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Relations between sensory symptoms, touch sensation, and sensory neurography in the assessment of the ulnar neuropathy at the elbow

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HIGHLIGHTS

- Little digit sensory anomalies are usual findings in ulnar neuropathy at elbow (UNE).
- Little digit neurographic/clinical anomalies have high predictivity for UNE diagnosis.
- Sensory anomalies are more frequent in predominantly axonal UNE.

ABSTRACT

Objectives: To evaluate sensitivity, specificity and predictive values of sensory findings in ulnar neuropathy at the elbow (UNE), differences according to UNE localization and pathophysiology, and relation between the sites of sensory symptoms, abnormal evaluation of sensation and neurographic findings of ulnar sensory nerve.
Methods: Hand diagram and Semmes-Weinstein monofilaments were used for clinical evaluation in four ulnar hand territories. Sensory neurography was measured in the fourth and fifth digits-wrist segments (U5) and in the dorsal ulnar cutaneous nerve.
Results: We enrolled 75 idiopathic UNE cases and 180 controls. Symptoms in the fifth digit, reduction of touch sensation and U5 sensory nerve action potential amplitude (SNAPa) had the highest sensitivity, specificity and predictivity in UNE diagnosis. The normal/abnormal sensory clinical findings of the fifth digit matched with normal/abnormal U5 SNAP more than the matching of sensory parameters in the other ulnar hand sites. Sensory anomalies were more frequent in predominantly axonal than demyelinating UNE. There were no differences according to UNE location.
Conclusion: Sensory anomalies of the fifth digit are constant findings in UNE more than anomalies of the other ulnar nerve hand regions.
Significance: Probably the fascicles from fifth digit are the most liable to damage at elbow.

1. Introduction

Differences in biophysical properties of sensory and motor axons make the former more predisposed to the injury by the identical mechanical stress (Lin et al., 2002). In addition, cutaneous afferents appear to depend more on Na+/K+ pump action than motor fibers to keep resting membrane potentials (Burke et al., 1997; Kiernan et al., 2004). Therefore, sensory axons show greater tendency to develop ectopic activity than motor axons. Accordingly, the entrapment nerve syndrome generally presents sensory symptoms in the cutaneous territory of the injured nerve as the first complaint. The ulnar neuropathy at the elbow (UNE) is no exception.

Palmar ulnar cutaneous nerve (PUCN), dorsal ulnar cutaneous nerve (DUCN), and terminal digital superficial branches represent the sensory branches of the ulnar nerve. The PUCN arises from the lateral aspect of the ulnar nerve a few cm proximal to the wrist and collects the sensitivity of the proximal part of hypothenar eminence. The DUCN originates from the medial aspect of the ulnar nerve in the distal third of the forearm, runs posteriorly, and supplies the medial side of the hand dorsum and the dorsal surface of

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IV and V digits. The terminal superficial branches arise from the wrist and collect the sensation of the distal part of medial side of the palm and of palmar aspects of the V and half of the IV digits.

The two major sites of ulnar nerve damage are at elbow and wrist; they should be easily detectable, but in practice, this is quite hard. In fact, the three sensory branches may be variably involved in UNE and sometimes the sensory symptoms complained by UNE patients do not fully match with the cutaneous territory of hand supplied by ulnar nerve. These discrepancies have been interpreted as result of a somatotopic organization of fascicles within ulnar nerve (Stewart, 2003). Partial nerve lesions may produce restricted deficits due to a particular susceptibility of some fascicles inside the nerve.

This study has three aims: (a) to calculate the sensitivity and specificity of the hand sites of subjective sensory complaints and of objective reduction of the sensation, in the diagnosis of UNE; (b) to report the matching between sensory symptoms, objective evaluation of touch hand sensation, and findings of ulnar nerve sensory neurography in UNE subjects; (c) to evaluate the differences of the site of sensory complaints, sensory loss and sensory neurography between UNE localizations beneath the humeroulnar arcade and at the retroepicondylar groove, and between the type of nerve damage (axonal vs. demyelinating).

2. Material and methods

2.1. Subjects

We prospectively enrolled UNE patients and controls among all consecutive subjects aged between 14 and 70 years, regardless of gender, admitted from October 2014 to September 2016 to a primary public outpatient electromyography (EMG) lab to carry out an electrodiagnostic examination (EDX) because of upper limb complaints.

To enclose a patient in UNE cases, the diagnosis of UNE was based on clinical history and symptoms (numbness, tingling, burning in the fourth and fifth digits, elbow pain spreading to the hand and forearm or subjective hand limitation and clumsiness) and/or abnormal physical examination (sensory changes in the cutaneous territory of the ulnar nerve and weakness or wasting of the intrinsic muscles of the hand supplied by the ulnar nerve). These clinical findings had to be mandatorily associated with abnormal motor neurography of the ulnar nerve across the elbow, according to the guidelines of the American Association of Neuromuscular & Electrodiagnostic Medicine (AAEM, 1999) (see minimum electrophysiological criteria descripted below) to enclose definitively the patients in UNE cases.

