M27

Surface Recording Technique, Study from Second Lumbrical (2L) and *Interosseous* (INT) Muscles

Original Settings Sensitivity was 1–2 mV/division, sweep speed was 2 ms/division, and the machines used were a Dantec Counterpoint and a Neuromatic 2000. Low-frequency filter, high-frequency filter, and duration of pulse were not specified.

Position This study was performed in the supine position.

Recording The active electrode (A) was placed slightly lateral to the midpoint of the third metacarpal space, over the belly (motor point) of both the second lumbrical (2L) and *interossei* (INT) muscles [1]. The reference (R) was placed over a bony prominence of the proximal interphalangeal joint of the digit II (Fig. 1). The motor point to the 2L was identified by an initial negative deflection with the fastest rise time. Occasionally, the median mixed nerve potential was seen prior to the motor response. However, this potential never obscured the initial negative deflection of the 2L compound muscle action potential (CMAP). Surface recording was made with 10 mm silver disks. The ground (G) electrode position was not mentioned in the text; it could be placed on the palm or on the dorsum of the hand. The figure shows the ground positioned on the palm.

Stimulation The stimulations were at the wrist, on the median nerve (S1) and on the ulnar nerve (S2), using an identical distance for both stimulations from the active electrode (A) positioned on the palm (Fig. 1). No fixed distance was mentioned in the text (mean distance of the wrist to the active electrode was 9.5 cm, range 8–12 cm).

Measurements Distal latency (ms) of the CMAP, for both 2L and INT muscles, was measured from the stimulus onset to the onset of the negative deflection of the CMAP. Latency difference (2L–INT DIFF) was measured between these two latencies. Amplitude (mV) of the CMAP was measured from the baseline to the peak of the negative deflection. Palmar skin temperature was maintained above 31 °C. The authors performed 2L–INT DIFF test in 51 control hands (Table 1) from either healthy volunteers or patients (age range 18–50 years, average age 31 years) referred to the EMG laboratory with symptoms not referable to carpal tunnel syndrome (CTS) and 107 consecutive hands (Table 2) of patients (age range 21–98 years, average age 49 years) referred with clinical symptoms and signs suggestive of CTS (patients were divided into four groups based on the least-sensitive standard median study needed to demonstrate CTS), female/male ratio 3:1, right-hand/left-hand ratio, approximately 2:1. For the authors, the advantages of this technique include: (1) both 2L and INT muscles can be recorded from the same active electrode in the distal palm, (2) the axons innervating both muscles are of similar diameter size, (3) the temperature is comparable for each distal nerve segment and muscle, (4) identical distances to each muscle are used, allowing direct comparison of distal motor latencies, (5) 2L is relatively spared in CTS, even in severe CTS when the *abductor pollicis brevis* (APB) muscle is completely wasted; a CMAP can be reliably recorded from the 2L, (6) this technique creates an ideal internal control for the median motor studies in which several variables are held constant (muscle and axon size, temperature, and distance).

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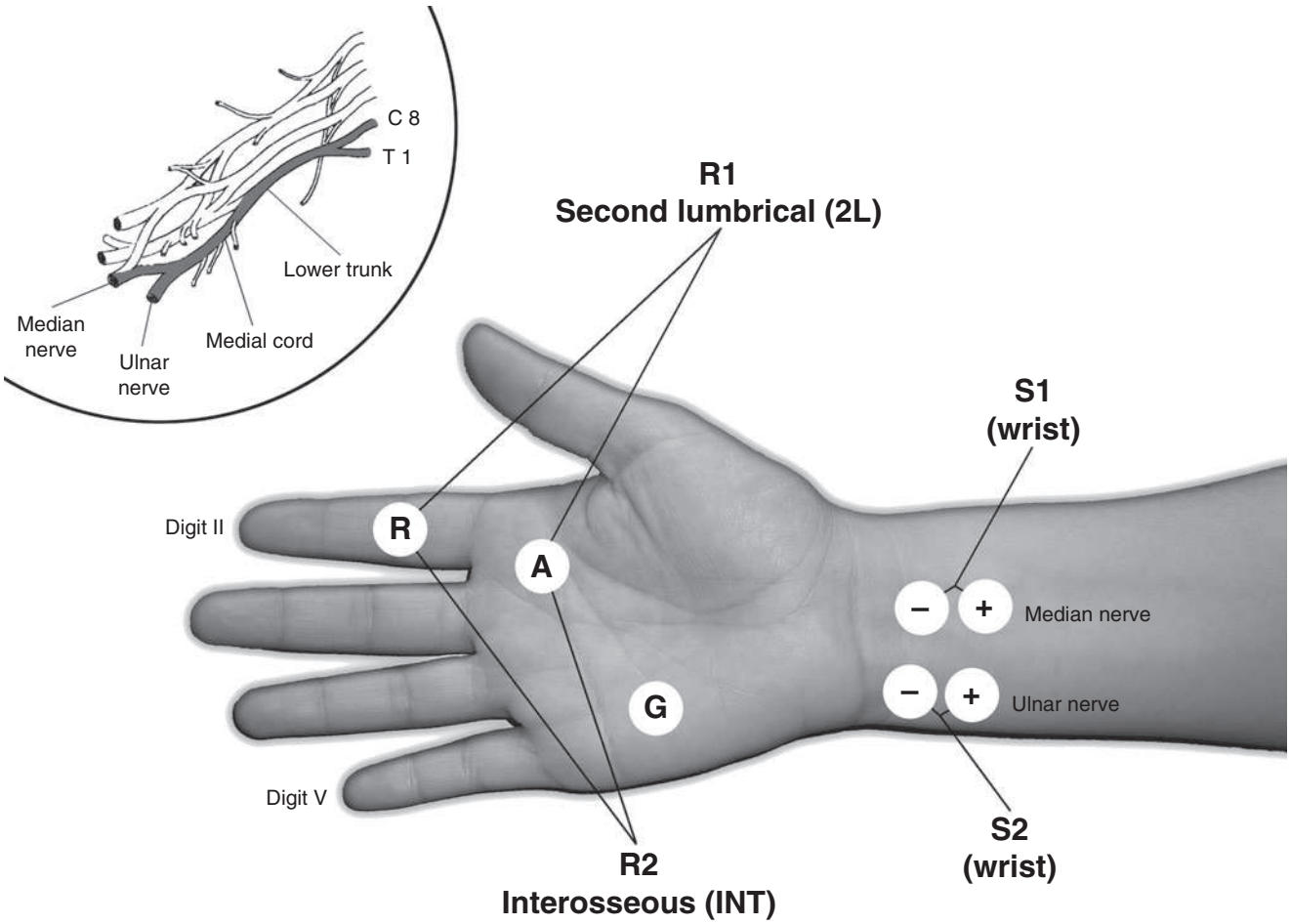


Typical waveform (wrist – 2L muscle, wrist – INT muscle):

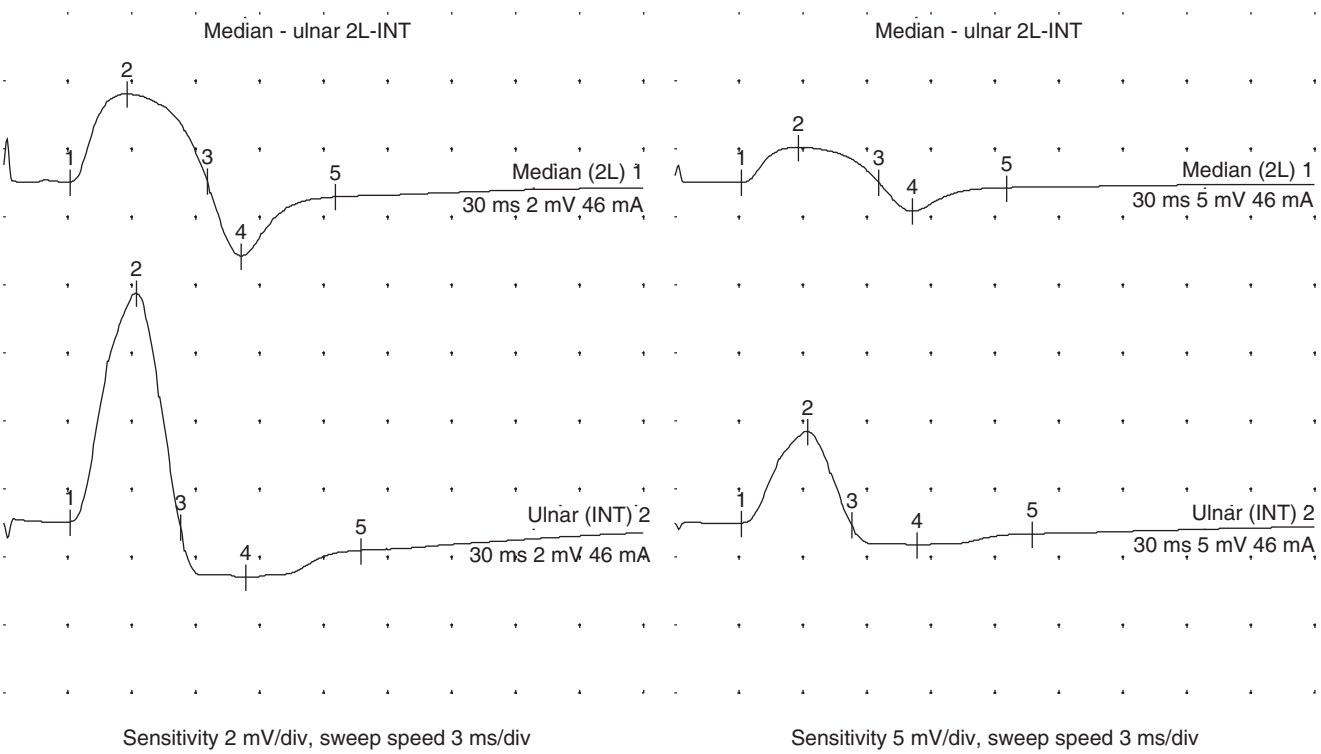


Fig. 1 Compound muscle action potentials (CMAPs) recorded at the hand from the 2L and INT muscles; stimulation of the wrist: 2L recording (*upper trace*) and INT recording (*lower trace*)

