Neurophysiological classification of carpal tunnel syndrome: assessment of 600 symptomatic hands

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Following the AAEM electrodiagnostic guidelines, we developed a neurophysiological classification of carpal tunnel syndrome (CTS). Sixhundred hands with clinical CTS (mean age 51.4 yr., female/male ratio 5.5/1, right/left ratio 1.8/1) were prospectively evaluated and divided into six classes of severity only on the basis of median nerve electrodiagnostic findings: extreme CTS (EXT – absence of thenar motor responses), severe CTS (SEV – absence of sensory response and abnormal distal motor latency – DML), moderate CTS (MOD – abnormal digit-wrist conduction and abnormal DML), mild CTS (MILD – abnormal digit-wrist conduction and normal DML), minimal CTS (MIN – exclusive abnormal segmental and/or comparative study), and negative CTS (NEG – normal findings at all tests)
Using this neurophysiological classification, the CTS groups appeared normally distributed (EXT 3% of cases, SEV 14%, MOD 36%, MILD 24%, MIN 21%, NEG 3%), and the age of patients and clinical findings appeared to be related to neurophysiological abnormalities. Significant differences in median neurophysiological parameters not included in the classification (such as palm-wrist sensory conduction velocity) were observed in the different CTS groups. The analysis of the groups showed that: 1) the majority of advanced cases (SEV and EXT) occurred in older patients (60-80 years), 2) most of the milder cases (MIN and MILD) occurred in young female patients.
The aim of this study was to standardise the neurophysiological evaluation of CTS.

Key Words: Carpal tunnel syndrome — Median nerve — Neurophysiological classification.

Introduction

In order to standardise the diagnostic and therapeutic approach of any disease, it is essential to have a common and interdisciplinary language and a classification that should be as objective as possible and not only based on referred symptoms or vague clinical signs.
Although carpal tunnel syndrome (CTS) is very common entrapment (with a 10% lifetime risk – 3) and many recent studies have increased the diagnostic sensitivity of neurophysiological tests [1, 4, 5, 6, 7, 8, 12, 13, 15, 16, 17, 18, 19], no systematic attempts have been made to identify the different degrees of the electrophysiological patterns; two papers have recently concentrated on the clinical pictures of C TS [9, 20].
We evaluated 600 hands with a clinical diagnosis of CTS using a neurophysiological classification developed by us. This classification follows the recent AAEM guidelines [1, 2] and follows the neurophysiological progression of the entrapment, which can be summarised as follows: 1) abnormalities of comparative (comparison of median nerve conduction through the carpal tunnel with the radial or ulnar nerve conduction in the same hand) and/or segmental studies (over a short conduction distance across the carpal tunnel); 2) sensory nerve conduction velocity (SNCV) slowing in digit-wrist segments; 3) increase in distal motor latency; 4) disappearance of digit-wrist sensory response; 5) disappearance of motor response. We then analysed the distribution and clinical-electrophysiological features of the different CTS groups.

Material and methods

We examined 409 consecutive patients (600 hands) with a clinical diagnosis of CTS. The clinical diagnoses were based on at least one of the following criteria: 1) paraesthesias and pain in the hand during the night; 2) activity-related sensory symptoms; 3) puffiness and pain in the morning; 4) positive Phalen test; 5) sensory deficits in the hand region innervated by the median nerve; 6) motor deficit and/or hypotrophy of the median-innervated thenar muscles.
The mean age of the patients was 51.4 years (range 20-88), the female/male ratio was 5.5/1, and the right/left side ratio 1.8/1. The age of the population as a whole appeared to be normally distributed (Lilliefors, K-S tests), but there were differences between males and