We included in the control group all the other consecutive patients admitted to the same EMG lab because of upper limbs complaints except those of UNE. We excluded from case and control groups subjects affected by Guyon's and carpal tunnel syndromes, C8-T1 radiculopathy, thoracic outlet syndrome, brachial plexopathy, polyneuropathy, motor neuron disease, central nervous system disease, cancer in the preceding five years, diabetes, connective diseases, and subjects who had undergone previous ulnar nerve and CTS surgery and with history of elbow fractures. Therefore, all patients had idiopathic UNE and controls were ulnar nerve symptoms-free and had normal motor neurography of the ulnar nerve.

We included in the physical examination of UNE cases and controls manual evaluation of the segmental muscle strength with Medical Research Council scale (MRC) of the first dorsal interosseous (FDI), abductor digiti minimi (ADM), flexor digitorum profundus (FDP), flexor carpi ulnaris (FCU), abductor pollicis brevis (APB), and at least one extensor muscles, osteotendinous reflexes and sensitivity (touch sensation).

In view of the aims of this study, we considered and reported in detail demographic data, duration, site and severity of sensory symptoms, objective evaluation of hand touch sensation, and sensory neurography. If the symptoms were bilateral we considered the results of the worst side and we chose the dominant side if the symptoms were similar in two sides. The same physician and the same neurophysiological technician performed all clinical examinations and electrodiagnostic studies.

2.2. Subjective and objective evaluation of sensation

The severity of symptoms was evaluated through a validated self-administered UNE questionnaire (Mondelli et al., 2006). In addition, the patients filled out a hand diagram to indicate the site of hand sensory symptoms in the last week (Werner et al., 2012). If the subjects filled out only a part of the cutaneous area supplied by the nerve, this was enough to consider the marking valid. The neurophysiologist, blind to signed hand diagram results, evaluated the sensation of the hand with the touch threshold test using Semmes-Weinstein monofilaments. We used 20 pieces full kit of monofilaments. Normal touch threshold of the hand is commonly identified with green, reduced light touch with blue, reduced protective sensation with purple, the red monofilaments identified the loss of protective sensation. The monofilaments were applied for about 1–1.5 s three times perpendicularly to test sites until they bent. The test sites were: the tip of the third, fifth and medial aspect of the fourth digits, the lateral and medial aspects of the palm and dorsum of the hand. While testing we proceeded from the small to large monofilaments. We explained this procedure to the patient and we instructed the patient to answer "yes" or "no" with closed eyes, if he felt the filament. The lightest monofilament that a patient could feel at least twice was considered the threshold value of the test site. We considered sensation reduced if the threshold values of the ulnar test site was obtained with blue monofilaments and those of the median and radial sites with green monofilaments or there was difference of the threshold of color monofilament purple vs. blue when a comparison between ulnar with median or radial aspects of the hand was made, or blue vs. green monofilament when the affected ulnar sites were compared with healthy one.

2.3. Electrophysiological examination

All the electrophysiological studies were conducted using bipolar surface electrodes. The arm temperature was kept, if necessary, higher than 32 °C by an infrared lamp. We confirmed the clinical diagnosis of UNE through EDX based on the protocol of the AANEM (AAEM, 1999). Ulnar nerve motor conduction velocity (MCV) was calculated from below-elbow to wrist, from above-elbow to below-elbow and from axilla to above-elbow. Distal motor latency (DML) was gauged at a distance of 7 and 14 cm from the wrist to the motor point of ADM and FDI muscles. Compound muscle action potential (CMAP) amplitude was measured from baseline to negative peak. We also measured the difference between MCV across elbow vs. below elbow-wrist segments ("MCV drop") and percentage decrease in CMAP amplitude from below elbow to above elbow ("conduction block"). The elbow was kept moderately flexed (80–90°) and the length of the segment studied across the elbow was always 10 cm. In addition to localize the site of UNE under humeroulnar arcade (cubital tunnel syndrome) or at the retroepicondylar groove we performed 2 cm short-segment MCV study with six positions of ulnar nerve stimulation from 4 cm distal to 6 cm proximal to the medial side of the epicondyle every two cm.

The segments were identified along the longitudinal course of the nerve and marked whit a pen: medial epicondyle; 2 and 4 cm distal to medial epicondyle (respectively); 2, 4 and 6 cm proximal to medial epicondyle, respectively. We took into account the percentage decreases of CMAP amplitude and the differences of latency between two adjacent sites of electrical stimulation (Azrieli et al., 2003; Omejec and Podnar, 2015a, 2015b).

We measured orthodromic sensory conduction velocity (SCV) of the ulnar nerve in the fourth digit -wrist tract (U4) and in the fifth digit-wrist tract (U5). In addition, we performed SCV of DUCN antidromically from the ulnar styloid to the metacarpal interspace between the fourth and fifth rays in the hand dorsum. Sensory nerve action potential amplitude (SNAPa) was calculated peak-to-peak. Because the dorsomedial aspect of the hand may be supplied partially or fully by the superficial radial nerve rather than DUCN, to search this anatomical variant we stimulated also the superficial radial nerve at the same distance of the radial aspect of the wrist recording at the same site of the dorsum of the hand used to test DUCN (Leis and Wells 2008; Parra et al., 2018). If we found this variant of innervation, UNE patients and controls were excluded from the study, because the presence of this variant may overestimate the neurographic anomalies of DUCN and reduce the matching with clinical finding of the hand dorsum. In the symptomatic arm, we also measured sensory and motor conduction values of the median nerve. Neurographic values were considered abnormal if were ±2 SDs of the mean of our normative data for DML, MCV (including "drop") and SCV, and if were lower than 5th percentile of the normative data for transformed logarithmic values of CMAP (including "block") and SNAPa. In our EMG lab we have two different abnormal cut-offs of all neurographic findings according to two age groups (10–59 years and 60->60 years).