Table 1 Reference values

Normal values [1]	Mean ± SD	Mean ± 2SD	Range	Limit of normal
Wrist–2L, distal latency (ms)	3.22	3.98	2.10–4.00	
Wrist–INT, distal latency (ms)	3.15	3.91	2.00–4.00	
2L–INT DIFF (ms)	0.08	0.40	(–0.30)–0.40	≤0.4
Wrist–2L, amplitude (mV)	2.81	0.40	1.00–6.00	
Wrist–INT, amplitude (mV)	6.55	1.67	2.60–13.60	

Table 2 Reference values

Pathological values [1]	Sensitivity	
	N	2L-INT DIFF
Severe CTS (58 hands)	58/107 (54 %)	57/58 (98 %)
Moderate CTS (22 hands)	22/107 (21 %)	22/22 (100 %)
Mild CTS (12 hands)	12/107 (11 %)	10/12 (83 %)
Very mild CTS (15 hands)	15/107 (14 %)	13/15 (87 %)

Comment

For Preston and Logigian [1], the 2L–INT DIFF was abnormal in 98 % (57/58) of patients with severe CTS (with prolonged or absent distal motor CMAP from the APB muscle). In patients with moderate CTS (with normal distal motor latency of CMAP from the APB muscle but prolonged latency or absent antidromic sensory to the digit II), the 2L–INT DIFF was abnormal in 100 % (22/22) of patients. In mild CTS (with normal distal motor latency of CMAP from the APB muscle and normal latency of the antidromic sensory to the digit II but prolonged median mixed-nerve palmar latency), the 2L–INT DIFF was abnormal in 83 % (10/12) of patients. When the only abnormal standard median study was the difference between the median and ulnar mixed-nerve palmar latencies (very mild CTS), the 2L–INT DIFF was abnormal in 87 % (13/15) of all cases. In 75 % (6/8) patients with possible CTS (normal standard conduction studies), the 2L–INT DIFF was abnormal. So, a prolonged lumbrical–*interossei* latency difference (2L–INT DIFF>0.4 ms) was found to be a sensitive indicator of CTS in all patient groups.

Muellbacher et al. [2] observed a considerable variability in the latency and amplitude of the CMAP in the same subject by searching the optimal recording site in the distal palm (using identical distances from the active electrodes—8 cm, 10 cm, 12 cm), and if the active recording electrode was not optimally placed over the motor point, the amplitudes and rise-times of the 2L and INT were lower, and the lumbrical–*interossei* latency differences increased, and the commonly used cutoff values were not valid [3]. Al-Shekhlee et al. [3] suggested as the optimal location for the active recording electrode a site, which can be approximated by first marking the midpoint of the third metacarpal (half the distance between the distal wrist crease and the proximal skin crease of the third metacarpal–phalangeal joint) and then measuring 1 cm proximal and 1 cm lateral from that point.

Table 3 Reference values

Normal values [4]	Mean	Range	Limit of normal
Wrist–2L, distal latency (ms)	3.30 ± 0.20	2.85–3.70	3.80
Wrist–INT, distal latency (ms)	3.10 ± 0.20	2.25–3.50	3.80
2L–INT latency DIFF (ms)	0.20 ± 0.20	0.00–0.60	0.60

Table 4 Reference values

Pathological values [4]	Mean	Range
Wrist–2L, distal latency (ms)	4.65 ± 1.17	2.95–9.65
Wrist–INT, distal latency (ms)	3.03 ± 0.35	2.20–4.15
2L–INT latency difference (ms)	1.59 ± 1.21	0.10–5.80

Foresti et al. [4], using the same distance (mean 11 cm) from the active recording electrode, performed 2L–INT DIFF test in 50 hands (Table 3) from 25 healthy subjects (average age 42 years, age range 18–69 years, male/female ratio 2.5:1) and 100 consecutive patients (Table 4) with suspected CTS (mean age 49 ± 11.9 years, age range 27–78 years, male/female ratio 3:1). They used a five-channel Mystro-Plus electromyograph. The hand temperature was monitored and, if it was less than 32 °C, the limb was warmed. The distal motor latency (DML)–onset latency was measured, and the DML difference between 2L onset latency and INT onset latency was calculated. The authors also studied 200 hands from 100 consecutive patients with suspected CTS (mean age 49 ± 11.9 years, age range 27–78 years, male/female ratio 3:1).

Comment

Foresti et al. [4], in a sample of 200 hands from 100 patients with suspected CTS, found 159 hands with a clinical suspicion of CTS, and 149 hands of these were found to have electrophysiological signs of CTS (10 hands were normal); 61 patients had bilateral CTS. For median 2L DML, the authors found high values of sensibility (85.23 % and 80.10 %) and specificity (>99 %, 89.10 %), on the base of an electrophysiological Gold Standard and using a clinical Gold Standard, independent of the electrodiagnostic procedures, respectively. For the median-ulnar 2L–INT DIFF test, the authors found high values of sensibility (87.23 % and 87.01 %) and specificity (96.87 %, 92.50 %), on the base of an electrophysiological Gold Standard and using a clinical Gold Standard, independent of the electrodiagnostic procedures, respectively.

In a short report, Trojaborg et al. [5], studying 63 control subjects (42 women, 21 men, mean age 42 years, age range 22–82 years), found normal values (3.4 ms±0.1 ms and 3.2±0.1 ms for 2L and INT, respectively) in agreement with those by Preston and Logigian [1] and Foresti et al. [4]. In 170 hands of 105 patients with symptoms and signs of CTS (70 women and 35 men, mean age 54 years, age range 23–90 years), they found an abnormal 2L–INT DIFF test in 83 % of CTS hands, while distal latency to the APB muscle was abnormal in 56 % only. They found a linear relation between the percentage prolongation of the distal latency to the APB muscle and that to the 2L muscle, indicating that fibers to these muscles may be equally entrapped. The authors also found a correlation between the prolonged distal latency to the 2L muscle (72 % of all hands) and the slowed orthodromic conduction velocity from the digit II and digit III, supporting the relationship that half of the fibers of the digit II and digit III run in a separate *funiculi*, close to those subserving the lumbricals [6]. The authors concluded, according to their findings, that the determination of the difference between latency to the second lumbrical and *interossei* (2L-INT DIFF test) is useful when routine tests are normal, even in cases with the absence of the SNAPs or CMAPs.

In 1997, Vogt et al. [7] applied a 2L–INT DIFF test to healthy controls and patients with CTS and polyneuropathy (PNP), stimulating the median nerve, 2 cm proximal at the wrist, and moving laterally at exactly the same level to stimulate the ulnar nerve. Their protocol differs from the arrangement of Preston and Logigian [1], who stimulated both the nerves at equal distances (range 8–12 cm) from the recording electrode. They chose anatomical landmarks criteria (Fig. 2) because in this

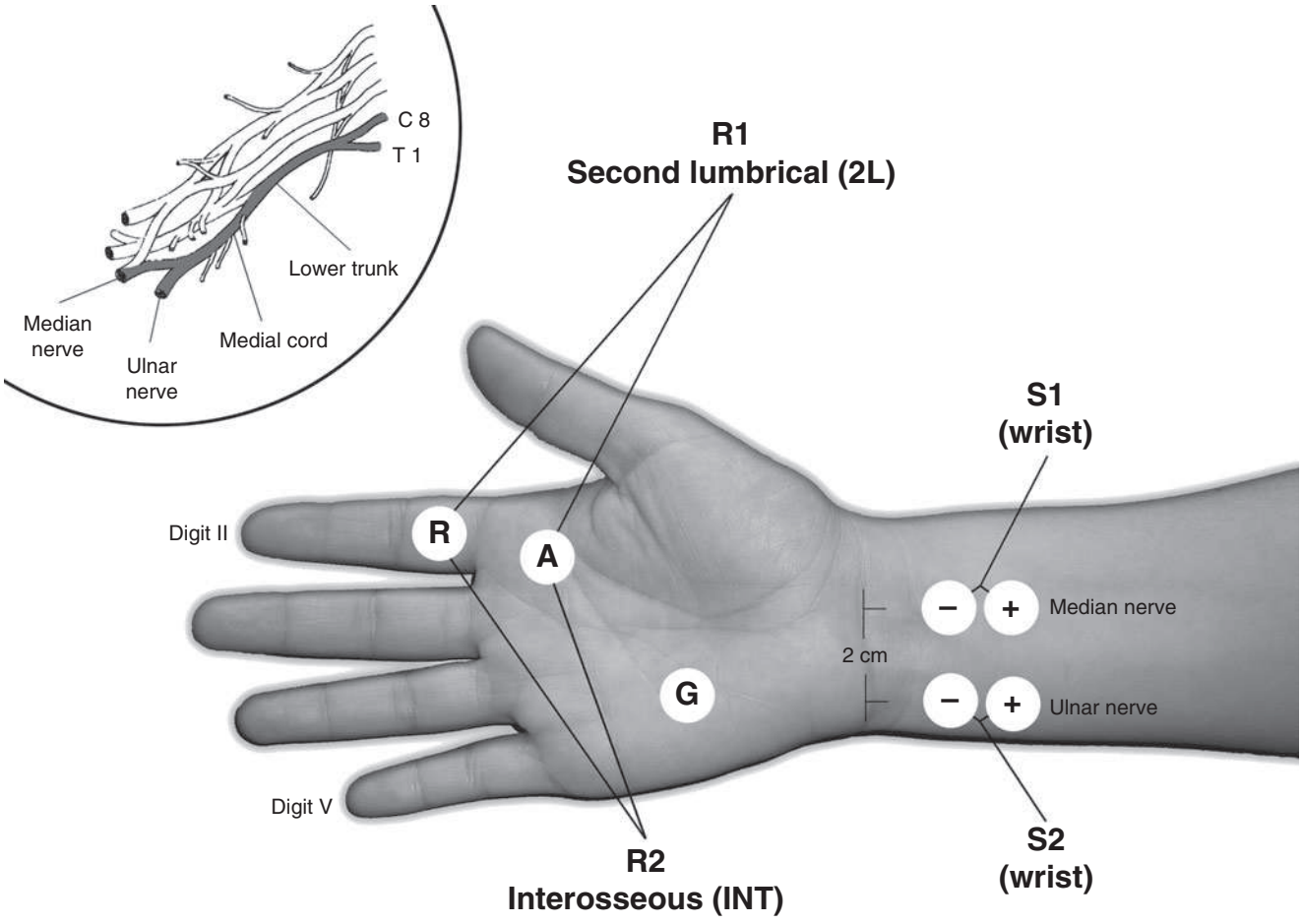


Fig. 2 2L–INT test; conduction distance set by anatomical landmarks

Table 5 Reference values

Normal values [7]	Mean
Wrist–2L, distal latency (ms)	3.8 ± 0.4
Wrist–INT, distal latency (ms)	3.3 ± 0.4
2L–INT latency DIFF (ms)	0.45 ± 0.25

