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ORIGINAL ARTICLE/ARTICLE ORIGINAL

# The relationship of pre- and postoperative median and ulnar nerve conduction measures to a self-administered questionnaire in carpal tunnel syndrome

## *Relation entre les mesures pré- et postopératoires des conductions des nerfs médians et cubitaux et les questionnaires d'autoévaluation dans le syndrome du canal carpien*

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**KEYWORDS**
Carpal Tunnel Release;
Carpal Tunnel Syndrome;
Nerve Conduction studies;
Hand-held device;
Boston Questionnaire

**Summary**
*Study aims.* — Following carpal tunnel release (CTR), only very modest correlations have been found between subjective symptoms and function indexes compared to neurophysiological measures. The objective of this study was to evaluate this relationship by comparing the self-administered Boston symptom severity score and function severity score questionnaire against nerve conduction studies (NCS) before and after CTR using two different electrophysiological techniques.
*Patients and methods.* — Carpal tunnel release was performed in 51 patients (62 hands). Pre- and postoperative NCS were evaluated using both conventional neurophysiological methods and by means of a new hand-held device.
*Results.* — Preoperatively there was almost no correlation between symptom severity and function scores and NCS results. Following surgery however, both symptom severity and function showed a modest, but significant improvement in their correlation to NCS (at highest $r = 0.405$, $P < 0.01$). This improvement in the relation of subjective measures to neurophysiological results was seen in both median nerve sensory and motor conduction as well as in ulnar nerve motor conduction.

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*Conclusions.* — In addition to median-nerve dysfunction, it might be suggested that ulnar nerve changes can contribute to symptoms of carpal tunnel syndrome in patients. Several associations were found using a median-ulnar sensory latency difference in the finger-wrist segment and a sensory conduction difference in the palm to wrist segment. Significant correlations were established by both conventional NCS and the new hand-held device.


**MOTS CLÉS**
Neurolyse du nerf médian ;
Syndrome du canal carpien ;
Neurographie ;
Boston Questionnaire

**Résumé**
*Objectifs de l'étude.* — Suite à une libération du canal carpien (CTR), seules des corrélations très modestes ont été constatées entre les symptômes subjectifs et les indices fonctionnels, d'une part, les mesures neurophysiologiques, d'autre part. L'objectif de cette étude était de mieux évaluer cette relation en comparant l'autoévaluation du score de sévérité des symptômes de Boston (BQSS) et le questionnaire du score de sévérité fonctionnel (BQFS) avec les études de conduction du nerf (NCS).
*Patients et méthodes.* — Des NCS ont été réalisées avant et après une CTR chez 51 patients. Nous avons comparé les méthodes traditionnelles de mesure et les mesures de conductions nerveuses avec celles obtenues en utilisant un nouveau dispositif portatif.
*Résultats.* — Avant l'intervention, il n'y avait presque pas de corrélation entre les scores BQSS et FS et les résultats de la NCS. Cependant, après intervention, les BQSS et FS ont connu une amélioration modeste mais significative dans leur corrélation avec la NCS (au maximum $r = 0405$, $p < 0{,}01$). Cette amélioration de la relation entre les mesures subjectives et les résultats neurophysiologiques a été constatée à la fois au niveau des conductions sensitives et motrices du nerf médian et des conductions motrices du nerf cubital.
*Conclusions.* — Nos résultats suggèrent qu'outre un dysfonctionnement du nerf médian, des altérations fonctionnelles du nerf cubital pourraient mener aux symptômes du syndrome du canal carpien. Plusieurs associations ont été trouvées en mesurant la différence de latence sensitive médian/cubital dans le segment poignet-doigts ainsi qu'une différence de conduction sensorielle dans le segment paume-poignet. Ces corrélations ont été établies aussi bien par les méthodes traditionnelles de NCS qu'en utilisant le nouveau dispositif portatif.