We also performed needle EMG of the ADM, FDI, ABP, FCU and biceps brachii muscles, and at least one extensor muscle of the arm. EMG study included the assessment of resting activity (positive sharp waves, fibrillations and high-frequency repetitive discharges), qualitative analysis of motor unit action potentials (MUAPs) and full recruitment pattern. We considered abnormal EMG of a muscle if we recorded denervation activity at rest in at least two separate areas and/or reduced recruitment at full effort (fewer MUAPs firing at higher rate).

Our minimum electrodiagnostic criteria to include UNE cases were one of the following "localizing" EDX anomalies: abnormal slowing of MCV across the elbow or abnormal conduction drop or abnormal conduction block recording from ADM and FDI muscles.

UNE was considered localized under humeroulnar arcade or at the retroepicondylar groove if at least one 2 cm short-segment motor interlatency was >0.55 ms or CMAP amplitude drop >15% in the respective segments. These cut-offs were obtained from the normative data of our EMG lab. We considered UNE cases with prevalent axonal damage if the cases showed abnormal neurogenic EMG evidence and/or reduction of CMAP amplitude at wrist, and cases with prevalent demyelinating form in presence of block and/or slowing of MCV across elbow without sign of axonal damage.

EDX of controls included EMG of the muscles and neurography of the nerves of upper limbs, which might vary among patients in relation to history, symptoms, and physical examination and to the request of referring physician. However, EDX protocol of all controls mandatorily included: ulnar nerve MCV 10 cm across-elbow and below elbow-wrist segments, DML, CMAP amplitudes, MCV drop, conduction block across the elbow recording from ADM muscle, U4, U5 DUCN SCV and SNAPa, median nerve motor and sensory neurography and EMG of FDI muscle.

The study was approved by the local ethics commission, and all cases and controls signed informed consent.

3. Statistical analysis

Descriptive statistics consisted in numbers and percentages or means and SDs. We estimated sensitivity, specificity, positive and negative predictive values (PPV and NPV respectively) of the sites of sensory symptoms and of abnormal objective sensation and sensory neurographic findings using the conventional 2x2 table. Because the data was not normally distributed according to Kolmogorov-Smirnov test with Lilliefors correction, we used Spearman's coefficient to correlate symptom duration and UNE questionnaire results with electrophysiological alterations. We employed Mann-Whitney nonparametric test to analyze the differences of neurographic findings between UNE cases and controls. We verified whether clinical sensory findings (abnormal or normal) of the ulnar hand territories matched with SNAP anomalies (abnormal or normal) of corresponding ulnar nerve branches. We used Fisher's exact test to test the differences in frequency of sensory abnormalities between the two UNE groups according to site of injury (under humeroulnar arcade or at the retroepicondylar groove) and to electrophysiological forms (prevalent demyelinating or prevalent axonal) and to check the differences of segmental muscle strength, EMG and motor neurographic findings between the cases and controls.

4. Results

Patients with UNE were 75 (mean age 52.3 ± 11.7 years, 50 males and 25 females, 66 right-handed and 9 left-handed). Control subjects were 180 (mean age 47.4 ± 12.6 years, 89 males and 91 females, 163 right-handed and 17 left-handed). According to hand diagram proposed by Werner et al. (2012), we classified all UNE cases into "definite" or "possible" categories. In UNE cases, the non-dominant side was more affected than the dominant side (44 vs. 31, corresponding to 45 left vs. 30 right sides), on the contrary in controls the dominant side was more affected than the non-dominant one (121 vs. 59, corresponding to 110 right vs. 70 left sides).

The Table 1 reports means and SDs of the motor and sensory neurographic findings in cases and controls. All electrophysiological parameters of the ulnar nerve significantly differed between the two groups. Results of manual reduced strength (MRC scale), EMG findings in muscles supplied by ulnar nerve and abnormal ulnar motor neurographic data of UNE cases and controls are reported in Table 2. Clinical examination of UNE cases showed combined weakness/hypotrophy of ulnar intrinsic hand muscles and sensory loss in 29 cases (38.7%) and sensory loss in ulnar territory alone in 42 (56%). No cases had motor deficit alone. All UNE cases had abnormal at least two out of six "localizing" motor neurographic parameters (i.e. between MCV slowing above-below the elbow, MCV drop and block of the motor conduction recording from FDI and ADM muscles). MCV drop and conduction block, when present, were accompanied by MCV delay across the elbow in almost all cases. Almost all UNE patients with reduced amplitude of wrist CMAP in at least one intrinsic hand ulnar muscle had abnormal EMG in the same muscle. In view of the aims of this study, these results were not further discussed.

According to the location of damage, in 20 cases the site of injury is under humeroulnar arcade and in 50 at the retroepicondylar groove. In 5 cases we were not able to localize the exact site. According to pathophysiology of the neuropathy 38 were predominantly axonal and 37 predominantly demyelinating forms.

