)
Controls	0.7 (0–4)			
Phalen's sign positive				
Patients				
Right hand	31%	36%	42%	73%
Left hand	33%	42%	47%	50%
Tinel's sign positive				
Patients				
Right hand	12%	7%	10%	19%
Left hand	14%	10%	12%	20%
Sensory deficits in median nerve territory				
Patients				
Right hand	30%	31%	46%	54%
Left hand	21%	28%	42%	45%
Weakness in thumb abduction				
Patients				
Right hand	8%	10%	13%	38%
Left hand	7%	15%	14%	20%

Table 3 Numbers and percentages of hands which, compared to traditional nerve conduction measurement, were correctly detected by the new device in the different groups of patients based on visual evaluation of the signals in (A) all examined hands and (B) after exclusion of the hands with a lacking signal, i.e. no peaks after ring finger stimulation, and poor signal quality, e.g. cutting of signal

	A, n (%)	Excluded	B, n (%)
Normal NCS			
Right hand	61/63 (96.8)	0	61/63 (96.8)
Left hand	84/86 (97.7)	2	82/84 (97.6)
Total	145/149 (97.3)	2	143/147 (97.3)
Mild CTS			
Right hand	27/36 (86.1)	4	27/32 (84.4)
Left hand	27/30 (90.0)	0	27/30 (90.0)
Total	54/66 (87.9)	4	54/62 (87.1)
Moderate CTS			
Right hand	41/47 (97.9)	5	41/42 (97.6)
Left hand	37/41 (95.1)	2	37/39 (94.9)
Total	78/88 (96.6)	7	78/81 (96.3)
Severe CTS			
Right hand	22/24 (91.7)	2	22/22 (100)
Left hand	17/20 (85.0)	3	17/17 (100)
Total	39/44 (88.6)	5	39/39 (100)
Motor CTS			
Right hand	0/1 (0)	0	0/1 (0)
Left hand	0/1 (0)	0	0/1 (0)
Total	0/2 (0)	0	0/2 (0)

the two peaks: 0.84 ($P < 0.001$) in right hands and 0.86 ($P < 0.001$) in left hands. The correlation coefficients for inter-technician day-to-day reproducibility was 0.74 ($P < 0.01$) for absolute latencies and 0.87 ($P < 0.01$) for peak latency differences. The peak latency differences were not temperature-dependent. For instance, the correla-

tion coefficient between the forefinger and ring finger peak difference and temperature was -0.083 (ns.) in all patients and -0.012 (ns.) in the controls.

In the ring finger examination with the new device, the neurophysiological severity of CTS was determined using the following values: normal: one peak with latency < 3.9 ms or two peaks with a latency difference < 0.8 ms, mild: two peaks with a latency difference 0.8–1.1 ms, moderate: two peaks with a latency difference 1.2 or more and severe: one peak, i.e. no median nerve response. The corresponding limits for the neurophysiological severity of CTS using the latency difference between the forefinger and ring finger values were: normal < 0.6 ms, mild 0.6–0.9 ms, moderate 1.0–1.6 ms and severe ≥ 1.7 ms or no response after forefinger stimulation. One or the other of these two classifications put most of the patients (89% in mild, 88% in moderate and 91% in severe CTS) into the same classes as the traditional NCS did.

Discussion

In patients examined for CTS suspicion, this new small handheld portable NC measuring device agreed with the findings of traditional NCS in 91% of the cases.

The test device study yielded only three false positive results (2.0%) in the patients compared with their traditional NCS. Moreover, on clinical grounds and according to our criteria, two of these three had CTS. False negative findings were

more frequent than false positive findings. This series included two hands with exclusively motor involvement, i.e. 1.0% of the electrophysiologically detected CTS hands, which agreed well with the earlier percentage of 1.2% (25). It is logical that the test device failed to detect these cases, because it measures merely SNC. Many other false negative findings were due to no response after ring finger stimulation or unsatisfactory data quality (e.g. excessive noise). One source of error may have been the technicians' lack of experience, as many of them had not performed NCS earlier. Missing responses are not always technical misses but may also be caused by polyneuropathy, which was also possible in some cases in this study, because lower limb NCS was not systematically performed. Both missing responses and unsatisfactory data are easily identifiable, and these patients should always be scheduled for traditional NCS. Fortunately, this group was small, consisting of 8% of the patients with abnormal traditional NCS, and the correct diagnosis was made based on complementary examinations. When this group was excluded from the group of false negative findings, the test device detected all severe cases and almost all moderate cases. There were, however, a few cases, mostly patients with mild CTS, for whom no abnormality was detected after either ring finger or forefinger stimulation, though significant median nerve slowing was seen in traditional measurements of the palm-to-wrist segment. The dilution effect of the longer distance in the finger stimulation recording than in the palm-to-wrist measuring possibly explains many of these cases. In ring finger stimulation, another possible explanation is the communicating branch from the median side of the ring finger in the palm to the ulnar nerve (26).