Table 6 Reference values

Pathological values [7]—Group 1	Mean
Wrist–2L, distal latency (ms)	6.2 ± 1.5
Wrist–INT, distal latency (ms)	3.3 ± 0.5
2L–INT latency DIFF (ms)	2.7 ± 1.4
Pathological values [7]—Group 2	Mean
Wrist–2L, distal latency (ms)	5.5 ± 1.7
Wrist–INT, distal latency (ms)	4.5 ± 1.6
2L–INT latency DIFF (ms)	1.1 ± 1.2
Pathological values [7]—Group 3	Mean
Wrist–2L, distal latency (ms)	7.1 ± 1.4
Wrist–INT, distal latency (ms)	4.2 ± 1.8
2L–INT latency DIFF (ms)	2.9 ± 2.0

way, there was a constant relationship between the lengths of both nerve segments, independent of measurement errors.

All patients (Tables 5 and 6) were divided by Vogt et al. [7] into four groups: Group 1—87 hands of 77 healthy volunteers, age range 25–72 years, mean age 43 years; Group 2—107 hands of 92 patients with clinical symptoms of CTS, age range 29–68 years, mean age 49 years; Group 3—34 hands of 30 patients with PNP, age range 5–73 hands, mean age 52 years; Group 4—27 hands of 22 patients with PNP and coexisting clinical symptoms of CTS, age range 39–72 years, mean age 58 years.

Comment

In the study by Vogt et al. [7], patients with CTS (Group 1) and PNP+CTS (Group 3) showed a markedly increased 2L–INT DIFF as compared to the controls. In the PNP+CTS group (Group 3), the 2L–INT DIFF was normal in only one patient and greater than 1.5 ms in 19 patients (73 %). In the PNP group (Group 2), the 2L–INT DIFF was slightly increased in 6 of 34 patients having a 2L–INT DIFF greater than 1.0 ms (mean 1.1 ms). The 2L–INT DIFF test was significantly prolonged in both CTS patients (Group 1) as compared to controls and patients with only PNP (Group 2). Setting the upper normal limit to 1.0 ms, the 2L–INT DIFF test was abnormal in 26 of 27 patients and was abnormal in only 6 of 34 patients with PNP. The specificity of the 2L–INT DIFF test was 78 %. For the authors, the 2L–INT DIFF test represented the best technique in the diagnosis of CTS in patients with an underlying chronic demyelinating PNP.

Table 7 Reference values

Normal values [8]	Mean ± SD	Range	Limit of normal
2L–INT latency DIFF (ms)	0.30 ± 0.09	0–0.5	≤0.5

Table 8 Reference values

Pathological values [8]	Mean ± SD	Range	Limit of normal
2L–INT latency DIFF (ms)—non-CTS patients	0.28 ± 0.12	0–0.7	≤0.5
2L–INT latency DIFF (ms)—CTS patients	1.47 ± 0.82	0.5–6.2	≤0.5

To record the 2L–INT distal motor latency, Loscher et al. [8], using the method proposed by Vogt et al. [7], stimulated both median and ulnar nerves on points (S1, S2) 2 cm proximal to the intermediate flexure line at the wrist (anatomical landmarks criteria). The authors preferred this stimulation protocol to avoid measurement errors, and because a constant relationship between the length of the nerve segments was still maintained. CMAPs recordings were made, placing the active electrode on the same motor point for both 2L and INT muscles (on the palmar aspect of the second intermetacarpal space); reference electrode was placed on the palmar aspect of the proximal phalanx of the digit II. They recorded 2L–INT DIFF in 100 asymptomatic hands (Table 7) of 87 healthy subjects (age range 15–86 years, mean age 47 years), and in a large sample (Table 8) of non-CTS patients (450 consecutive hands from 417 patients classified as 276 CTS and 174 non-CTS, based on clinical criteria, age range 16–92 years, mean age 50 years) and CTS patients (276 patients).

Comment

Using the 2L–INT DIFF, Loscher et al. confirmed the clinical diagnosis of CTS in 269 of 276 hands, resulting in a sensitivity of 97.5 %. For the authors, 2L–INT DIFF test was a reliable and easy-to-perform conduction test. It was a highly sensitive method for assessing the median nerve function across the carpal tunnel, similar to the combination of the standard motor and sensory nerve conduction studies.

Like Löscher et al. [8], other authors measured 2L–INT latency difference in controls and its sensitivity in patients with a clinical diagnosis of CTS, using the protocol of Preston and Logigian [1]. Chang et al. [9] used a fixed 10 cm distance (Fig. 3) from the active electrode for both sites of stimulation (S1—median nerve, S2—ulnar nerve); Meena et al. [10] used instead a fixed 8 cm distance from the 2L–INT motor point (Fig. 4). During a 1-year period, Chang et al. [9] performed several sensory and motor conduction techniques to compare the sensitivities in the diagnosis of CTS. They used a Nicolet Viking IV or Dantec Keypoint 4

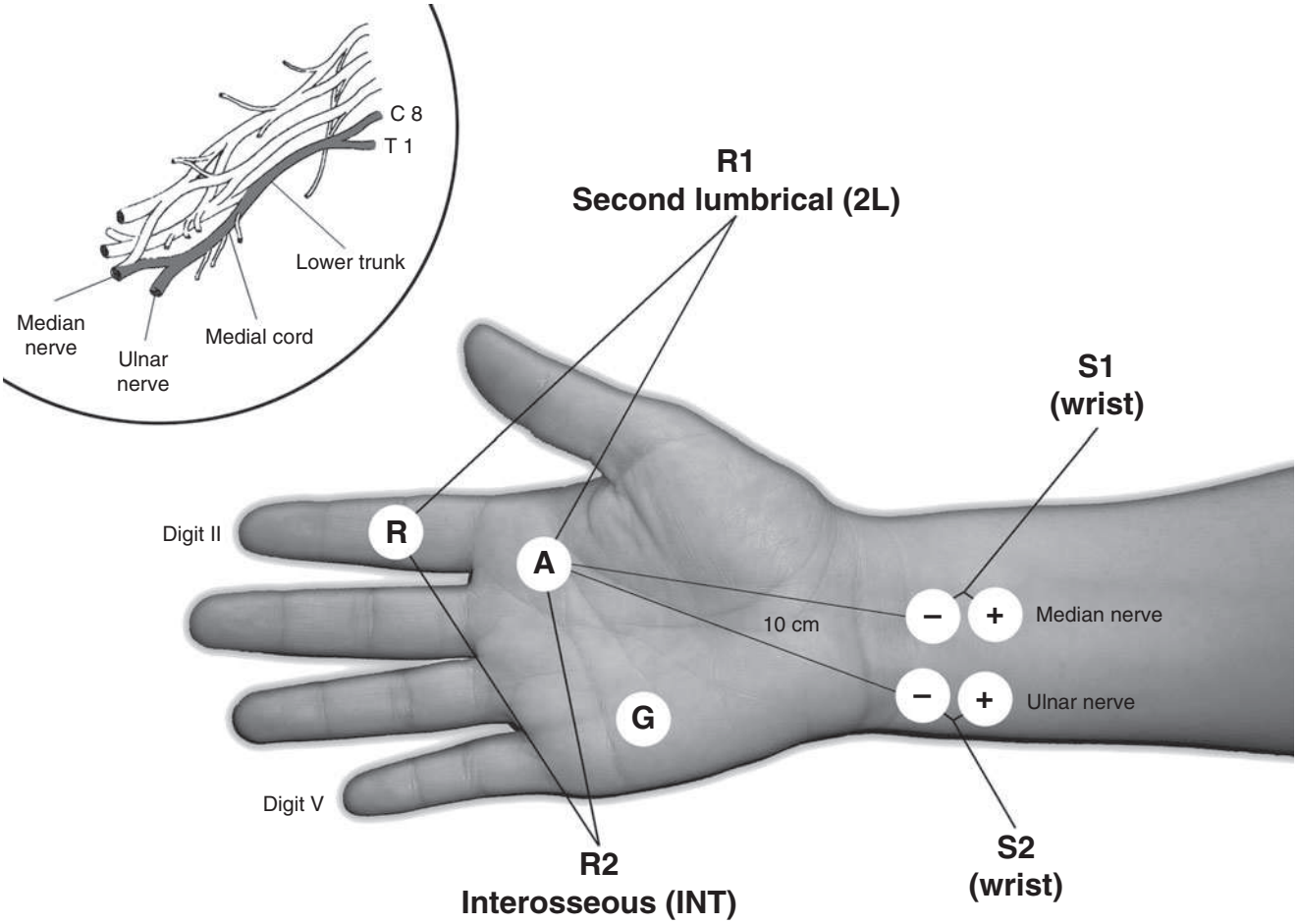


Fig. 3 2L–INT test; fixed conduction distance—10 cm

Table 9 Reference values

Normal values [9]	Mean ± SD	Limit of normal (±2.5SD)
2L–INT latency DIFF (ms)	0.15 ± 0.17	<0.58

electromyograph, and skin temperature at the hand was maintained at or above 32 °C. The 2L and INT CMAP latency difference was calculated in 100 control (Table 9) subjects (64 women 36 men, age range 22–65 years, mean age 47.4 years), and the sensitivity to detect CTS was measured in 160 symptomatic hands from 116 patients with CTS (86 women and 30 men, mean age 48.5 ± 6.3 years). One hundred forty-nine hands were found to have had at least one abnormal electrophysiological study; 11 hands (6.88 %) were found to have normal electrophysiological results; 36 hands (22.5 %) had normal 2L–INT, and 124 hands (77.5 %) had prolonged 2L–INT (>0.58 ms). The sensitivity of 2L–INT was 77.5 % (124 hands).