We found significant relation between UNE questionnaire scores and U4 SNAPa ($r = -0.24$, $p = 0.037$), U5 SNAPa ($r = -0.23$, $p = 0.04$) and DUCN SNAPa ($r = -0.25$, $p = 0.026$). The same electrophysiological parameters and symptoms duration showed no rela-

Table 1
Means and SDs of the ulnar nerve motor and sensory neurographic findings in cases and controls, and cutoff values of our EMG lab.

	% CMAP changes above-below elbow (ADM)	% CMAP changes above-below elbow (FDI)	MCV above-below elbow (m/s) (ADM)	MCV above-below elbow (m/s) (FDI)	U4 SCV (m/s)	U4 SNAPa (μV)	U5 SCV (m/s)	U5 SNAPa (μV)	DUCN SCV (m/s)	DUCN SNAPa (μV)
Patients (n.75)	−9.8 ± 14.5	−10.8 ± 16	38.4 ± 8.8	37.2 ± 9.9	35.5 ± 27.9	2.5 ± 2.8	39.4 ± 25	4.3 ± 4.7	43.7 ± 20.1	11.4 ± 10.7
Controls (n.180)	−2.8 ± 2.5	−2.7 ± 2.7	57.2 ± 5	53.12 ± 4.2	59.8 ± 4.5	7 ± 3.2	58.5 ± 4.8	11 ± 4	57 ± 6	22.5 ± 10.1
Cutoff LAB values (subjects < 60 years)	−15.2%	−14.9%	49.5	49.2	43.2	3.83	45.1	8.19	47.9	11.9
Cutoff LAB values (subjects > 60 years)	−23.2%	−23.8%	47.1	46.8	40.7	1.99	42.6	3.95	45.2	6.1

ADM: Abductor digiti minimi muscle; CMAP: compound muscle action potential; DUCN: dorsal ulnar cutaneous nerve; FDI: first dorsal interosseus; LAB: our EMG laboratory; MCV: motor conduction velocity; n.: number; SNAPa: sensory nerve action potential amplitude; SCV: sensory conduction velocity; U4: ulnar nerve, fourth digit-wrist tract; U5: ulnar nerve, fifth digit-wrist tract. 28 U4 SNAP, 21 U5 SNAP and 12 DUC SNAP were inelicitable. Results are reported as mean values ± SD. All the electrophysiological parameters of UNE subjects were statistically different from controls (p < 0001).

Table 2
Abnormal segmental muscle strength (MRC score < 5), EMG and motor neurographic findings in case and controls.

	UNE Cases No. and percentage	Controls No. and percentage	Fisher's exact test
MRC score < 5			
FDI	42.7% (32/75)	1.1% (2/180)	p < 0.0001
ADM	37.3% (28/75)	1.1% (2/180)	p < 0.0001
FCU	14.7% (11/75)	0.6% (1/180)	p < 0.0001
Abnormal EMG*			
FDI	48% (36/75)	0.9% (1/107)	p < 0.0001
Abnormal Motor neurography from ADM			
MCV across elbow	94.7% (61/75)	0% (0/180)	p < 0.0001
Conduction "drop"	84% (63/75)	3.3% (6/180)	p < 0.0001
Conduction "block"	17.3% (13/75)	0% (0/180)	p < 0.0001
Reduced wrist CMAP amplitude	12% (9/75)	1.1% (2/180)	P = 0.0004

ADM: abductor digiti minimi; CMAP: compound muscle action potential; FDI: first dorsal interosseous; MCV: motor conduction velocity.
* Spontaneous activity/denervation at rest and or neurogenic changes at maximum voluntary effort.

tion. In control subjects there was no relation between sensory ulnar neurographic findings and UNE questionnaire results and symptoms duration.

Fig. 1(A and B) shows the percentages of hand regions with sensory symptoms on the hand diagram and the loss of touch sensation detected in the four territories supplied by ulnar nerve branches, in UNE subjects and controls, respectively. In the bottom of the Fig. 1(C and D) the percentages of abnormal SNAPa and SCV of U4, U5 and DUCN are reported in cases and controls, respectively. In UNE cases, the fifth digit showed the highest percentage of subjective and objective sensory abnormalities; on the other hand the medial side of hand dorsum showed the lowest percentage of sensory changes if compared to the other areas. When we considered neurographic findings, SNAPa demonstrated more anomalies than SCV and DUCN neurography showed the lowest number of cases with anomalies. In controls, the percentages of ulnar sensory changes and ulnar neurographic abnormalities were very low.

Table 3 reports the sensitivity, specificity and predictive values of sensory clinical and neurographic findings. Reduction of touch sensation, symptoms complained by the patients in the V digit and U5 SNAPa anomalies had the highest values of sensitivity and specificity and of predictive values. The symptoms complained in IV digit had high sensitivity and specificity, reduced sensation of IV digit and U4 SNAPa had high specificity but low sensitivity. Similar results were found in clinical and neurographic findings of hand dorsum and palm regions. All SCV had the lowest sensitivity (lower than 40%).

Fig. 2(A and B) shows the percentage of matching of abnormal/normal SNAPa of U4, U5 and DUCN with abnormal/normal hand diagram and sensation in UNE subjects and controls, respectively. Fig. 2(C and D) shows the matching between abnormal/normal sensation and abnormal/normal hand diagram in the four sensory territories supplied by the ulnar nerve in UNE subjects and controls, respectively. In UNE cases, the fifth digit showed the highest matching, the fourth digits showed the lower percentage of matching. In controls the matchings were sufficiently high in almost all pairs.