## Introduction

Median-nerve conduction studies (NCS) significantly improve in relation to baseline after carpal tunnel release (CTR) [16,27]. It is recognised in many patients with carpal tunnel syndrome (CTS) that, in addition to the median nerve distribution, the area innervated by the ulnar nerve may also exhibit paraesthesias [6]. In CTS, damage to ulnar-nerve sensory axons in Guyon's canal is also found [6]. Moreover, a recent report demonstrated an improvement in ulnar sensory conduction values after operation [19]. These ulnar nerve conduction disturbances become evident with increasing severity of CTS [6]. In CTS mild ulnar-nerve motor conduction disturbances have previously been described [5,28], though not in all studies [7].

In addition to NCS, several self-administered questionnaires such as the Boston questionnaire (BQ) have been used for the assessment of severity of symptoms and functional status. These have also been used to assess the results of surgery [16,27,12,14]. After surgery there is a significant improvement in the BQ scores [16,27,17,18]. The correlation between the NCS and the questionnaire score has, however, been often absent or modest at best [16,27,17,24]. It may be that the BQ and the NCS reflect different aspects of CTS. NCS exclusively evaluate nerve function, whereas the patient-orientated questionnaires take into account not only the symptoms of CTS but accompanying pathologies as well, such as flexor tenosynovitis. Some authors have suggested that both methods should be used together because these are complementary [16,27].

In this study, we aimed to evaluate the impact of CTR on various NCS measures performed both by conventional instrumentation and by the use of a new hand-held device designed to perform neurophysiological studies of CTS more easily. These results will be compared to a validated, self-administered questionnaire. The correlation between NCS measures and clinical scores before and after CTR was calculated. Any association between CTS, CTR and ulnar nerve NCS will also be assessed.

## Patients and methods

The study was based in secondary care in a single hospital that is the normal base for a regional Carpal Tunnel Service. Approval was sought from and granted by the local Ethics Committee.

Participants exhibiting symptoms suggestive of CTS were recruited from the normal referral stream to the Carpal Tunnel Service. They were referred by their general practitioners or other specialists within secondary care.

An experienced member of the study unit clinically assessed all those referred. If the clinical findings were consistent with a diagnosis of CTS, they were formally recruited to the study. In this phase, the study group consisted of 63 patients with clinical CTS. Clinical symptoms of CTS were

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unilateral in 34 participants and bilateral in 29. All 126 hands were tested by neurophysiological means using both the conventional and the hand-held nerve conduction measurement devices. This first part of the study, a methodological device comparison has been accepted for publication [8]. After re-assessment of clinical and neurophysiologic findings, 51 patients [40 females aged from 24 to 82 years (mean 53.6) and 11 males aged from 42 to 68 years (mean 49.6)] were allocated to open CTR. In eleven patients, both hands were operated on.

CTR was performed using a short 2—3 cm palmar incision under local anaesthesia without the use of a tourniquet or formal operating theatre [15]. In selected cases, i.e. in constricted, visually pale nerves, neurolysis was performed.

### Main outcome measures

In both preoperative and postoperative examinations the BQ [12] for CTS was used to quantify a symptom severity score (BQSS) and a functional severity score (BQFS).

Clinical neurophysiologists carried out the conventional NCS. Measurements were made using Keypoint® 4 and Keypoint® Portable, Medtronic (Skovlunde, Denmark). The portable hand-held device was operated by local clinicians after a brief familiarisation period. The portable device (Mediracer®, Mediracer Ltd, Oulu Finland) is a small hand-held instrument designed for distal nerve-conduction measurement in hands [30]. The first measurement was performed from 0.2 to 6.5 (mean 1.9) months before operation. The second measurement was performed from 1 to 7.2 (mean 5.5) months after the operation. During testing, the groups using the different measurement devices were blinded to the results obtained by the other group.

For both pre- and postoperative measurements, conventional device motor and sensory NCSs were performed for both ulnar and median nerves using standard felt pad or pre-gelled disposable surface electrodes (Alpine Biomed, Skovlunde, Denmark).

In these conventional NCS, median and ulnar orthodromic sensory nerve conduction latencies were measured by stimulating fore- and ring fingers and then recording at the wrist. Median and ulnar mixed nerve conduction velocities (mNCV) and nerve action potentials (mNAP) over palm to wrist segment with equal distances were recorded stimulating the interspace between 2nd and 3rd, and 3rd and 4th metacarpal bones for the median nerve and 4th and 5th for ulnar nerve studies. Median and ulnar compound muscle action potentials (CMAP) and distal motor latencies (DML) were also recorded with equal inter-electrode distances.