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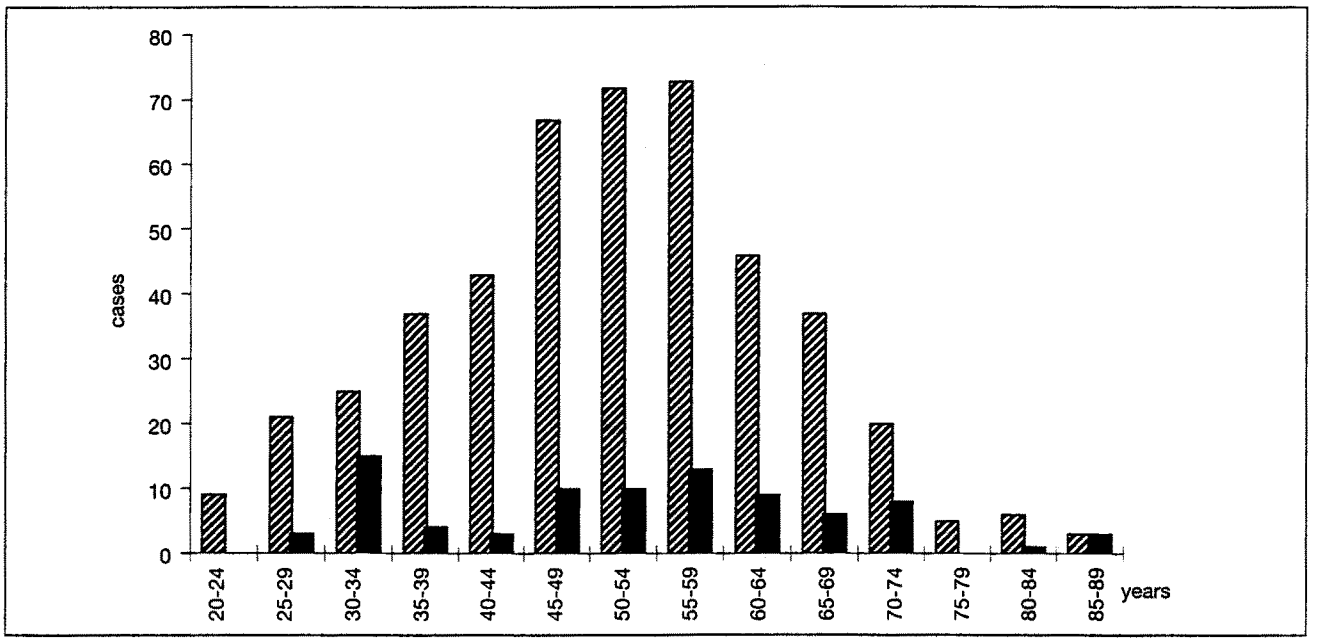

Fig. 1. Age distribution in 600 CTS hands: *the ages in the female population (grey) is normally distributed (K-S, Lilliefors probabilities tests), whereas the distribution of age in the male population (black) appeared to be bimodal.*

females: the age distribution in the male population appeared to be bimodal (not normal at Lilliefors, K-S test), with two peaks of incidence at the ages of 30-34 yr. and 55-59 yr.; in the female population, it was normal with one peak at 55-59 years (*Figure 1*).

Ninety-seven percent of the hands were affected by paraesthesias, mainly during night, associated with hand-wrist pain in 75% of cases (in the more advanced cases, the paraesthesias were often associated with hypoestesia and striking dysesthesia). In 17 cases (4%), there were no paraesthesias but the patients complained of pain in the wrist, nocturnal cramps in the hand, and puffiness of the hands early in the morning. A positive Phalen sign was present in 70% of the hands. In all cases, concomitant polyneuropathy or radiculopathy was excluded by means of a careful clinical examination and an extended neurophysiological evaluation.

The neurophysiological studies were carried out using a Medelec Sapphire 4ME electromyograph (Medelec, Surrey, England). An infrared lamp was used to maintain hand skin temperatures > 31°C during all of the tests. The following "standard" tests were used for all of the hands:

- median sensory nerve conduction velocity (SNCV) from first digit to wrist (1M)
- median SNCV from third digit to wrist (3M)