Taking into account the above results, the subjective and objective clinical and neurographic findings of the little digit have the highest accuracy in UNE diagnosis. On the contrary, symptoms and sensory loss in the ulnar dorsum and palm of the hand, and reduced SNAPa of DUCN demonstrated the lowest accuracy. We do not report the matching results between sensory findings of the ulnar palmar aspect of the hand and SNAPa of the PUCN because we performed sensory neurography of PUCN in an insufficient number of subjects to obtain reliable results. There are no significant differences in hand diagram, loss of touch sensation and neurographic findings between the two locations of ulnar nerve injury (beneath humeroulnar arcade vs. retroepicondylar groove). Table 4 shows the differences between prevalent axonal and demyelinating forms of UNE. Objective and subjective sensory

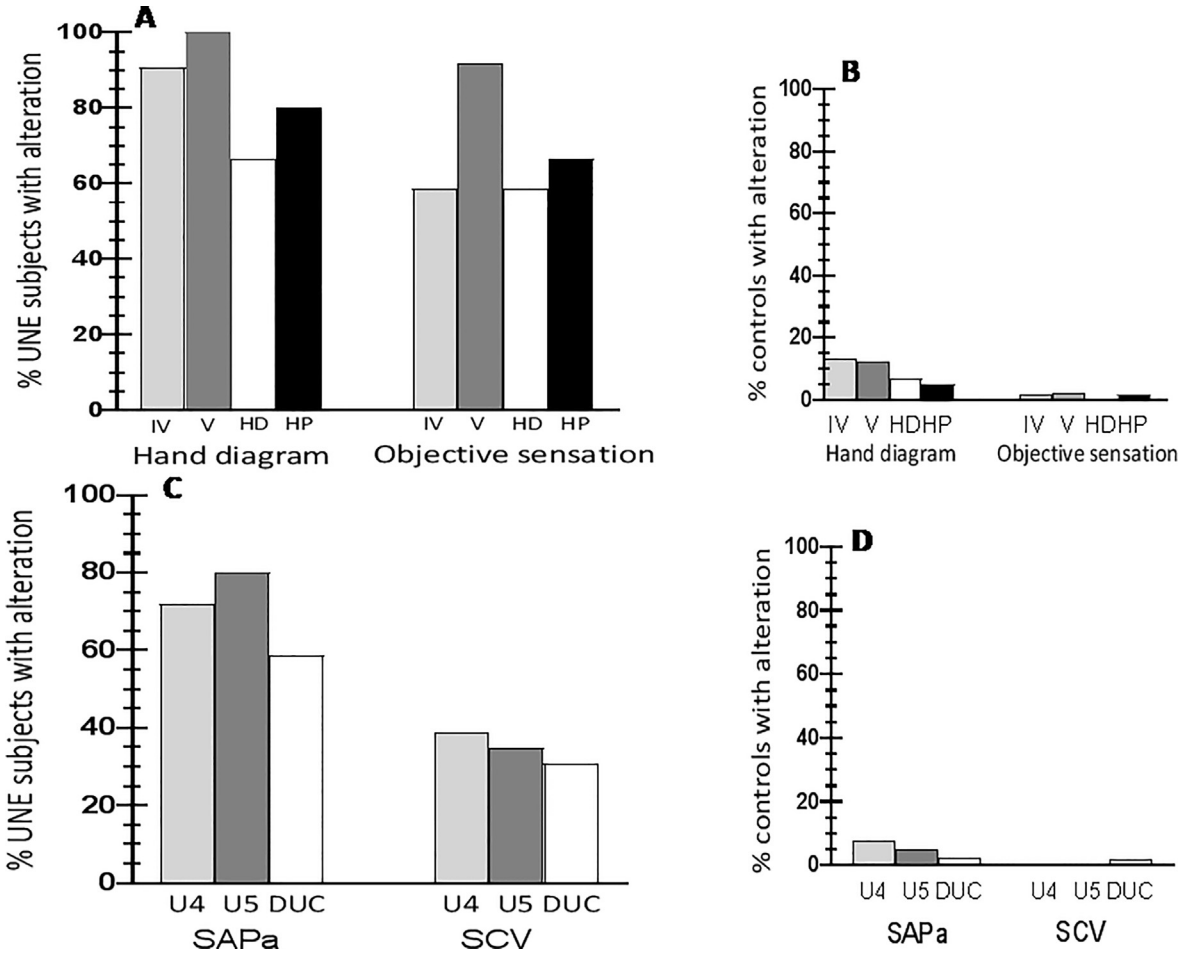

Fig. 1. A and B: percentage of UNE subjects (n. 75) (A) and controls (n.180) (B) showing anomalies of the hand diagram and touch sensory loss in the four ulnar territories: fourth and fifth digits, medial side of hand dorsum (HD) and of hand palm (HP). C and D: percentage of UNE subjects (C) and controls (D) showing alterations of SNAPa and SCV of all the three ulnar nerve branches. DUCN: dorsal ulnar cutaneous; SCV: sensory conduction velocity; SNAPa: sensory nerve action potential amplitude; U4: fourth digit-wrist tract, U5 fifth digit-wrist tract.

Table 3
Sensory findings: sensitivity, specificity, positive and negative predictive values (PPV and NPV).