Using the new device, examination a stimulating electrode is wrapped around the finger being tested and the recording plate electrode is placed over the wrist between the median and ulnar nerves [30]. Tests are made on both the ring finger and the forefinger. For the ring finger, sensory peak latency (4PU) and double peak latency difference (4PM-U) was used. For the forefinger, the peak latency (2P) and the difference between forefinger and ring finger ulnar sensory peak latencies (2P-4PU) were used as the measures [30].

The control values for latencies and their differences are taken from the previous study [30]. In the conventional NCS, the neurophysiological severity of CTS was classified with Padua et al's five abnormal NCS classes [21] and simplifying this classification to the following three classes: mild (includes minimal), moderate and severe (includes extreme). The same classification was applied also to the hand-held device NCS data [30].

### Statistical analysis

The number and percentages of the changes in the neurophysiological severity classification and BQ score were documented. Differences in pre- and postoperative electrophysiological measures and BQ scores were evaluated by the Wilcoxon Signed Rank Test. The proportion of normalised individual electrophysiological measures was evaluated by McNemar's Test. Spearman's rho correlation was calculated between electrophysiological measures, neurophysiological severity classification and BQ scores. All variables found to be significant in univariate analyses were entered into the multivariate analyses. Multiple stepwise linear regression analysis was used to assess the relationship between pre- and postoperative values and their changes using SPSS 17.0 software.

## Results

### Nerve conduction measurements

Using conventional NCS methods both motor and sensory nerve conduction values of the median nerve were found to improve significantly after the operation (Table 1). Also the ulnar nerve DML improved and CMAP tended to improve, but the ulnar palm to wrist mNAP amplitude decreased and the mNCV remained unchanged (Table 1). Nerve conduction measures obtained by the new hand-held device also clearly improved after CTR (Table 1).

### Neurophysiological classification

The effect of CTR on neurophysiological classification [21] is seen in Table 2. In the conventional NCS measurements, the neurophysiological classification improved in 21 hands (34%) by at least one stage and worsened in three hands (5%). In the hand-held device measurements, an improvement of the classification was seen in 26 hands (42%) and worsening in none. In conventional NCS classification, an improvement was seen in 67% of severe and 39% of moderate cases while the number of the mild cases more than doubled with numbers of normal cases remaining unchanged. Using the hand-held device classification, 75% of the severe cases and 54% of the moderate cases improved, mild cases doubled and normal cases increased by 53%.

### Correlations between NCS and Boston questionnaire

Preoperatively, both the sensory and motor NCS measures correlated well with postoperative neurophysiological changes and in multiple stepwise regression analysis the preoperative values were the best independent predictors of

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**Table 1** Pre-and postoperative nerve conduction measures and the significance of the changes postoperatively in 62 hands.