Compared with newer earlier automatic testers, the sensitivity values of the study device were of the same order (12, 15), though the present procedure is simpler to perform and does not need implementation on conventional EMG equipment as in one of these devices (12).

The measuring system used here involves certain advantages. First, the method is simple to perform. Only one recording point and two stimulation points are needed. The median and ulnar responses in the wrist could be recorded between the median and ulnar nerves as reported earlier (20). The riding effect, i.e. the mild slowing of median nerve conduction in CT, changes the shape of the response and shifts the peak latency when two signals are simultaneously recorded at the same point, as in the

present system. This phenomenon, however, does not prevent the use of this method in CTS, because according to our control values, the riding effect remained within the normal range and two clearly separate peaks were needed for an abnormality to be recorded. Mere ring finger stimulation, however, is not enough in all patients, as also pointed out earlier (21). In cases of more advanced CTS, the median response is often lacking. Hence, the only single peak due to ulnar activity could be interpreted as a normal finding. In that case, the stimulation of another finger innervated by the median nerve, such as forefinger stimulation by the test device, ensures that the median nerve lesion produces a delayed response or no response. Secondly, though absolute nerve conduction is dependent on skin temperature, the latency difference, which was used as an index in the present study, was not skin temperature-dependent. This facilitates the new tester examination: it is not necessary to warm the hand or even to measure skin temperature. Thirdly, when the test device is used, the usual demand for supramaximal stimulation intensity in NCS is not mandatory. The new device is only used to measure the latencies. In practice, in CTS, the occurrence of amplitude abnormality without a simultaneous latency change is extremely unusual (12). The routine stimulation intensity, two and a half-times higher than the subjective sensory threshold, is not always supramaximal, but seemed to be sufficient for latency measurements. Fourthly, the automatic peak detection algorithm of the test device correctly detected the peaks in most cases. This helps to interpret the results, but visual confirmation is still needed. Fifthly, the measuring algorithm is not device-dependent. The same measurement can be easily performed with any traditional NCS equipment, and as seen in the present study, the concordance between the test device and the traditional NCS results is high, especially in the used parameters, i.e. the peak latency differences.

The method has certain limitations. First, it is true that associated conditions, such as generalized neuropathy, radiculopathy or more proximal nerve entrapments than CTS, are missed if the examiner relies solely on the handheld tester. Therefore, the tester should be used for NCS only in cases with a clinical suspicion of CTS. If the signs and symptoms originally suggest a diagnosis other than CTS, traditional NCS is needed. Secondly, seldom, though never in this study, ulnar SNC may slow down instead of median nerve SNC after stimulation of the ring finger. In that case, however, the

clinical symptoms do not suggest primarily CTS. Moreover, forefinger stimulation produces normal findings.

The day-to-day inter-technician reproducibility was acceptable for the used index, i.e. the peak latency difference. The distance between the stimulating and recording electrodes may slightly vary between measuring on different days and by different technicians, leading to reduced reproducibility. In the present study the used index, the latency difference, was not temperature dependent. However, according to some earlier reports in some cases temperature does not always affect normal and pathological nerves in the same manner (27, 28). Also this might have caused the variance somewhat of because warming of the hands was not systematically performed.

The new handheld SNC measuring device seems to detect reliably the median nerve lesion in CTS. Further research is required to establish the utility of the new device also in the primary health care and occupational health care settings as well as in follow-up studies. The same concerns the effect of the new tester on economic impact and possible time savings in treatment of CTS.

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Disclosure

U. Tolonen, M. Kallio and V. Lesonen V will receive benefits from a commercial company (EMG Technologies Ltd) with which they are associated. The other authors will receive no direct or indirect benefit of any kind.

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