In a prospective study, Meena et al. [10] measured 2L–INT latency difference in controls (120 hands of 60 healthy subjects, age range 20–75 years, mean age 47.55 years) and its sensitivity in patients with a clinical diagnosis of CTS (250 hands of 130 consecutive patients, age range 21–76 years, mean age 48.62 years), using the Preston and Logigian [1] protocol (Tables 10 and 11). Patients were divided into three groups, based on the least-sensitive standard median study needed to demonstrate CTS. Nerve conduction studies were performed using a Dantec Keypoint EMG machine, and limb temperature was maintained above 31 °C. They used a fixed 8 cm distance (Fig. 4) from the active electrode for both sites of stimulation (S1—median nerve, S2—ulnar nerve).

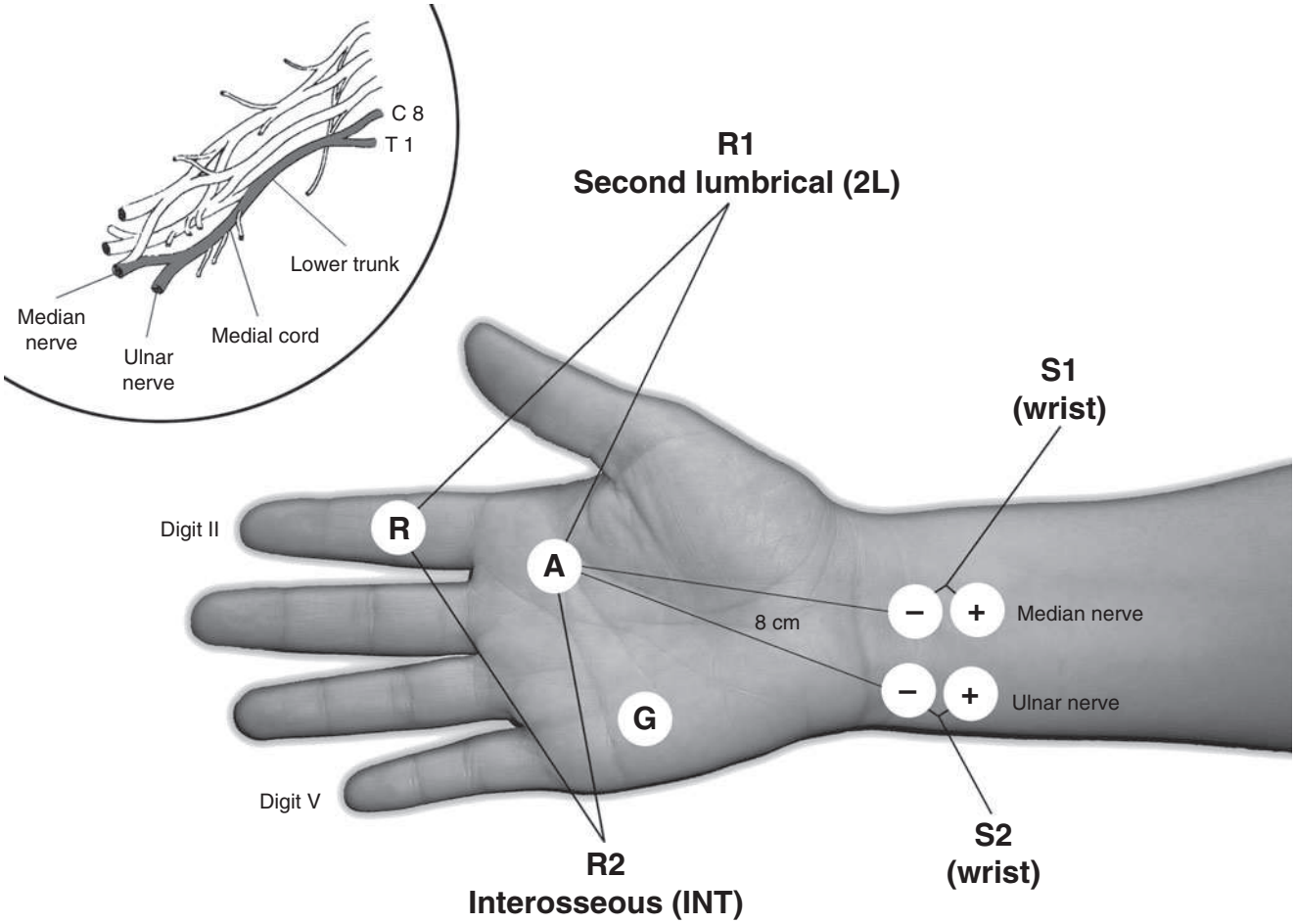


Fig. 4 2L–INT test; fixed conduction distance—8 cm

Table 10 Reference values

Normal values [10]	Mean ± SD	Limit of normal (+2SD)
Wrist–2L, distal latency (ms)	3.25 ± 0.38	
Wrist–INT, distal latency (ms)	3.10 ± 0.35	
2L–INT latency DIFF (ms)	0.12 ± 0.19	≤0.5
2L muscle, negative peak amplitude (mV)	1.38 ± 0.67	
INT muscle, negative peak amplitude (mV)	4.62 ± 1.53	

Table 11 Reference values

Pathological values [10]	Mean ± SD	Limit of normal (+2SD)
Wrist–2L, distal latency (ms)	5.44 ± 1.93	
Wrist–INT, distal latency (ms)	3.03 ± 0.57	
2L–INT latency DIFF (ms)	2.44 ± 1.81	≤0.5
Wrist–2L, distal amplitude (mV)	0.88 ± 0.56	
Wrist–2L, distal amplitude (mV)	4.33 ± 1.47	

Patients group	2L-INT DIFF
Severe CTS (73 hands)	71/73 (97.26 %)
Moderate CTS (65 hands)	65/65 (100 %)
Mild CTS (111 hands)	78/111 (70.27 %)

Similar to all motor nerve conduction studies, the proper location for the active electrode is over the motor point (slightly lateral to the midpoint of the third metacarpal with the reference electrode placed over a bony prominence of the proximal interphalangeal joint of the digit II). However, in the lumbrical–*interossei* comparison study, the 2L and underlying INT muscles cannot be seen or palpated. The second lumbrical (2L) muscle originates from the radial border of the tendon of the *flexor digitorum profundus* (FDP) muscle (to the digit III) and inserts at the proximal phalanx of the digit III. The first palmar *interosseous* (INT) muscle originates

from the medial surface of the second metacarpal bone and inserts on the proximal phalanx of the digit II (index finger). Under the first palmar *interosseous* (INT) muscle is the second dorsal *interosseous* muscle, which is likely corecorded as well during the 2L–INT latency difference study. It originates from the proximal lateral border of the third metacarpal bone and inserts on the radial base of the proximal phalanx of the digit III (middle finger).

Comment

Meena et al. [10] reported test results on a total of 250 hands. The overall sensitivity of 2L–INT DIFF was 85.60 % (214/250), and the specificity was 96.67 %. The authors, reporting results on 249/250 hands, measured sensitivity of the 2L–INT DIFF test in patients with CTS divided in three groups (classified into different grades of severity of CTS): mild CTS (no neurophysiological abnormality or an abnormal difference between the median and ulnar mixed-nerve palmar latencies), moderate CTS (normal or prolonged distal motor latency of CMAP from the APB muscle, and preserved or slow SNAP), severe (very prolonged distal motor latency with low amplitude and absent SNAP). The 2L–INT DIFF was abnormal in 97.26 % (71/73) hands with severe CTS, and the excitability of the second lumbrical muscle (2L) was preserved approximately in all hands with severe CTS, till the most severe stages. In the moderate CTS group, 2L–INT DIFF test was abnormal in 100 % (65/65) hands, while in the mild CTS it was abnormal in 70.27 % (78/11) hands. For the authors, 2L–INT DIFF was an accurate, highly sensitive, and a specific test in the diagnosis of CTS, especially in moderate and severe CTS (frequently associated with polyneuropathy), when other standard methods fail. In agreement with Preston and Logigian [1], many authors employed the technique in CTS; Kaul and Pagel [11] compared the sensitivity of the 2L–INT DIFF with MED-ULN PALM DIFF, and they found equal sensitivity across a broad range of CTS severity. They obtained 2L–INT DIFF from 158 hands (100 %) of 158 patients with CTS (age range 18–85 years, mean age 53.4 years, 90.5 % males, 95 % white, 90 % right hand, 62 % bilateral symptoms), and they validated the technique in mild CTS in cases in which routine median and sensory nerve conduction studies were normal.

Foley and Buschbacher [12], for the 2L CMAP recording, placed the active recording electrode on the palm—slightly radial to the midpoint of the third metacarpal, and the reference electrode at the base of the digit III—slightly distal to the third metacarpophalangeal joint. The ground was placed on the dorsum of the hand (the figure shows the ground electrode placed on the palm, between the stimulating and recording sites). Stimulation was at the wrist, 10 cm proximal to the active electrode placed on the palm, in a line measured from the first to the midpoint of the distal wrist crease and then to a point slightly ulnar to the tendon of the *flexor carpi radialis* (FCR) muscle. The anode was proximal. They studied 196 healthy subjects (Table 12); skin temperature over the dorsum of the hand was controlled and maintained at or above 32 °C) (Fig. 5).