| | Pre | Post | | |
|---|---|---|---|---|
| | Mean (SD) | Mean (SD) | Z-value | *P* |
| *Conventional nerve conduction measurement* | | | | |
| Distal Motor Latency (ms) | | | | |
| Median nerve | 4.7 (1.4) | 4.1 (0.7) | −5.34[a] | < 0.0001* |
| Ulnar nerve | 2.8 (0.2) | 2.7 (0.2) | −3.93[a] | 0.0001* |
| Compound Muscle Action Potential (mV) | | | | |
| Median nerve | 6.0 (2.9) | 6.8 (2.4) | −2.45[b] | 0.0144 |
| Ulnar nerve | 8.6 (2.4) | 9.0 (2.7) | −1.73[b] | 0.0840 |
| Mixed Nerve Conduction Velocity (m/s) | | | | |
| 2-3 interdigit to wrist segment | 39.1 (13.8) | 44.6 (7.7) | −4.60[b] | < 0.0001* |
| 3-4 interdigit to wrist segment | 34.2 (16.3) | 40.8 (10.8) | −5.12[b] | < 0.0001* |
| 4-5 interdigit to wrist segment | 57.6 (4.6) | 57.6 (3.6) | −0.20[a] | 0.8414 |
| Mixed Nerve Action Potential (μV) | | | | |
| 2-3 interdigit to wrist segment | 20.9 (15.4) | 23.6 (13.3) | −1.90[a] | 0.575 |
| 3-4 interdigit to wrist segment | 19.7 (16.8) | 24.6 (16.5) | −3.18[a] | 0.015 |
| 4-5 interdigit to wrist segment | 22.0 (14.3) | 18.0 (9.6) | −2.98[a] | 0.028 |
| Mixed Nerve Conduction Velocity Difference (m/s) | | | | |
| Median − Ulnar nerve | 23.0 (16.2) | 16.1 (9.6) | −4.73[a] | < 0.0001* |
| Orthodromic Sensory Peak Latency (ms) | | | | |
| Ring finger stimulation | 2.5 (0.3) | 2.5 (0.3) | −.368[a] | 0.7131 |
| Forefinger stimulation | 3.8 (1.0) | 3.3 (0.7) | −5.06[a] | < 0.0001* |
| Orthodromic Sensory Peak Latency Difference (ms) | | | | |
| Forefinger − Ring Finger latency Difference | 1.3 (1.0) | 0.8 (0.7) | −5.18[a] | < 0.0001* |
| *Hand-held device measurements* | | | | |
| Orthodromic Sensory Peak Latency (ms) | | | | |
| Ring finger stimulation | 2.6 (0.4) | 2.6 (0.3) | −2.015[a] | 0.0439 |
| Forefinger stimulation | 2.9 (1.8) | 3.0 (0.8) | −1.723[a] | 0.0849 |
| Orthodromic Sensory Peak Latency Difference (ms) | | | | |
| Forefinger − Ring Finger latency Difference | 1.1 (0.9) | 0.5 (0.4) | −5.32[a] | < 0.0001* |

Wilcoxon Signed Ranks Test. *$P$ is significant after Bonferroni adjustment.
[a] Based on positive ranks.
[b] Based on negative ranks.

their own change in most of the conventional NCS measures (Table 3). Besides being its own best predictor, the preoperative hand-held device sensory 2P-4PU peak latency difference also predicted the improvement of median nerve 3-4 palm to wrist mNCV ($R^2 = 0.662$, $P < 0.001$) and ulnar-median mNCV difference ($R^2 = 0.588$, $P < 0.001$), as displayed in Table 3.

Preoperative median or ulnar nerve NCS measures did not correlate to preoperative BQSS (Tables 3 and 4). Consequently, only the preoperative forefinger peak latency P2 measured by the hand-held device was weakly associated with preoperative BQFS ($r = 0.275$, $P < 0.05$), but the ulnar nerve findings did not relate to BQFS. Though preoperative correlation between the NCS findings and the BQ scores was lacking, many of the preoperative NCS measures correlated to postoperative BQSS scores and median nerve 3-4 palm to wrist mNAP also to BQFS scores (Table 4). Using stepwise regression the change in the median nerve 3-4 mNAP explained most of the variation in the postoperative questionnaire scores, especially in the BQFS (adjusted $R^2 = 0.251$, $P = 0.0039$). The most significant independent predictor for the change in both BQSS and BQFS was the 2P-4PU change measured with the hand-held device (Table 3). The change in ulnar CMAP had negative correlation between the change and the preoperative values of both BQSS and BQFS (Table 4). No significant correlation occurred between the CTS neurophysiological classification scores and either preoperative or postoperative BQSS and BQFS findings.