	Sensitivity	Specificity	PPV	NPV
Abnormal sensory symptoms in IV digit	90.7%	86.7%	73.9%	95.7%
Abnormal sensory symptoms in V digit	100%	87.8%	77.3%	100%
Abnormal sensory symptoms in hand dorsum	66.7%	93.3%	80.6%	87%
Abnormal sensory symptoms in hand palm	80%	95%	87%	91.9%
Touch sensory loss in IV digit	58.7%	98.3%	93.6%	85.1%
Touch sensory loss in V digit	92%	97.8%	94.5%	96.7%
Touch sensory loss in hand dorsum	58.7%	99.4%	97.8%	85.2%
Touch sensory loss in hand palm	66.7%	98.3%	94.3%	87.6%
Abnormal U4 SNAP amplitude	72%	92.2%	79.4%	88.8%
Delayed U4 SCV	38.7%	100%	100%	79.8%
Abnormal U5 SNAP amplitude	80%	95%	87%	91.9%
Delayed U5 SCV	30.7%	99.4%	95.8%	77.5%
Abnormal DUCN SNAP amplitude	58.7%	97.8%	91.7%	85%
Delayed DUC SCV	34.7%	98.3%	89.7%	78.3%

DUCN: dorsal ulnar cutaneous nerve; NPV: negative predictive value; PPV: positive predictive value; SNAP: sensory nerve action potential; SCV: sensory conduction velocity; U4: ulnar nerve fourth digit–wrist tract; U5: ulnar nerve fifth digit –wrist tract.

abnormalities (except for the symptoms involving the fourth and fifth digits), U4, U5 and DUCN SNAPa anomalies were more frequent in prevalent axonal than in demyelinating forms.

5. Discussion

The clinical localization of the site of ulnar nerve damage is not simple. Abnormalities in the intrinsic hand muscles and relative sparing of the forearm muscles are common findings in UNE. (Jabre and Wilbourn, 1979; Miller, 1979; Craven and Green, 1980). The involvement of the cutaneous areas supplied by the three ulnar sensory branches is somewhat variable, and only the superficial digital branches may be affected even if the site of injury is at the elbow. This implies that the clinical examination could misdirect the physician to a diagnosis of ulnar nerve neuropathy at wrist.