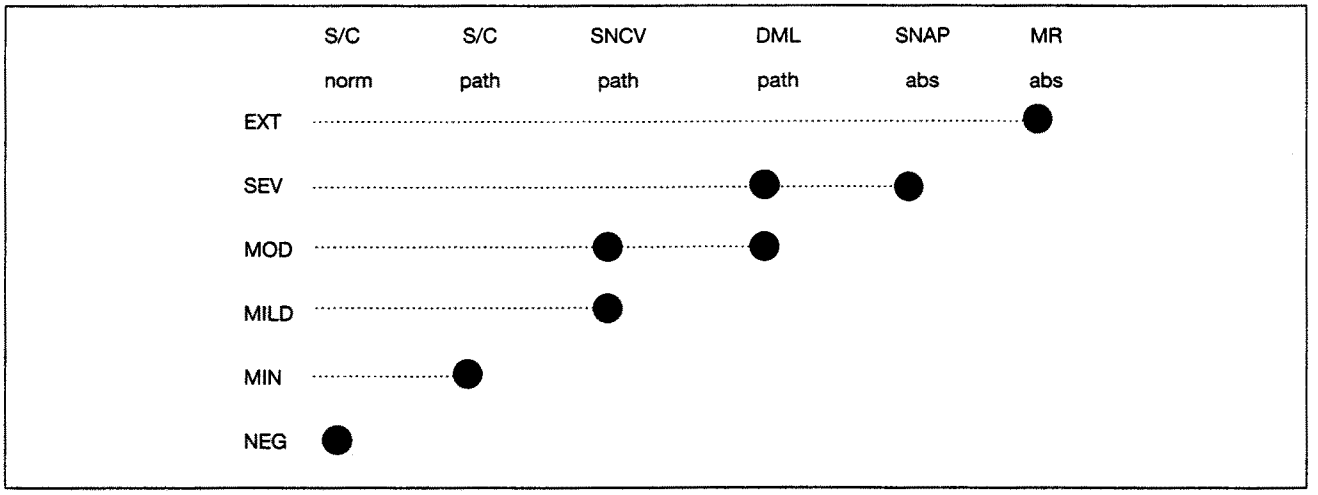

Fig. 2. Neurophysiological CTS classification: *electrodiagnostic patterns of different groups. Abbreviation: S/C: segmental/comparative tests, SNCV: sensory nerve conduction velocity in digit-wrist segment, MR: motor response, norm: normal, path: pathological, abs: absent, other abbreviation in text.*

– median distal motor latency from wrist to thenar eminence (DML)
– radial SNCV from first digit to wrist (1R)
As recommended by the AAEM [1], when the standard tests yielded normal results ("standard negative" hands), more sensitive studies (disto-proximal ratio) were carried out as follows:
– median SNCV from third digit to palm (3P)
– median SNCV from palm to wrist (P-W) calculated as (3M) – (3P)
– the disto-proximal ratio (R) calculated as (3P) / (P-W).
In the first 110 consecutive "standard positive" hands (with detectable sensory nerve action potential – SNAP), the 3P, P-W and R studies were also performed.
All of the nerve conduction studies were performed orthodromically by means of superficial stimulation and recording; the methods used have been previously reported [12].
Normal values are: 1R ≥ 40, 1M ≥ 42m/s, 3M ≥ 44m/s, DML< 4 ms ,PW ≥ 45m/s, 3P ≥ 37 m/s, R<1 [12].
In the cases in which no median motor thenar response was detectable, EMG of the forearm muscles was undertaken in order to exclude a lesion of the median nerve proximal to the wrist. Extended sensory and motor nerve conduction studies (sural, peroneal and ulnar nerve) were also carried out to exclude polyneuropathy.
The hands were divided on the basis of the following neurophysiological classification (*Figure 2*):
– *"Extreme CTS"* (EXT); absence of thenar motor (and sensory) response;
– *"Severe CTS"* (SEV): absence of median SNAPs (digit-wrist segment) and abnormal DML;
– *"Moderate CTS"* (MOD): slowing of median digit-wrist segment and abnormal DML;
– *"Mild CTS"* (MILD): slowing of median digit-wrist segment and normal DML;
– *"Minimal CTS"* (MIN): "standard negative" hands with abnormal comparative or segmental (<7-8 cm) tests
– *"Negative CTS"* (NEG): normal findings in all tests (including comparative or segmental tests)
As previously mentioned, we adopted 1M and 3M for the digit-wrist segment studies, and R as the comparative/ segmental test.
The data were statistically analysed by means of ANOVA, the Student T tests, and the K-S and Lilliefors probabilities tests for normality.