## Discussion

### The impact of carpal tunnel release on nerve conduction measures

Our results agree with earlier findings that not only median nerve but also ulnar nerve conduction improves after CTR [19]. Clear improvement was detected not only by using

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**Table 2** The impact of carpal tunnel release to the neurophysiological classification of the median nerve damage in the carpal tunnel syndrome according to Padua et al.

| | Conventional NCS device | | Hand-held NCS device | |
|---|---|---|---|---|
| | Pre | Post | Pre | Post |
| *Extreme* | | | | |
| All | 0 (0%) | 0 (0%) | 1 (2%) | 1 (2%) |
| dx | 0 (0%) | 0 (0%) | 1 (3%) | 1 (3%) |
| sin | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| *Severe* | | | | |
| All | 6 (10%) | 2 (3%) | 8 (13%) | 2 (3%) |
| dx | 4 (11%) | 1 (3%) | 4 (11%) | 1 (3%) |
| sin | 2 (7%) | 1 (4%) | 4 (15%) | 1 (4%) |
| *Moderate* | | | | |
| All | 28(45%) | 17 (27%) | 24 (39%) | 11 (18%) |
| dx | 19 (54%) | 12 (34%) | 16 (46%) | 7 (20%) |
| sin | 9 (33%) | 5 (19%) | 8 (30%) | 4 (15%) |
| *Mild* | | | | |
| All | 10 (16%) | 22 (35%) | 10 (16%) | 20 (32%) |
| dx | 3 (9%) | 13 (37%) | 4 (11%) | 13 (37%) |
| sin | 7 (26%) | 9 (33%) | 6 (22%) | 7 (26) |
| *Minimal* | | | | |
| All | 0 (0%) | 3 (5%) | 0 (0%) | 0 (0%) |
| dx | 0 (0%) | 1 (3%) | 0 (0%) | 0 (0%) |
| sin | 0 (0%) | 2 (7%) | 0 (0%) | 0 (0%) |
| *Normal* | | | | |
| All | 18 (29%) | 18 (29%) | 19 (31%) | 28 (45%) |
| dx | 9 (26%) | 8 (23%) | 10 (29%) | 13 (37%) |
| sin | 9 (33%) | 10 (37%) | 9 (33%) | 15 (56%) |

Pre- and postoperative proportions of the neurophysiological classification obtained by conventional and hand-held device.

a conventional device, but also by using the handheld device, which uses the comparison of the peak latencies of orthodromic median and ulnar sensory nerve responses as a measure of median nerve damage in the wrist. Similar latency comparison measure that is used in the new device appeared to be the most sensitive follow up measure in an earlier neurophysiological follow up study of CTS [3]. Strong Z-values for the new device measures were also obtained in our study. Distal sensory latencies also seem to be more sensitive than distal sensory NCVs in CTS [4]. Sensory nerve fibres are more susceptible to ischemic damage [29], and the use of comparative measures instead of absolute latencies has been shown to be more accurate and effective in detecting median nerve abnormalities consistent with the CTS [11,26]. Comparative methods also help control for confounding variables such as temperature, height, age, and other patient-related factors [26,31]. Combining these studies with our findings, evidence exists for the use of this new handheld device for the evaluation of nerve conduction improvement in CTR.

A slight postoperative conduction improvement was seen in ulnar nerve DML and a trend was also seen towards an ulnar nerve CMAP increase, thus supporting the idea that ulnar nerve fibres may be subject to compression forces in the Guyon's canal as a consequence of high pressure in the carpal tunnel [6]. A recent study demonstrated changes in the ulnar motor nerve fibres in non-operated CTS patients for the first time [32]. The findings are in line with the observations that both canals show a volumetric increase and decrease in pressure with respect to their pre-surgical status [25,1,2].

Several recent papers report changes in ulnar sensory nerve action potential (SNAP) both before and after operation [6,19,32] that were not seen in our study. This may be due to methodological differences. We measured the palm to wrist mNAP instead of pure ulnar SNAP and therefore as reliable and reproducible amplitude measurement as seen in the digit to wrist SNAP recording may not be as easy to achieve. In small hands, small intensity stimulation currents can spread to the area of the neighbouring nerve and produce artificially large amplitudes [20]. After CTR, the palmar anatomy may also change. For example, scar tissue may thicken the skin and it has been shown that thick palmar skin decreases sensory nerve amplitudes [9]. It is also the case that one month after CTR altered recruitment in both sensory and motor median nerve axons may occur [6]. This is also seen preoperatively in ulnar nerve motor axons [5] has been established. This results in a transient median nerve CMAP amplitude decrease. What happens to ulnar axons is not known. The execution time for our NCS