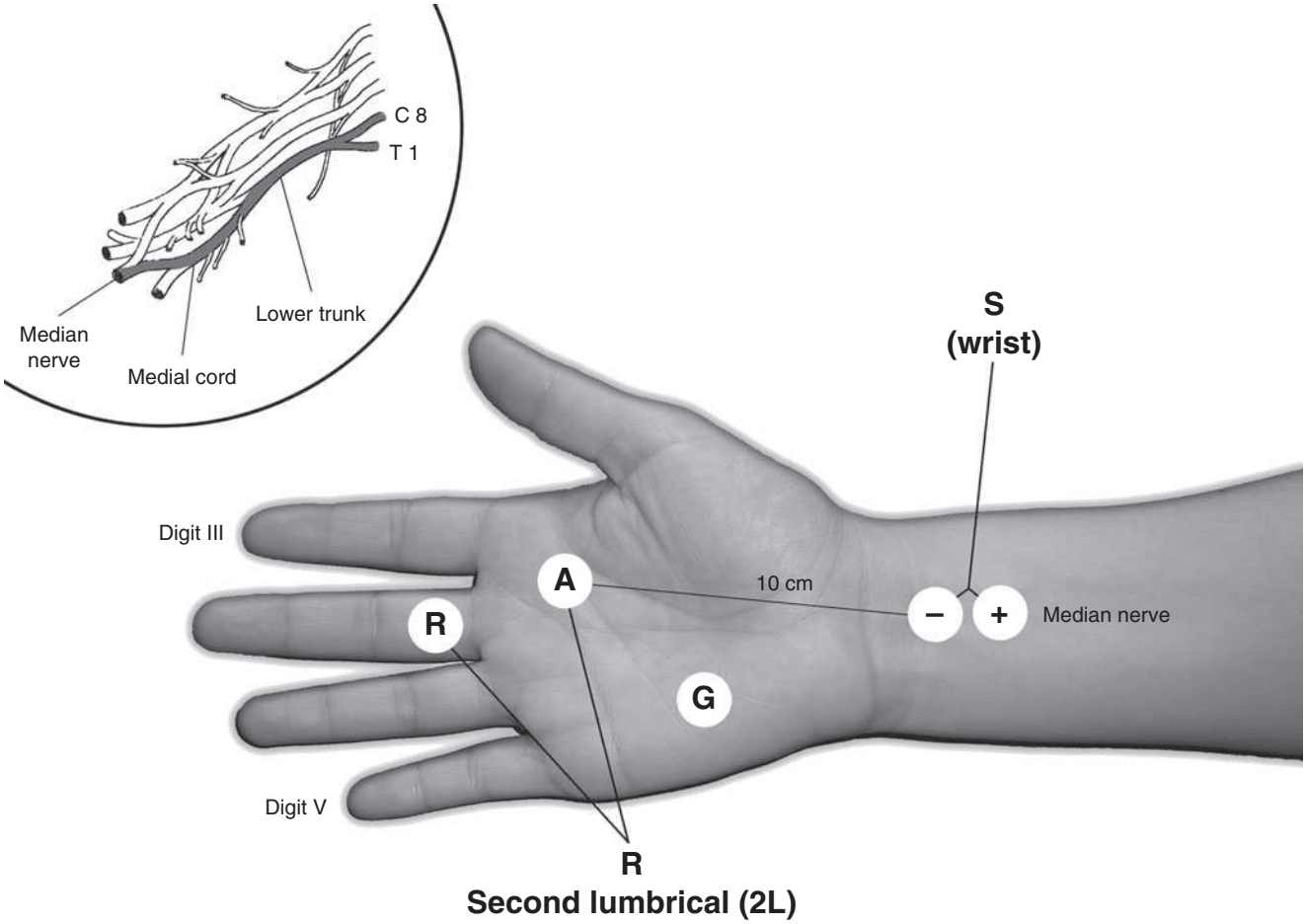


Fig. 5 2L CMAP recording; fixed conduction distance—10 cm

Table 12 Reference values

Normal values [12]	Mean ± SD	Range	Limit of normal
Wrist–2L, distal latency (ms)	3.7 ± 0.4	2.7–5.1	4.5
Wrist–2L, amplitude (mV)	3.0 ± 2.0	0.7–11.7	1.0
Wrist–2L, area of negative phase (μVs)	9.4 ± 5.4	1.6–33.7	3.3
Wrist–2L, duration of negative phase (ms)	5.7 ± 1.1	3.3–10.4	8.4

Comment

Foley and Buschbacher [12] used 2–3 Hz for a low-frequency filter and 10 kHz for a high-frequency filter. The upper limit of normal for onset latency was 4.5 ms; the upper limit of a normal increase side-to-side was 0.8 ms; the upper limit of a normal decrease in amplitude side-to-side was 67 %. The authors also compared the latency of a 2L muscle with the other muscles of the hand, innervated by the median nerve (1L and APB muscles) and the ulnar nerve (INT muscle). As the 2L and INT muscles lie superimposed in this location, the concomitant median and ulnar nerve stimulation must be avoided. Stimulating the median nerve activates the 2L muscle, whereas stimulating the ulnar nerve activates the INT muscle, but for the authors, both the nerve studied had the same latencies and could thus be compared to detect the slowing of one nerve or the other. They found that the upper limit of normal difference between the first lumbrical (1L) muscle and the second lumbrical (2L) muscle in the same hand was 0.7 ms in cases where 2L had the longer latency; it was 0.6 ms in cases where 1L was longer. The upper limit of normal difference between the 2L muscle and the APB muscle latency in the same hand was 1.0 ms in cases where the APB had the longer latency; it was 0.8 ms in cases where the 2L muscle latency was longer. The upper limit of normal difference between the 2L muscle and INT muscle latency in the same hand was 0.2 ms in cases where the INT had the longer latency; it was 1.2 ms in cases where 2L was longer.

Table 13 Reference values

Normal values [13]	Mean ± SD	Cut off
2L–INT latency DIFF (ms)	0.1 ± 0.3	≤0.5

Table 14 Reference values

Pathological values [13]	Mean ± SD
2L–INT DIFF (ms)—CTS Group	1.2 ± 0.7
2L–INT DIFF (ms)—DMPNP CTS- Group	0.2 ± 0.3
2L–INT DIFF (ms)—DMPNP CTS+ Group	0.9 ± 0.6

Using the lumbrical–*interossei* recording technique in 12 control hands, in 1994, Muellbacher et al. [2] observed a considerable variability in latency and amplitude of the CMAP in the same subject by searching the optimal recording site in the distal palm (using identical distances from the active electrodes—8 cm, 10 cm, 12 cm), and if the active recording electrode was not optimally placed over the motor point, the amplitudes and rise-times of the 2L and INT were lower, and the lumbrical–*interossei* latency differences increased, and the commonly used cutoff values were not valid [3]. These authors suggested as the optimal location for the active recording electrode a site, which can be approximated by first marking the midpoint of the third metacarpal (half the distance between the distal wrist crease and the proximal skin crease of the third metacarpal–phalangeal joint) and then measuring 1 cm proximal and 1 cm lateral from that point.

Using a 2L–INT DIFF test set by anatomical landmarks (stimulation at 3 cm fixed distance, proximal to the proximal wrist crease), Gazioglu et al. [13] recently investigated sensitivity and specificity of some tests in the diagnosis of CTS in patients with diabetic polyneuropathy. They performed standard nerve conduction studies, segmental and comparative median nerve conduction tests in 86 hands (Table 13) from 43 healthy individuals (32 women and 11 men, 42 right hands and 1 left hand, BMI 27.5 ± 3.4, mean age 53.7 ± 5.5 years). They used a Nihon Kohden 9100 electromyograph at a room temperature of 25 °C, and a palmar temperature was maintained at approximately 32 °C. A greater diagnostic accuracy can be observed in tests with a higher sensitivity and specificity. Following the median–second lumbrical and ulnar–*interosseous* CMAP latency comparison [1], latency difference was calculated by subtracting the *interosseous* distal latency from the second lumbrical distal latency, using a distance range from 8 to 10 cm (Fig. 6). They found normal 2L–INT DIFF values (0.1 ± 0.3 ms) consistent with the previous values reported [1]. The authors also compared the sensitivity and specificity of some different tests in the diagnosis of CTS in diabetic polyneuropathy patients on a group of patients (Table 14) with CTS (140 hands from 72 patients, 59 women and 13 men, 71 right hands and 1 left hand, BMI 29.0 ± 3.3, mean age 53.9 ± 3.5 years)—CTS Group on a group of diabetic patients with polyneuropathy, without associated CTS (61 hands from 32 patients, 19 women and 13 men, 30 right hands and 2 left hands, BMI 29.1 ± 5.4, mean age 55.6 ± 9.5 years)—DMPNP CTS - Group and on a group of diabetic patients with polyneuropathy, with associated CTS (62 hands from 35 patients, 26 women and 9 men, 26 right hands and 9 left hands, BMI 31.4 ± 7.1, mean age 55.5 ± 7.3 years)—DMPNP CTS + Group. The sensitivities and specificities of the tests were compared in the diagnosis of CTS in patients with diabetic polyneuropathy. The median–second lumbrical and ulnar–*interosseous* latency difference (2L–INT DIFF) was higher in CTS Group than in DMPNP CTS+ Group (polyneuropathy with CTS), and in DMPNP CTS- Group (polyneuropathy without CTS) than controls. These differences were significant between DMPNP CTS+ Group and DMPNP CTS- Group and between CTS Group and DMPNP CTS+ Group. The authors found, using a 0.5 ms cutoff, a sensitivity of 75 % and a specificity of 82 %.

Following stimulation at 2 cm fixed distance, proximal to the proximal wrist crease [7, 8], more recently, Ozben et al. [14] investigated the contribution of this method in addition to the routine examinations in the diagnosis and staging of carpal tunnel syndrome (CTS). Normal values (Table 15) were obtained from 81 subjects (50 healthy volunteers and 31 patients without CTS, age range 20–66 years, mean age 43.1 ± 10.2 years). A total of 92 control hands were studied (73 hands of women—79.34 %, 19 hands of men—20.66 %), with a mean 2L motor distal latency (2L-MDL) found to be 2.99 ± 0.31 ms, while 2L–INT DIFF was 0.26 ± 0.24 ms. The authors also studied 283 CTS hands from 161 patients with CTS (Table 16) electrophysiologically diagnosed (242 hands of women—85.51 %, 41 hands of men—14.49 %, age range 23–73 years, mean age 47.3 ± 9.3 years), divided into six groups: CTS grade 1 (159 hands), CTS grade 2 (46 hands), CTS grade 3 (57 hands), CTS grade 4 (5 hands), CTS grade 5 (14 hands), CTS grade 6 (2 hands).