Results

The standard tests (1M, 3M, DML) showed abnormal findings in 479 hands (79.8%): DML was abnormal in 297 hands (49.5%), 1M in 440 hands (73.3%) and 3M in 393 hands (65.5%). In the 141 "standard negative" hands (23.5%), R was abnormal in 123 and PW in 24: all of these cases were included in the MIN group.
The data and mean values of neurophysiological parameters in the different CTS groups are shown in *Tables I-II.*
In the *EXT* CTS group, both SNAPs (1M and 3M) and motor responses were absent in 12/16 cases (and SNCV was markedly slowed in four cases with detectable 1M and/or 3M SNAPs); in the remaining four cases, there was an absence of only the 1M or 3M SNAP. In the majority of cases in the *SEV* CTS group (63/81), the absence of both median SNAPs, and an increase in DML was observed (in one case, DML was normal); in the other hands, only the 1M or 3M SNAP was absent. In the *MOD* CTS group, both 1M and 3M were usually

TABLE I. *Incidence, mean age and sex of CTS groups in 600 hands*

CTS group	n° cases	%	mean age	f/m ratio	right/left ratio
EXT	16	3	63.1 ± 11.2	7.0	1.0
SEV	81	14	58.8 ± 13.7	4.3	2.1
MOD	217	36	52.0 ± 12.8	5.0	2.0
MILD	145	24	50.8 ± 11.4	5.1	1.3
MIN	123	21	46.1 ± 13.8	7.5	1.4
NEG	18	3	42.1 ± 12.0	all female	0.8

TABLE II. *Mean values of neurophysiological parameters in CTS groups*

CTS group	1R		1M		3M		3P		P-W	R	W-T	
	NCV (m/s)	SNAP (μV)	NCV (m/s)	SNAP (μV)	NCV (m/s)	SNAP (μV)	NCV (m/s)	SNAP (μV)			DML (ms)	CMAP mV
SEV	59.5±5.7	7.4±2.8	-	-	-	-	-	-	-	-	6.6±1.8	5.3±3.7
MOD	50.9±5.2	9.2±4.8	32 ±5.6	8.7±6.8	35.5±6.2	7.7±7.4	43.3±7.2	11.9±8.8	32.2±7.6	1.4±0.3	4.7±0.7	8.0±4.2
MILD	51.2±4.9	10.3±4.4	38.1±3.4	13.4±7.2	42.3±3.7	12.8±7.2	50.0±7.3	16.5±10.3	40.4±3.4	1.2±0.2	3.6±0.3	8.9±4.4
MIN	53.4±5.7	15.1±7.1	47.6±4.3	21.2±11.2	51.4±5.0	20.0±9.8	54.8±6.3	24.4±12.5	48.4±6.5	1.2±0.2	3.3±0.4	10.1±4.4
NEG	52.8±5.3	17.5±8.5	51.2±4.4	19.3±8.5	53.7±3.8	19.9±8.8	48.6±5.3	29.7±14.3	57.7±4.0	0.8±0.1	3.1±0.2	11.1±4.6
	51.5±5.4	10.5±5.8	37.8±8.3	12.9±9.6	41.9±8.6	12.4±9.6	50.4±8.6	19.6±12.7	43.2±10.0	1.2±0.3	4.4±1.4	8.1±4.5

EXT CTS hands were not included because of the absence of Median parameter. *Abbreviations*: W-T: wrist-thenar motor conduction study, CMAP: motor response, NCV: nerve conduction velocity, other abbreviations on text. * Mean values of cases with detectable response; † P-W, 3P and R measured in 110 hands. SNAPs and NCV are expressed in μV and m/s respectively.