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**Table 3** Stepwise multivariate regression among the nerve conduction studies values and Boston questionnaire scores.

| Dependent variable | Constant predictor | Adjusted $R^2$ | S.E. of the estimate | *P* |
|---|---|---|---|---|
| *Conventional NCS measurements* | | | | |
| Median DML change | Preoperative Median DML | 0.799 | 0.34 | < 0.0001 |
| Median CMAP change | Preoperative median CMAP | 0.461 | 1.72 | < 0.0001 |
| Ulnar DML change | Preoperative ulnar DML | 0.258 | 0.19 | 0.0031 |
| Ulnar CMAP change | Postoperative ulnar CMAP | 0.334 | 1.57 | 0.0003 |
| Median 3-4 mNCV change | Preoperative 2P-4PU HD | 0.662 | 4.20 | < 0.0001 |
| Median-ulnar mNCV difference change | Preoperative 2P-4PU HD | 0.588 | 5.21 | < 0.0001 |
| Median 3-4 mNAP change | preoperative Median 3-4 mNAP | 0.449 | 10.07 | < 0.0001 |
| Ulnar mNCV change | Preoperative Ulnar mNCV | 0.437 | 3.00 | <0.0001 |
| Ulnar mNAP change | Preoperative ulnar mNAP | 0.522 | 6.90 | < 0.0001 |
| 4P change CD | Postoperative 4P CD | 0.377 | 0.23 | 0.0001 |
| 2P change CD | 2P change HD | 0.822 | 0.29 | < 0.0001 |
| 2P-4PU change CD | 2P-4PU change HD | 0.817 | 0.28 | < 0.0001 |
| *Handheld device measurements* | | | | |
| 4P change HD | Preoperative 4P HD | 0.260 | 0.22 | 0.0030 |
| 2P change HD | Preoperative 2P-4PU HD | 0.743 | 0.36 | < 0.0001 |
| 2P-4PU change HD | Preoperative 2P-4PU HD | 0.814 | 0.28 | < 0.0001 |
| *Boston Questionnaire* | | | | |
| BQSS change | 2P-4PU change HD | 0.196 | 0.88 | 0.0215 |
| BQSS preoperative | Postoperative ulnar CMAP | 0.093 | 0.87 | 0.4240 |
| BQSS postoperative | Median 3-4 mNAP change | 0.104 | 0.77 | 0.3107 |
| BQFS change | 2P-4PU change HD | 0.217 | 0.88 | 0.0113 |
| BGFS preoperative | No variables were entered into the equation | | | |
| BQFS postoperative | Median 3-4 mNAP change | 0.251 | 0.62 | 0.0039 |

*P* corrected for multiple comparisons. DML: Distal Motor Latency; CMAP: Compound Muscle Action Potential; mNCV: mixed Nerve Conduction Velocity; mNAP: mixed Nerve Action Potential; 2P: forefinger sensory nerve response peak latency; 4P: ring finger sensory nerve response peak latency; 2P-4PU: difference between forefinger and ring finger sensory nerve response peak latencies; CD: Conventional Device; HD: Hand-held Device

varied 1-7 months, which also might have caused some bias in our results. Median nerve DML and sensory conduction velocity has been shown to improve further between 1 and 6 months follow-up [24]. However, this was not seen in ulnar nerve measurements.

## Correlation between nerve conduction measures and clinical symptoms

Neither median nor ulnar nerve preoperative conduction measures correlated to preoperative BQSS in our study. Moreover, a very weak correlation between the median nerve sensory conduction and preoperative BQFS was seen, which is in accordance with earlier reports. [16,22]. In postoperative follow-up, the improvement in both BQSS and BQFS was best explained by the electrophysiological improvement measured by the handheld device, which utilizes the difference between median and ulnar sensory nerve readings.