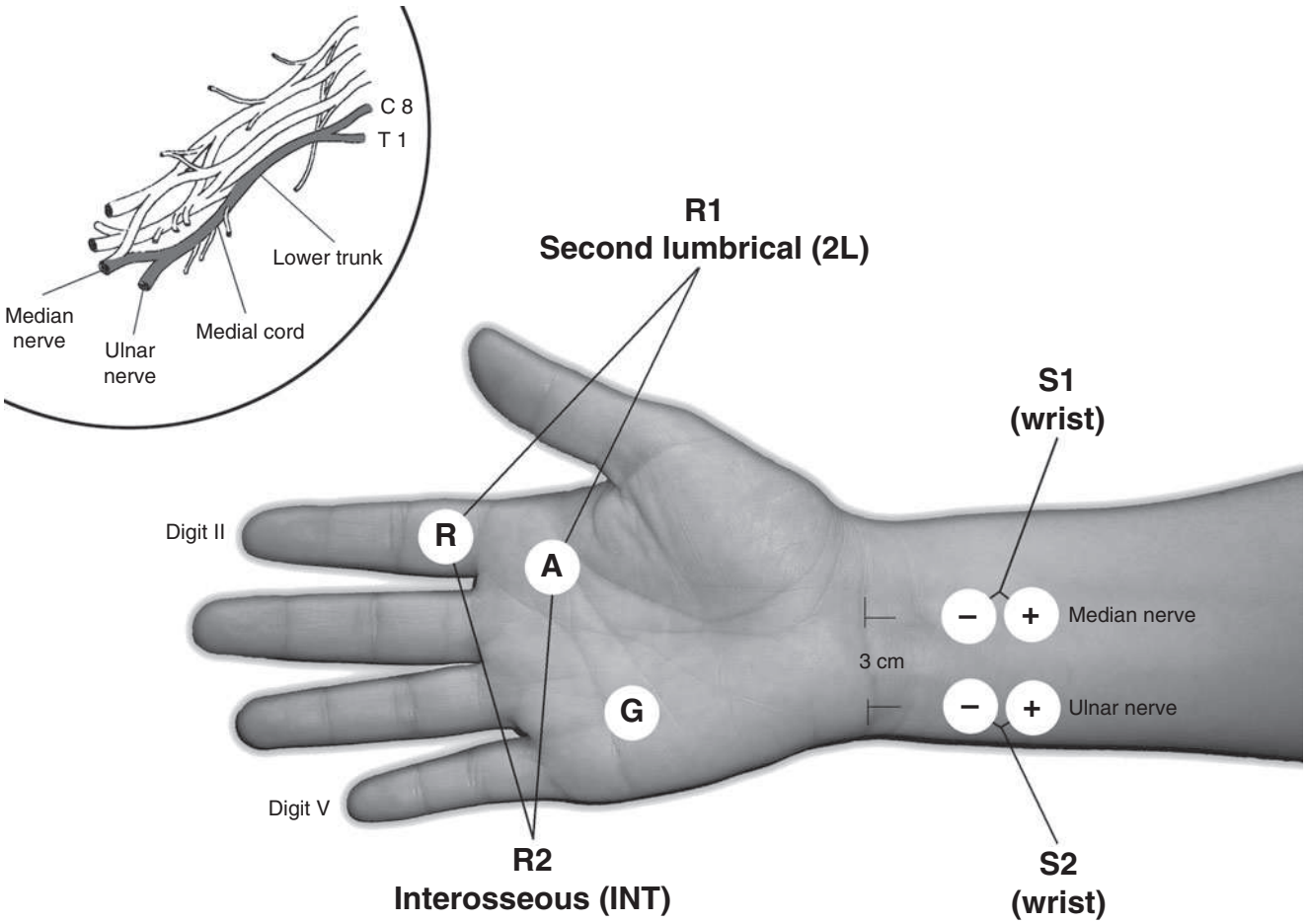


Fig. 6 2L–INT test; conduction distance set by anatomical landmarks

Table 15 Reference values

Normal values [14]	Mean ± SD	Range	Limit of normal
Wrist–2L, distal latency (ms)	2.99 ± 0.31	2.30–3.65	≤3.15
2L–INT DIFF (ms)	0.26 ± 0.24	0.00–1.65	≤0.5

Table 16 Reference values

Pathological values [14]	Mean ± SD	Range
Wrist–2L, distal latency (ms)	4.18 ± 1.29	2.55–13.85
2L–INT DIFF (ms)	1.46 ± 1.21	0.00–10.30
Pathological values [14]—CTS grade 1	Mean ± SD	Range
Wrist–2L, distal latency (ms)	3.54 ± 0.50	2.55–6.35
2L–INT DIFF (ms)	0.87 ± 0.49	0.00–3.55
Pathological values [14]—CTS grade 2	Mean ± SD	Range
Wrist–2L, distal latency (ms)	4.39 ± 0.85	2.95–8.05
2L–INT DIFF (ms)	1.60 ± 0.68	0.70–4.05
Pathological values [14]—CTS grade 3	Mean ± SD	Range
Wrist–2L, distal latency (ms)	4.76 ± 0.80	3.55–7.40
2L–INT DIFF (ms)	2.03 ± 0.80	0.90–4.65
Pathological values [14]—CTS grade 4	Mean ± SD	Range
Wrist–2L, distal latency (ms)	6.37 ± 1.98	4.80–9.25
2L–INT DIFF (ms)	2.92 ± 1.59	2.00–5.75
Pathological values [14]—CTS grade 5	Mean ± SD	Range
Wrist–2L, distal latency (ms)	6.92 ± 1.66	4.60–9.55
2L–INT DIFF (ms)	4.18 ± 1.79	2.00–7.05
Pathological values [14]—CTS grade 6	Mean ± SD	Range
Wrist–2L, distal latency (ms)	13.85 (one hand)	
2L–INT DIFF (ms)	10.30 (one hand)	

Comment

Ozben et al. [14] studied a total of 375 hands (201 right, 174 left) from 242 patients (201 women and 41 men, age range 20–73 years, mean age 45.8 ± 9.8 years), referred to the laboratory with a clinically diagnosed CTS. Electrophysiological CTS were diagnosed in 283 hands of 161 patients. They found bilateral CTS in 122 patients and unilateral CTS in 20 patients. According to the Bland's CTS classification scale [15], 283 CTS hands were graded between 0 and 6: 159 hands—grade 1 (very mild CTS), 46 hands—grade 2 (mild CTS), 57 hands—grade 3 (moderately severe CTS), 5 hands—grade 4 (severe CTS), 14 hands—grade 5 (very severe CTS), 2 hands—grade 6 (extremely severe CTS). In patients with grade 1 CTS, the mean 2L motor distal latency (2L–MDL) was found to be 3.54 ± 0.51 ms, while the mean 2L–INT DIFF was 0.87 ± 0.49 ms; the sensitivity of the test was 81.8 %, specificity was 84.8 %, positive predictive value was 90.1 %, and negative predictive value was 72.9 %. In their study, Ozben et al. [14] found abnormal 2L–INT DIFF (≥0.5 ms) in 14 hands, which were found to be normal with the routine CTS tests (false-positivity), and 29 hands with the CTS diagnosed by routine CTS tests were in normal limits (<0.5 ms, false-negativity). The authors also found a significant association between 2L–MDL and CTS. When they took the cutoff value for 2L–MDL as ≥3.15 ms in the diagnosis of CTS, sensitivity was 87.3 %, specificity was 70.7 %, positive predictive value was 90.1 %, and negative predictive value was 64.4 %. As a result of these findings, they suggested in a routine CTS diagnosis to use not only the 2L–INT DIFF test, but also the 2L–MDL value.

Other authors have tested sensitivity of the 2L–INT DIFF test, comparing different techniques; Uncini et al. [16] compared the 2L–INT test with a sensory orthodromic digit IV (comparative median–ulnar nerves) and a sensory orthodromic palm (comparative median-ulnar nerves) and found a very low sensitivity (10 %) to assess CTS in 193 hands from 113 consecutive patients (78 % women) with clinical signs of CTS. Preston et al. [17] compared the median–ulnar latency difference studies to test their sensitivity in 34 patients with mild CTS (25 right hands, 9 left hands, mean age 44 years, age range 24–68 years). For the palmar mixed median–ulnar peak latency difference, the normal value was <0.4 ms. For the antidromic digit IV median–ulnar onset latency difference, the normal value was <0.5 ms. For the 2L–INT DIFF test, the normal value was <0.5 ms. The palmar-mixed, digit IV, and 2L–INT DIFF studies were abnormal in 33 (97 %), 31 (91 %), and 30 (88 %) patients, respectively. Two or more tests were abnormal in 33 (97 %), while all three tests were abnormal in 27/34 (79 %). In the mild CTS patients, the authors found that the palmar-mixed was the most sensitive study followed closely by the antidromic digit IV and 2L–INT study, and their results showed a good correlation between all three tests in the mild CTS patients. The high sensitivity found for a 2L–INT DIFF test (88 %) was markedly in contrast with the very low sensitivity (10 %) found by Uncini et al. [16]. Preston et al. [17] explained the disparity between these studies with different patient samples (patients had clinical CTS, and also nerve conduction studies demonstrated a median neuropathy at the wrist, in contrast to Uncini's study), and they used 0.3 and 0.4 ms as an upper limit of normal for the palmar-mixed and for 2L–INT DIFF studies, respectively (while Uncini et al. used 0.4 and 0.5 ms, respectively). A 0.1 ms difference likely decreased the sensitivity of the study, especially in the mild CTS patients.