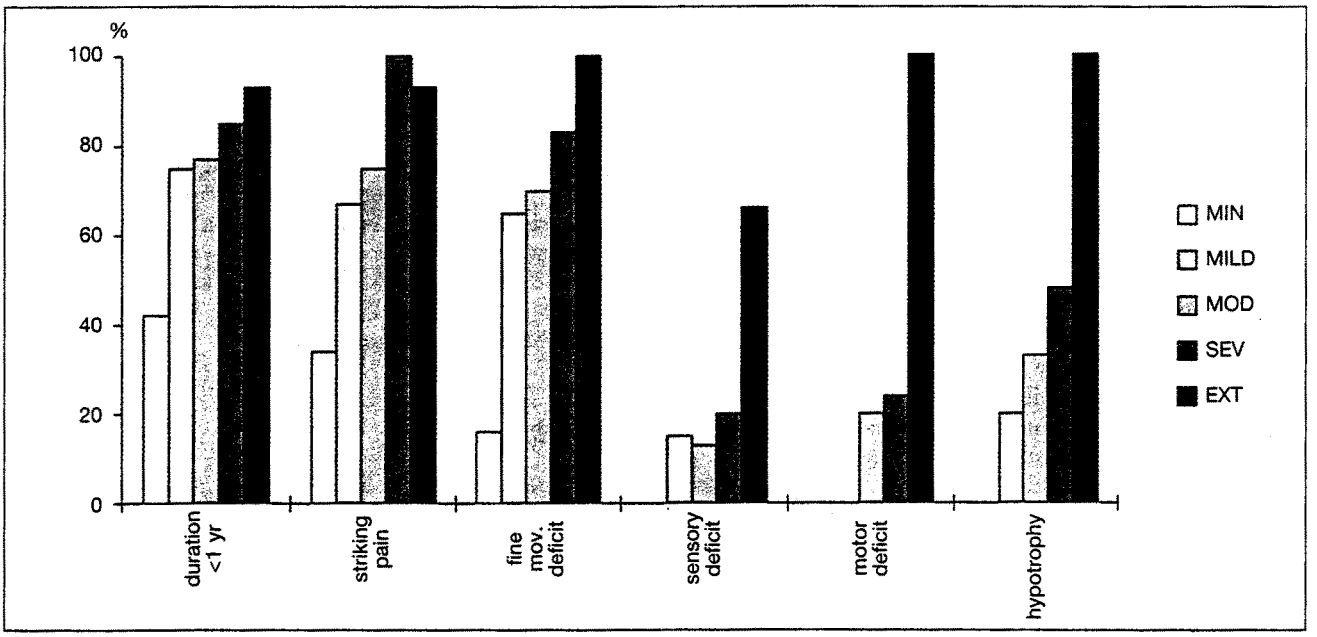

Fig. 3. Incidence of symptoms and clinical findings in CTS groups: *note the incidence of striking pain in MIN group. Abbreviation = "fine mov. deficit": difficulty in making fine everyday hand movements (e.g. buttoning small buttons, turning pages etc.)*

abnormal (204/217 cases); in one patient (both hands), an abnormal DML, but normal 1M and 3M, were observed. About half of the cases in the *MILD* CTS group (79/145) presented a slowing of both 1M and 3M; 12 hands presented only an abnormal 1M, and 53 only an abnormal 3M.

Figure 3 shows clinical symptoms and sign in different CTS groups. Severe symptoms with functional deficits were observed mainly in EXT and SEV groups, although some MOD CTS patients also presented functional deficits. No sensory and/or motor deficits were ever observed in the MIN group, although the patients often complained of severe symptoms.

CTS groups appeared to be normally distributed ($p < 0.05$), as shown by the "normal" distribution of all of the median conduction parameter ($p < 0.05$). ANOVA revealed a highly significant increase in the mean age of the patients in the SEV and EXT groups, in comparison with that observed in the MOD, MILD and MIN groups ($p < 0.0005$). The difference in P-W were highly significant differences ($p < 0.0005$) between the NEG, MIN, MILD and MOD CTS groups, and the difference in DML was highly significant between MOD and SEV groups ($p < 0.0005$). In 110 standard positive hands in which segmental/comparative study was performed, both P-W and R were always abnormal.

Discussion

After a wide-ranging review of CTS literature, the AAEM recently concluded that should be performed more sensitive neurophysiological studies (comparative and/or segmental < 7-8 cm) in suspected CTS cases with normal conduction in digit-wrist segment and normal DML [1, 2]. Our data confirm the importance of a thorough electrodiagnostic examination involving these more sensitive test [1, 4, 5, 6, 7, 8, 12, 13, 15, 16, 17, 18, 19]; in terms of classification, segmental/comparative tests made it possible to diagnose MIN CTS, which affects a considerable percentage of (especially younger) CTS patients. In our study, the use of the disto-proximal ratio increased the diagnostic yield by 20% (32% in the patients aged less than 40 years) in comparison with those who would have been diagnosed by means of standard test procedures.

An evaluation of the severity of CTS is important in both therapeutic and prognostic terms [3].

We adopted a neurophysiological classification that has the following advantages:

– it makes it possible to assign every hand to its specific group in any easy and non-arbitrary manner on the basis of electrophysiological cut-off points (normal/abnormal conduction findings and the presence/absence of evoked responses);

– different laboratories can adopt their own normal neurophysiological ranges;

– it can be used regardless of the neurophysiological techniques adopted by the different EMG laboratories (for example, digit-wrist SNCV measurements can be made using orthodromic and antidromic methods; or the more sensitive studies of palm-wrist nerve conduction, ulnar-median difference or the disto-proximal ratio can be used).