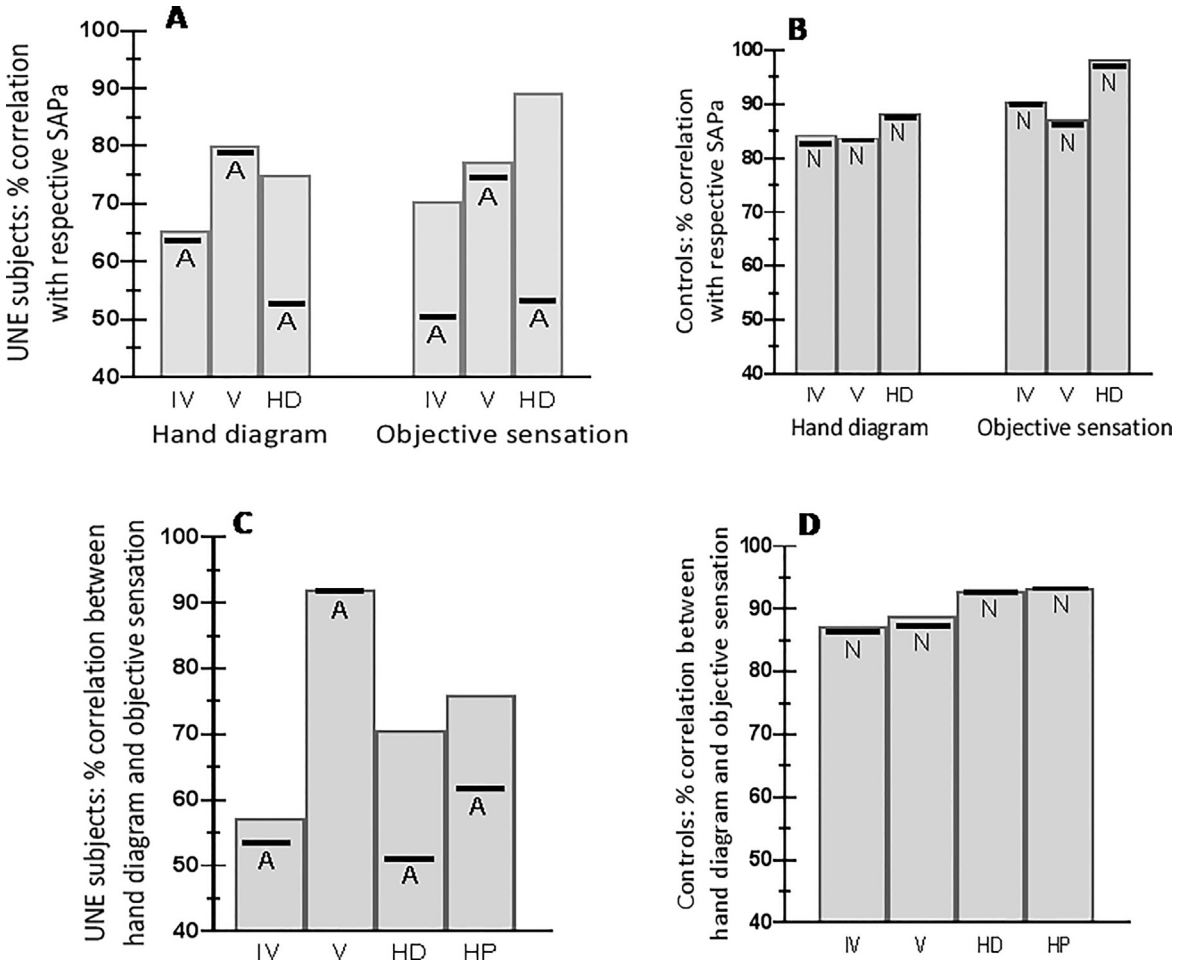

Fig. 2. A and B: percentage of matching of hand diagram findings and touch sensory loss in the fourth and fifth digits and in the medial side of hand dorsum (HD) in UNE subjects and controls, respectively. A: the percentage of matching of abnormal findings are reported below the black line for the UNE subjects (A: abnormal). B: the percentage of matching of normal findings are reported below the black line for the controls (N: normal). C and D: percentage of matching of hand diagram findings and touch sensory loss for each of the four hand territories in UNE subjects and controls, respectively. C: the percentage of matching of abnormal findings are reported below the black line for UNE subjects (A: abnormal). D: the percentage of matching of normal findings are reported below the black line for the controls (N: normal).

If the physicians analyzed the longitudinal course of the main trunk to localize the site of nerve lesion, this approach may cause diagnostic pitfalls. For example, in UNE the branches to FDP muscle, PUCN and DUCN, arising at considerable distances from the medial epicondyle, may be affected or spared. The selective clinical picture following nerve lesion may depend from selective liability of individual fascicles into the nervous trunk.

There are evidences of the existence of a high degree of spatial preservation of nerve fascicles positioning in cross-section (Stewart, 2003). Fascicular nerve organization has been demonstrated not only in the distal parts of peripheral nerves but also in the proximal one (Bäumer et al., 2015). The fascicles containing the fibers from the terminal digital sensory branches and direct to the small hand muscles, mostly to the FDI, are the most involved in the UNE (Stewart, 1987). A proximal partial injury of the ulnar nerve may selectively damage just some nerve fibers/fascicles sparing others resulting in restricted motor and sensory deficit; the lesion may then appear to be more distal than it actually is (Stewart, 2003). Our study provides a clear confirmation of this hypothesis, and quantifies the damage of the individual sensitive branches.

The main data of present study is that sensory anomalies of the fifth digit are constant findings in UNE more than anomalies of the other ulnar nerve hand regions. Consequently, it is plausible that the fascicles containing fibers from the fifth digit are more liable to damage at elbow than the others. In our sample the specificity is high for almost all sensory clinical and electrophysiological parameters considered in this study (see Table 3). Sensory symptoms and reduced sensation of the little digit are the most frequent abnormal clinical sensory findings in UNE subjects. The 100% of UNE cases signed the palmar aspect of the fifth digit on hand diagram and the 92% demonstrated loss of touch sensation in the same territory. About 12% of controls subjects filled out the palmar aspect of IV and V digits, but only a negligible percentage reported also hypoesthesia. Moreover almost all the controls who filled out the IV and V digits, often also marked the other digits. It is possible that these control subjects may have a low cervical radiculopathy (with unremarkable electrophysiological study), or intermittent symptoms of an initial ulnar neuropathy or psychosomatic symptoms; finally they could be false positive. Our data showed a high relation between subjective and objective sensory anomalies of the fifth digit and electrophysiological abnormalities of U5 SNAPa. This relation appears sound because paresthesia, touch sensation and abnormalities of sensory neurography are due to injury to the same type of sensory fibers (A beta fibers). On the contrary, in controls, this relation is usually absent. In controls normal sensory examina-

Table 4
Sensory anomalies according to predominantly axonal or predominantly demyelinating forms of UNE.

	Abnormal sensory symptoms in IV digit	Abnormal sensory symptoms in V digit	Abnormal sensory symptoms in hand dorsum	Abnormal sensory symptoms in hand palm	Touch sensory loss in IV digit	Touch sensory loss in V digit	Touch sensory loss in hand dorsum	Touch sensory loss in hand palm	Abnormal U4 SNAPa	Abnormal U5 SNAPa	Abnormal DUCN SNAPa
AXONAL (38 pt)	36 (94.74%)	38 (100%)	35 (92.1%)	36 (94.7%)	29 (76.3%)	38 (100%)	34 (89.47%)	33 (86.84%)	35 (92.1%)	36 (94.74%)	32 (84.21%)
DEMYELINATING (37 pt)	32 (86.49%)	37 (100%)	15 (40.5%)	24 (64.86%)	15 (40.54%)	31 (83.78%)	10 (27.03%)	17 (45.95%)	19 (51.35%)	24 (64.86%)	12 (32.43%)
Fisher's exact test	*p = 0.26*	p > 0.99	*p < 0.0001*	*p = 0.0014*	*p = 0.0023*	*p = 0.0115*	*p < 0.0001*	*p = 0.0002*	*p < 0.0001*	*p = 0.0014*	*p < 0.0001*

DUCN: dorsal ulnar cutaneous nerve; SNAPa: sensory nerve action potential amplitude; U4: ulnar nerve fourth digit–wrist tract; U5: ulnar nerve fifth digit –wrist tract.

tion, absence of sensory symptoms showed high correlation with normal respective SNAP, emerging as a finding with high specificity to exclude UNE.