In 1995, Sheean et al. [18], in 66 hands from 66 patients (50 females, 16 males)—49 hands (74 %) with CTS confirmed electrophysiologically—found abnormal 2L–INT DIFF test in 48/49 cases. Their findings were in close agreement with those of Preston and Logigian [1], but a marked variance with that of Uncini et al. [16], possibly reflecting the similarity of their technique and criteria for patient selection and of 2L–INT DIFF abnormality to the former. As in

Table 17 Reference values

Pathological values [21]—all CTS hands	Mean ± SD	Rate of abnormality (%)
Wrist–APB, distal latency (ms)	5.47 ± 1.93	79
Wrist–2L, distal latency (ms)	5.58 ± 1.77	
Wrist–INT, distal latency (ms)	2.98 ± 0.37	
2L–INT DIFF (ms)	3.13 ± 1.99	85
Pathological values [21]—Mild CTS	Mean ± SD	Rate of abnormality (%)
Wrist–APB, distal latency (ms)	4.34 ± 0.69	60
Wrist–2L, distal latency (ms)	4.36 ± 0.73	
Wrist–INT, distal latency (ms)	2.98 ± 0.37	
2L–INT DIFF (ms)	2.68 ± 1.29	81
Pathological values [21]—moderate CTS	Mean ± SD	Rate of abnormality (%)
Wrist–APB, distal latency (ms)	5.05 ± 0.68	85
Wrist–2L, distal latency (ms)	5.46 ± 1.15	
Wrist–INT, distal latency (ms)	2.98 ± 0.37	
2L–INT DIFF (ms)	2.77 ± 1.38	84
Pathological values [21]—severe CTS	Mean ± SD	Rate of abnormality (%)
Wrist–APB, distal latency (ms)	7.68 ± 2.57	94
Wrist–2L, distal latency (ms)	7.07 ± 2.24	
Wrist–INT, distal latency (ms)	2.98 ± 0.37	
2L–INT DIFF (ms)	4.09 ± 3.87	92

their study, Preston and Logigian [1] examined patients suspected of having CTS, which was subsequently confirmed electrophysiologically, whereas the study by Uncini et al. [16] reported only patients with a clinical diagnosis of CTS; despite this and other few little technical and methodological differences, for Sheean et al. [18], the reasons for this discrepancy were still not entirely clear. Like Preston and Logigian [1], Sheean et al. [18] encountered cases where the median sensory potentials and sometimes the CMAP from APB were absent, but a response could still be obtained from the second lumbrical; in all such cases, an abnormal 2L–INT DIFF was found, usually quite marked, allowing localization of the lesion at the wrist. Boonyapisit et al. [19] found a prolonged 2L latency (mean 9.2 ms, range 3.9–16.7 ms) and 2L–INT DIFF (mean 6.0 ms, range 0.5–13.5 ms) in 26 (92.8 %) of 28 hands from 23 patients with severe CTS (9 men, 14 women, 5 bilateral CTS, age range 39–89 years), with absent sensory responses recording from the second and third digits, and absent motor responses recording from the APB muscle. In 2007, Brannegan and Bartt [20] recorded a CMAP from 2L muscle in 17 of 22 hands (77 %), in which the CMAP from APB muscle was absent.

Recently, in a prospective study, Lee et al. [21] performed 2L–INT DIFF test on 30 hands of normal subjects (22 women and 8 men, average age 53.3 ± 12.2 years), and on 67 hands of 41 patients (Table 17) with electroclinically diagnosed CTS (53 hands from 32 women, 14 hands from 9 men, average age 56.2 ± 11.2 years). A Dantec Counterpoint Mk2 was used for the electrodiagnostic study. Among the 67 hands with diagnosed CTS, 23 hands were of mild degree (average age 55.7 ± 9.8 years), 27 hands were moderate (average age 55.0 ± 8.9 years), and 17 hands were of severe degree (average age 59.3 ± 9.1 years). 2L–INT DIFF was 2.68 ± 1.29 ms in the mild CTS group and 2.55 ± 1.38 ms in the moderate CTS group. In the severe CTS group, the latency difference was 4.09 ± 3.87 ms with statistical significance compared to the other groups. The authors found the frequency of latency differences longer than 0.4 ms in 81 %, 84 %, and 92 % in the mild CTS group, moderate CTS group, and severe CTS group, respectively. Like Sheean et al. [18], they also observed that the latency prolongation with APB muscle recording was significantly lower in frequency than 2L–INT DIFF test in the mild degree of CTS group. For Lee et al. [21], demyelination is the main pathology of the disease, which occurs in the early process of CTS; so, when the damage is minimal, the latency of the CMAP from the second lumbrical (2L) muscle may appear within normal range. In the early stage of CTS, the prolonged median nerve latency, compared to the latency obtained from the *interossei* muscle (innervated by the ulnar nerve, which does not pass through the carpal tunnel), makes 2L–INT DIFF test more sensitive than the latency from the *abductor pollicis brevis* (APB) muscle. As the disease progresses, the pathophysiology of CTS changes, and due to its anatomically favorable position, the branch to the 2L muscle is less affected by the conduction block or axonal injury, and is relatively preserved in the nerve conduction study. In conclusion, the authors found that the 2L–INT DIFF test is a useful tool for increasing sensitivity in CTS diagnosis, and consistent with the previous studies, as the disease progresses, 2L muscle is relatively preserved in severe degree of CTS. All these studies confirmed the utility of 2L–INT DIFF test to localize the

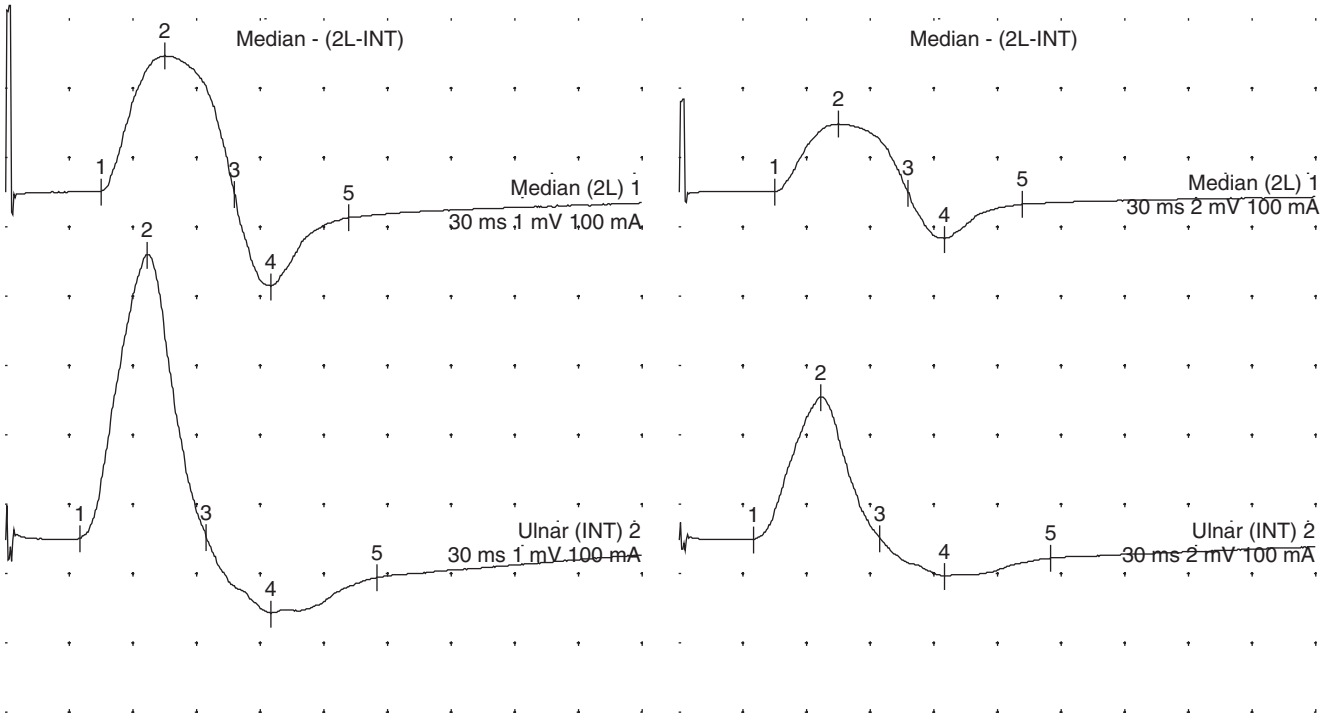
lesion at the wrist in patients with severe CTS, even with routine absent distal median motor responses.

Sharma and Wilder Smith [22], employing the routinely electrodiagnostic tests, found CTS in only 66 hands (41.8 %) from 158 symptomatic hands of 80 patients with end-stage renal failure on hemodialysis (age range 17–87 years, mean age 57.1 years, 45 men and 35 women, 53 race Chinese, 22 race Malay, 5 race Indian, 64 with hypertension, 57 with diabetes mellitus), but applying the 2L–INT DIFF resulted in a significant increase in the incidence of median neuropathy by diagnosing an additional 59 cases and raising the total percentage of patients with median neuropathy to 79.1 %. Their data suggested that the 2L–INT DIFF method was a highly sensitive neurophysiological parameter in diagnosing median neuropathy of all grades as well in the presence of a peripheral polyneuropathy.

Sheean et al. [18] found also interesting that a test in which responses are preserved (but abnormal) in very advanced cases, when other responses are unrecordable, should also be sensitive to mild lesions. For the authors, this seemed to suggest that the motor fibers to the second lumbrical (2L) muscle are more sensitive than those to the *abductor pollicis brevis* (APB) muscle to the effects of compression, which produces conduction slowing, but that once affected are more resistant to the total conduction block or axonal degeneration. This observation seemed to apply to the median sensory fibers as well. Anatomical factors alone are unlikely to produce this combination of results. The fibers to the lumbrical muscles lie within the center of the median nerve in the carpal tunnel (the fibers to the APB muscle are superficially located anterior to this), which may protect them somewhat from the effects of compression [23], thus preserving them in severe cases, but they cannot explain the early affliction in mild cases. They had frequently used the 2L–INT DIFF test as a quick screening assessment of the asymptomatic side, proceeding to further tests when the results were abnormal. For Brannegan and Bartt [20], although the second lumbrical fibers are relatively protected from the Wallerian degeneration in severe CTS, they still show the conduction-slowing characteristic of chronic demyelination and remyelination. In all cases they studied (22 hands from 19 patients with CMAP, from the APB muscle absent), they found a prolonged distal latency to the 2L muscle (mean latency 9.1 ms). The reason why 2L fibers are affected early in mild CTS to produce demyelinative changes and slowed conduction, and yet are resistant to an axon injury in more advanced compression, is not completely clear.