Our findings of a significant correlation between the postoperative improvements in the distal nerve conduction and the total BQ scores is partly contradictory to many earlier results obtained 1, 6 and 12 months after CTR [16,27,24,10]. One explanation for this is the use of different electrophysiological measures used in comparisons. Considerable bias might also follow due to different execution time of the NCS, especially in median nerve responses but not so obviously in ulnar NCS. In two of the studies, the BQ score was evaluated in respect to follow-up improvement in the neurophysiologic severity classes of the patients [16,24]. In our study these class scores did not correlate either. When using individual electrophysiological measures, especially median-ulnar nerve conduction differences [27] as in our study, or a combined sensory index [13] for comparisons, significant correlations were found.

In the CTR study of Schrijver et al. [27], a modest correlation occurred separately between two single symptoms (night awakenings and night paraesthesias) and median-ulnar nerve sensory latency differences but not between the BQ scores and absolute sensory or motor conduction measures [27]. In our study median and ulnar sensory peak latency differences correlated with BQ changes. By using peak latencies instead of onset latencies, we possibly emphasised these correlations, since the peak latencies are somewhat more sensitive measures of median nerve pathology in CTS than the onset latencies [23]. In this context median-ulnar peak latency difference, not used in the study of Schrivjer et al. [27], seemed to be of particularly valuable.

Overall, the difference between median and ulnar orthodromic sensory nerve peak latencies, the main parameter used in the hand-held device, correlated best with both the neurophysiological improvement and the subjective

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**Table 4** Spearman's rho correlation table between pre- and postoperative values and their changes in neurophysiological measures and Boston Questionnaire.

| | BQSS | | | BQFS | | |
|---|---|---|---|---|---|---|
| | Pre | Post | Change | Pre | Post | Change |
| 2P pre HD | 0.179 | −0.025 | 0.189 | 0.275* | −0.109 | 0.314* |
| 2P post HD | −0.018 | −0.005 | 0.089 | −0.051 | −0.124 | 0.034 |
| 2P change HD | 0.203 | −0.053 | 0.191 | 0.307* | −0.111 | 0.320* |
| 2P - 4PU pre HD | 0.182 | −0.035 | 0.250 | 0.192 | −0.088 | 0.300* |
| 2P - 4PU post HD | 0.001 | −0.126 | 0.107 | −0.038 | −0.122 | 0.047 |
| 2P - 4PU change HD | 0.234 | −0.005 | 0.239 | 0.347** | −0.046 | 0.373** |
| 2P pre CD | −0.008 | −0.309* | 0.240 | −0.025 | −0.258* | 0.151 |
| 2P post CD | −0.074 | −0.268* | 0.186 | −0.010 | −0.219 | 0.165 |
| 2P change CD | 0.180 | 0.039 | 0.205 | 0.068 | −0.024 | 0.096 |
| 2P - 4PU pre CD | 0.028 | −0.277* | 0.254 | 0.048 | −0.200 | 0.199 |
| 2P - 4PU post CD | −0.065 | −0.241 | 0.136 | 0.025 | −0.126 | 0.151 |
| 2P - 4PU change CD | 0.183 | −0.079 | 0.308* | 0.071 | −0.167 | 0.156 |
| med DML pre | 0.056 | −0.235 | 0.258* | 0.060 | −0.218 | 0.195 |
| med DML post | −0.048 | −0.256* | 0.159 | 0.053 | −0.125 | 0.198 |
| med DML change | 0.083 | −0.218 | 0.266* | 0.039 | −0.230 | 0.153 |
| med CMAP pre | −0.051 | 0.123 | −0.142 | −0.083 | −0.042 | −0.129 |
| med CMAP post | 0.062 | 0.113 | −0.036 | −0.018 | −0.085 | −0.033 |
| med CMAP change | −0.123 | 0.047 | −0.162 | −0.107 | 0.039 | −0.161 |
| uln DML pre | 0.050 | −0.074 | 0.006 | −0.032 | −0.161 | 0.009 |
| uln DML post | −0.142 | −0.025 | −0.134 | −0.098 | −0.269* | 0.035 |
| uln DML change | 0.218 | −0.011 | 0.169 | 0.092 | 0.142 | −0.013 |
| uln CMAP pre | −0.071 | 0.084 | −0.065 | −0.206 | 0.045 | −0.201 |
| uln CMAP post | 0.088 | −0.032 | 0.167 | 0.053 | −0.109 | 0.140 |
| uln CMAP change | −0.254* | 0.047 | −0.266* | −0.371** | 0.108 | −0.405** |
| med 2-3 mNCV pre | −0.037 | 0.278* | −0.268* | −0.026 | 0.223 | −0.172 |
| med 2-3 mNCV post | 0.036 | 0.235 | −0.183 | −0.002 | 0.215 | −0.162 |
| med 3-4 mNCV pre | 0.057 | 0.364** | −0.207 | 0.003 | 0.235 | −0.160 |
| med 3-4 mNCV post | 0.068 | 0.255* | −0.107 | −0.007 | 0.182 | −0.145 |
| med 3-4 mNCV change | −0.030 | −0.274* | 0.240 | −0.062 | −0.203 | 0.074 |
| med-uln mNCV? pre | 0.009 | −0.340** | 0.266* | 0.034 | −0.233 | 0.189 |
| med-uln mNCV? post | −0.063 | −0.235 | 0.079 | −0.008 | −0.133 | 0.065 |
| med-uln mNCV? change | 0.078 | −0.202 | 0.330** | 0.062 | −0.146 | 0.207 |
| uln mNCV pre | 0.047 | 0.042 | 0.054 | 0.092 | 0.166 | 0.074 |
| uln mNCV post | 0.021 | 0.108 | −0.110 | 0.005 | 0.222 | −0.163 |
| uln mNCV change | −0.107 | −0.044 | −0.139 | −0.175 | −0.081 | −0.239 |
| med 3-4 mNAP pre | 0.045 | 0.405** | −0.221 | −0.047 | 0.279* | −0.220 |
| med 3-4 mNAP post | 0.039 | 0.113 | −0.053 | −0.092 | −0.034 | −0.104 |
| med 3-4 mNAP change | −0.000 | −0.255* | 0.206 | −0.070 | −0.303* | 0.154 |
| uln mNAP pre | 0.109 | 0.064 | 0.062 | 0.002 | 0.067 | −0.069 |
| uln mNAP post | 0.389** | 0.238 | 0.207 | 0.185 | 0.242 | 0.031 |
| uln mNAP change | 0.232 | 0.113 | 0.160 | 0.194 | 0.083 | 0.165 |
| med 2-3 mNAP pre | −0.047 | 0.265* | −0.190 | −0.121 | 0.086 | −0.218 |
| med 2-3 mNAP post | 0.046 | 0.094 | −0.038 | −0.120 | −0.071 | −0.118 |
| med 2-3 mNAP change | 0.024 | −0.281* | 0.135 | −0.110 | −0.257* | 0.049 |