To localize precisely the site of the ulnar nerve lesion at the elbow, sensory neurography performed in the distal tract of the ulnar nerve is obviously less useful than motor neurography. Any sites of ulnar nerve injury localized proximally to the wrist may produce abnormalities of ulnar SNAPa if measured in the digit-wrist tract of the nerve. Thoracic outlet syndrome, C8-T1 radiculopathy, lower trunk plexopathy may cause abnormal U5 SNAP, but these patients have almost always different symptoms in respect to UNE (especially pain) and MCV across the elbow is usually normal. In addition, in the most frequent Guyon's canal syndrome only motor fibers to interosseous muscles are involved and if sensory fibers are damaged SCV is usually delayed. DUCN SNAPa is abnormal only in about more than half of patients, although we have ruled out all UNE subjects with superficial radial variant of innervation to the dorsomedial side of the hand, to make DUCN neurographic anomalies reliable. However, DUCN conduction matches with clinical findings much less frequently than U5. The low sensitivity of DUCN SNAP limits its use in UNE diagnosis (Kim et al., 1981; Venkatesh, 1995; Dutra de Oliveira et al., 2000). The other sites of hand ulnar nerve are less frequently involved and there are no UNE cases with abnormalities of fourth digit, dorsal and palmar ulnar aspect of the hand without fifth digit anomalies.

In our sample there were no differences of the frequency of sensory alterations between two UNE groups according to location of UNE (under humeroulnar arcade vs. retroepicondylar groove). This result is in line with the findings of Omejec et al. (2016) who did not report differences in the perception of pinprick and light touch in ulnar hand cutaneous territory in patients with diverse location of UNE. Using these tools for the sensory examination, the same authors did not show differences between patients with axonal and demyelinating UNE (Omejec et al., 2016), whereas by using Semmes-Weinstein monofilaments the same authors showed differences in all the cutaneous territories supplied by the three main sensory ulnar nerve branches (Omejec and Podnar, 2018). In particular, the differences were more frequent in axonal and conduction slowing pathophysiologies than in conduction block UNE (Omejec and Podnar, 2018). In the present paper, we demonstrated in all cutaneous territories of the ulnar nerve that the sensory symptoms and loss of sensation were more frequent in the predominantly axonal than in predominantly demyelinating forms of UNE. On the other hand, we used definite criteria to distinguish the UNE cases according to pathophysiology: (1) we did not consider the SNAP studies as tool for defining UNE pathophysiology, because these studies have significant pitfalls and limitations (see AAEM 1999) and, because SNAPa was recorded distally to the location of the lesion, the possible abnormalities might be due to axonal loss or sensory conduction block; (2) to ascertain the axonal form, we performed standard needle EMG.

Our study has some limits. The sample size is relatively small (75 cases). In the period of the enrolment, we diagnosed 146 cases of UNE, but according to selection criteria, we included in the study only idiopathic UNE, because the other forms for example patients with diabetes, polyneuropathy might have clinical and neurographic anomalies not due to UNE and the patients older than 70 years might give unreliable answers. It was possible that we excluded from the study some subjects with symptoms of UNE but with normal EDX (false negatives). In a recent study some subjects with UNE showed ultrasound alterations (increased cross sectional area of the ulnar nerve) with normal EDX (Omejec et al., 2015). However, in our sample the number

of patients with symptoms of UNE and normal conduction velocity excluded from the study were very few (about 10%).

Moreover, compared to previous clinical and electrophysiological studies, our study has a population of control. However, our controls were not completely "normal" because they have symptoms significantly enough to warrant an EDX study; on the other hand, our controls were unselected and consecutive and had no peripheral nervous system disorders and systemic diseases. We did not match the controls with cases by age and gender. We think that this type of matching might cause a bias greater than selecting the controls irrespective of age and sex; our controls were consecutive and met the same exclusion criteria of the cases. In addition we considered abnormal touch sensation if in the same subject there were differences of the threshold values of sensation between ulnar regions of the hand and those of median or radial nerves, and we separated the normative data of neurographic findings by age groups. Another aspect to consider is that we decided to use EDX because our expertise in this method and we were unable to perform imaging studies to all our patients. In the last decades ultrasonography and MRI provide valuable images of the nerve and neighboring structures supplying additional morphological information in respect to EDX in peripheral nerve diseases including UNE (Hobson-Webb et al., 2012; Kwee et al., 2014; Omejec et al., 2015). Then, it is possible that we have lost some information, since few patients had UNE symptoms but normal ulnar neurography.

A strength of our study that differentiates it from the others is the mandatory exclusion of all subjects with innervation variant of the hand dorsum from the radial nerve. This peculiarity makes the results quite reliable.

In conclusion, the objective and subjective sensory anomalies of the little digit are constant findings in UNE more than anomalies of the other regions supplied by the ulnar nerve, because probably the fascicles from this digit is more liable to damage at elbow than the others. Often sensory clinical anomalies match with abnormal U5 SNAPa that, if present, may help to document axonal degeneration.

Conflict of interest statement

None.

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