For Sheean et al. [18], it has an advantage over screening with the median–ulnar palmar comparison in that only one recording site is used and no special skin preparation is generally needed. It is also reportedly useful where there is a co-existing peripheral neuropathy [1], although they did not encounter any such cases. Another potential use of the 2L–INT DIFF test is in the diagnosis of lesions of the deep palmar branch of the ulnar nerve, where the expected 2L–INT latency difference would be in the opposite direction (delayed *interosseous* latency). In this case, the study can be used like a useful adjunct in demonstrating ulnar neuropathy at the wrist, when the distal latency to the INT is prolonged, compared to 2L [24, 25]. Some 2L-INT DIFF tests in several pathological cases are here reported (Figs. 7, 8 and 9)

Pathological waveform (wrist – 2L muscle, wrist – INT muscle):



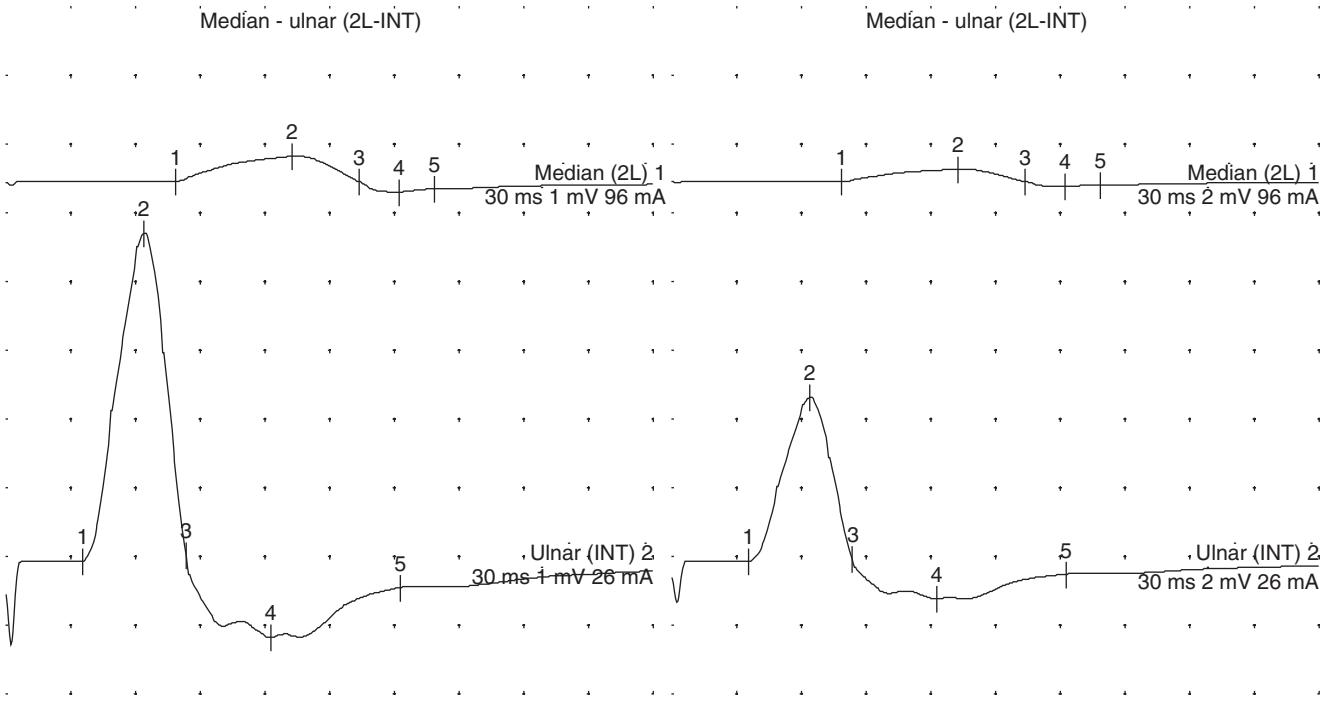
Sensitivity 5 mV/div, sweep speed 3 ms/div

Sensitivity 2 mV/div, sweep speed 3 ms/div

Onset latency (median 2L): 4.50 ms; **Onset latency** (ulnar INT): 3.50 ms; **Onset latency difference** (median 2L) – (ulnar INT): 1.0 ms; **Peak latency** (median 2L): 7.40 ms; **Peak latency** (ulnar INT): 6.55 ms; **Onset to peak amplitude** (median 2L): 2.0 mV; **Onset to peak amplitude** (ulnar INT): 4.1 mV; **Peak to peak amplitude** (median 2L): 3.3 mV; **Peak to peak amplitude** (ulnar INT): 5.2 mV

Fig. 7 Compound muscle action potentials (CMAPs) recorded at the hand from the 2L and INT muscles in moderately severe CTS—grade 3 by Bland's CTS classification scale [15]— onset latency delay 1.0 ms; stimulation of the wrist: 2L recording (*upper trace*) and INT recording (*lower trace*)

Pathological waveform (wrist – 2L muscle, wrist – INT muscle):



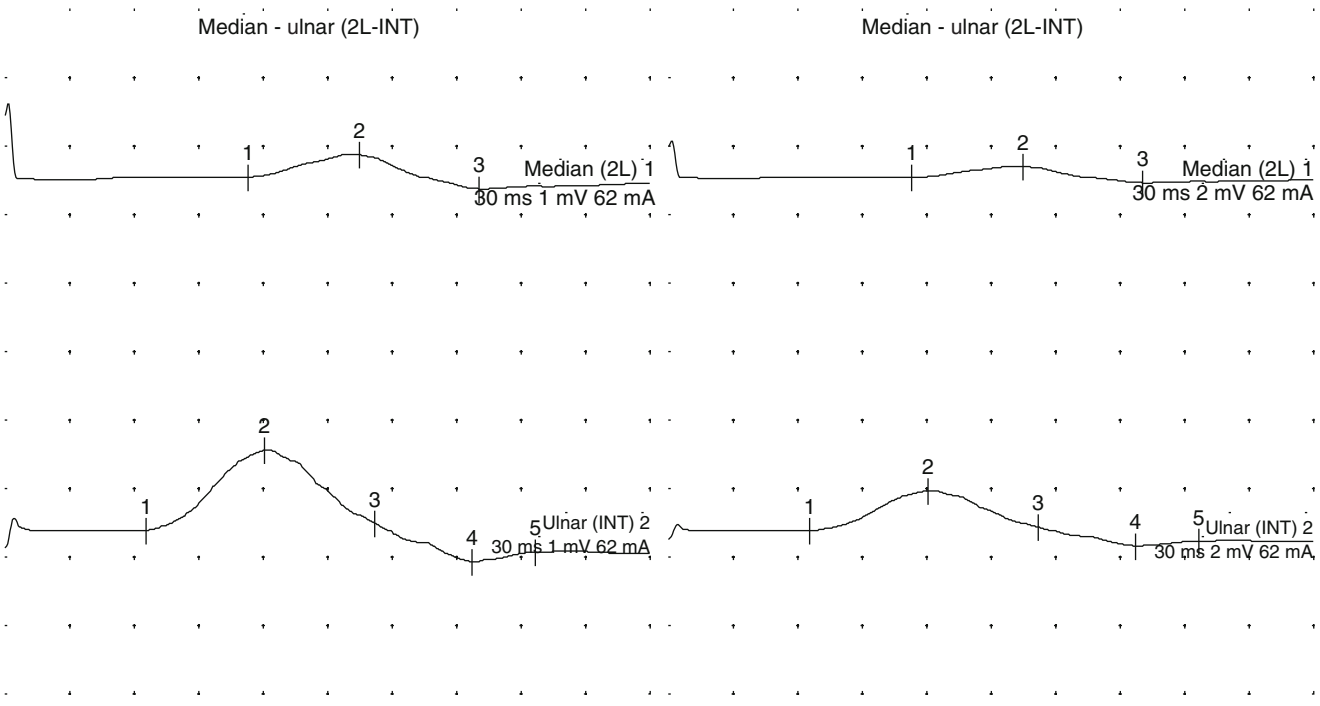
Sensitivity 1 mV/div, sweep speed 3 ms/div

Sensitivity 2 mV/div, sweep speed 3 ms/div

Onset latency (median 2L): 7.80 ms; **Onset latency** (ulnar INT): 3.50 ms; **Onset latency difference** (median 2L)- (ulnar INT): 4.30 ms; **Peak latency** (median 2L): 13.40 ms; **Peak latency** (ulnar INT): 6.25 ms; **Onset to peak amplitude** (median 2L): 0.4 mV; **Onset to peak amplitude** (ulnar INT): 4.8 mV; **Peak to peak amplitude** (median 2L): 0.5 mV; **Peak to peak amplitude** (ulnar INT): 5.9 mV

Fig. 8 Compound muscle action potentials (CMAPs) recorded at the hand from the 2L and INT muscles in extremely severe CTS—grade 6 by Bland's CTS classification scale [15]—onset latency delay 4.30 ms; stimulation of the wrist: 2L recording (*upper trace*) and INT recording (*lower trace*)

Pathological waveform (wrist – 2L muscle, wrist – INT muscle):



Sensitivity 1 mV/div, sweep speed 3 ms/div

Sensitivity 2 mV/div, sweep speed 3 ms/div

Onset latency (median 2L): 11.25 ms; **Onset latency** (ulnar INT): 6.50 ms; **Onset latency difference** (median 2L)- (ulnar INT): 4.75 ms; **Peak latency** (median 2L): 16.45 ms; **Peak latency** (ulnar INT): 12.0 ms; **Onset to peak amplitude** (median 2L): 0.3 mV; **Onset to peak amplitude** (ulnar INT): 1.2 mV; **Peak to peak amplitude** (median 2L): 0.5 mV; **Peak to peak amplitude** (ulnar INT): 1.7 mV

Fig. 9 Compound muscle action potentials (CMAPs) recorded at the hand from the 2L and INT muscles in extremely severe CTS—grade 6 by Bland's CTS classification scale [15] and Guillain–Barré syndrome (2 weeks of onset of symptoms)—onset latency delay 4.75 ms; stimulation of the wrist: 2L recording (*upper trace*) and INT recording (*lower trace*)

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