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). 2P: Sensory nerve response peak latency for forefinger stimulation; 2P-4PU: difference between forefinger and ring finger sensory nerve response peak latencies; DML: Distal Motor Latency; CMAP: Compound Muscle Action Potential; mNCV: mixed Nerve Conduction Velocity; mNCV: ulnar-median mixed Nerve Conduction Velocity difference; mNAP: mixed Nerve Action Potential; HD: Hand-held Device; CD: Conventional Device; med: median nerve; uln: ulnar nerve.

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improvement after CTR. It is significant that a similar median - ulnar latency difference parameter in an earlier neurophysiological follow up study of CTS appeared to be the most sensitive follow up measure [3]. Moreover, distal sensory latency seems to be also more sensitive than distal sensory NCV in CTS [4] Combining these studies with our findings, there is further support for the use of this parameter for the evaluation of CTR.

Our study thus confirmed that not only median-nerve but also ulnar-nerve distal conduction is improved after CTR. Similarly, the improvement in total symptom and functional score correlates to NCS improvement. Finally, the new small hand-held NCS device seemed to be a useful tool for the neurophysiological follow up of patients following CTR.

## Disclosure of interest

M.A.K.: owner (3.76%), Board Member, Mediracer Ltd.
E.U.T.: owner (5.88%), Mediracer Ltd.

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Since this study was completed, the senior author Professor Uolevi Tolonen has died. His contribution and presence is greatly missed by his co-authors, both in Finland and the United Kingdom.

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