The CTS groups identified by the neurophysiological classification were normally distributed, and the mean age of patients and their functional deficits appeared to be related to the neurophysiological pattern because

the older patients and those with sensory and/or motor deficits mainly fell within the EXT and SEV groups. However, no clear correlation was found between neurophysiological pattern and symptoms [14]. Furthermore, P-W (a neurophysiological parameter that was not included in the classification) seemed to be significantly different between groups. As P-W is one of the most sensitive and specific neurophysiological parameters in detecting median nerve impairment, the differences in P-W values between our groups can be considered a validation of our proposed classification.

Analysis of our CTS groups showed that:

- more advanced cases (EXT and SEV) generally occur in older patients (60-80 years);
- milder cases (MIN and MILD groups) are mainly observed in young female patients;
- the NEG cases were exclusively female, mainly affected on the left side and mainly young (although it is important to remember that the NEG group consisted of a small number of hands).

In a previous study performed in our laboratory, this classification appeared to be a reliable tool for the prediction of post-surgical prognosis [10], but its prognostic value in relation to the natural history of CTS has still to be evaluated.

Nevertheless, on the basis of these observation, this classification (and more generally the correlation between age and neurophysiological findings) may help in the recognition of "atypical" CTS pictures (i.e. severe CTS in young people), the identification of which would suggest the extension of diagnostic investigations in order to exclude the presence of an underlying systemic disease [11].

In conclusion neurophysiological assessment of CTS patients and identification of different neurophysiological patterns may be useful in making clinical and therapeutical decisions; furthermore, our classification may be helpful to future research studies of this frequent entrapment neuropathy.

A word of caution is necessary regarding the use of this CTS classification in clinical practice: the fact that it simply provides standardised neurophysiological quantitative evaluation of median nerve impairment in CTS patients means that it should be used "in addition to" and not "instead of" clinical evaluation.

For the Italian version of this CTS classification, we suggest using the term "medio" for "moderate" (because "moderate" does not exactly correspond to the Italian term "moderato"); for the other CTS groups we suggest "estremo" (extreme), "grave" (severe), "lieve" (mild) and "minimo" (minimal).

This classification has the advantage/disadvantage to using commonly used adjectives, and so we suggest that any use of this classification should be specified.

Sommario

Seguendo le linee guida elettrodiagnostiche stabilite dall'AAEM abbiamo messo a punto una classificazione neurofisiologica della sindrome del tunnel carpale (CTS). Sono state studiate prospetticamente 600 mani con diagnosi clinica di CTS (età media 51.4 anni, rapporto femmine/maschi: 5.5/1, destra/sinistra: 1.8/1). Le mani sono state divise in sei classi di gravità sulla base dei reperti elettrodiagnostici del nervo mediano: CTS "estrema" (EXT – assenza della risposta motoria tenare), "grave" (SEV – assenza della risposta sensitiva e patologica latenza distale motoria – DML), "media" (MOD – reperti patologici della conduzione sensitiva dito-polso e della DML), "lieve" (MILD – conduzione sensitiva del segmento dito-polso patologica e DML normale), "minima' (MIN – anormalità solo dei test segmentari e/o comparativi), "negativa" (NEG reperti normali in tutti i test). L'utilizzo di tale classificazione ha evidenziato che i gruppi CTS sono distribuiti in modo "normale" (EXT 3% dei casi; SEV 14%, MOD 36%, MILD 24%, MIN 21%, NEG 3%) e che l'età dei pazienti ed i reperti clinici sono correlati con le anormalità neurofisiologiche. Sono state inoltre osservate tra i diversi gruppi differenze statisticamente significative di parametri neurofisiologici del nervo mediano non inclusi nella classificazione (come la velocità di conduzione palmo-polso).

L'analisi dei gruppi CTS ha mostrato che: 1) la maggior parte dei casi avanzati (EXT e SEV) sono stati osservati nei pazienti più anziani (60-80 anni), 2) la maggior parte dei casi lievi (MIN e MILD) sono stati osservati nelle donne giovani.

Scopo di questo studio è di standardizzare la valutazione neurofisiologica del CTS.

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