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# Electrophysiologic correlations and diagnostic accuracy analysis of quantitative surface electromyography in median neuropathy

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## Abstract

**Introduction:** electromyography (EMG) is a valuable diagnostic modality for assessment and diagnosis of neuromuscular pathologies that can lead to different degrees of disability. Quantitative electromyography (QEMG) uses time domain and frequency domain descriptors for analyzing maximum effort phase of the EMG signal or interference pattern (IP). These descriptors, using surface electrodes, can offer physicians a more objective tool and easier to carry out for describing abnormal IPs, and may offer patients a more comfortable option for performing an EMG study. **Objective:** describe the diagnostic accuracy using ROC curve analysis of the quantitative variables of surface EMG in patients with median neuropathy of carpal tunnel syndrome (CTS). **Material and methods:** 32 patients (50 hands) with electrophysiological diagnosis of CTS were compared with 14 patients (17 hands) without CTS. The IP of abductor pollicis brevis (APB) was obtained with a 10 second contraction, QEMG analysis included time domain and frequency domain variables. **Results:** mean amplitude of turns was lower and T/M ratio was higher in CTS group compared with non-CTS ($p < 0.001$). On frequency domain, root mean square amplitude (RMS) ($p < 0.001$) and power of peak frequency ($p < 0.05$) was lower on CTS group. Differences remained significant when an analysis matched by age was performed. ROC curve analysis showed an AUC of 0.96 for RMS and 0.93 for mean amplitude of turns. **Conclusion:** maximum effort EMG can be described with quantitative variables of the IP using superficial electrodes. Mean amplitude of turns and RMS obtained through surface EMG have high diagnostic accuracy for distinguishing between neuropathic and non-neuropathic patterns.

**Abbreviations:**
APB = Abductor Pollicis Brevis.
AUC = Area Under the Curve.
CMAP = Compound Muscle Action Potential.
CTS = Carpal Tunnel syndrome.
CV = motor Conduction Velocity.
EMG = Electromyography.
IP = Interference Pattern.
M = Mean amplitude of turns.
MUAP = Motor unit action potential.
NCS = Nerve conduction studies.
Pfreq = Peak frequency.
Pw = Spectral power.
RMS = Root Mean Square amplitude.
ROC = Receiver Operating Characteristic.
SNAP = Sensory Nerve Action Potential.
T/M = Turns/amplitude ratio.
T = Turns per second.

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## INTRODUCTION

The most common analysis of electromyography (EMG) is performed using a needle electrode and requires a slight effort of muscle contraction where individual motor unit action potentials (MUAP) can be identified and measured. This has been for many years the milestone for identifying abnormal patterns in needle EMG. As the level of force increases so does the number and firing rate of active motor units. This normal phenomenon makes the analysis of individual MUAP impossible as several activated MUAP overlap.[1-3] This configuration of MUAPs at increased force output is described as an interference pattern (IP). The common IP analysis uses qualitative methods almost since 1920 that EMG analysis began, described as: complete, incomplete or diminished interference pattern.[4] Quantitative analysis applied to an electromyographic signal of continuous maximum muscle activation are available in the majority of equipment used nowadays.

The IP analysis is influenced by the number of motor units recruited, their size, form, architecture, firing rate, firing duration, synchrony and recovery time.[4] While not commonly used, because it stills lacks strong evidence for clinical application.[5-7] Different properties of the IP can be analyzed using quantitative methods, mostly described as the time domain and frequency domain. Time domain assess features that can be observed on the screen, such as the number of turning points of the signal and the amplitude differences between turns. Originally described by Willison[8] and modified by Stalberg[9] the turns represent a change in signal direction of at least 50 or 100 μV. Turns indirectly reflect the number of active MUAP and can be affected by MUAPs morphology or firing rate, it reflects interaction between overlapping MUAP.[10,11] The data has also been expressed as a ratio called turn/amplitude ratio (T/M), which is derived from the number of turns for a given time interval divided by the averaged amplitude of turns for that same interval.[3,8,10] Different studies[4,12] have evaluated details about how much force and how many times the contraction should be applied to obtain consistent results, this may still vary between laboratories and the electromyographer experience.

The T-M relationship expressed in a cloud has one of the most important clinical applications in the detection of neuromuscular pathologies. Turns per second and mean amplitude of turns, are depicted into a graph, where T is the X axis and M is the y axis, within this graph boundaries of the area where normal values should appear are depicted, this boundaries are also called a «cloud».[12] 10 epochs of which each one will be graphed as a point in the graph, if more than two fall outside the cloud is considered abnormal, reference values have been developed in eight muscles.[3] IP quantitative analysis do not replace the evaluation of individual MUAP, but increase sensitivity and specificity.[13-15]

The frequency domain analysis is a less common method. It refers to the application of fast Fourier transformation to the interference pattern, obtaining the band power of different frequencies. This can be calculated and displayed across the entire frequency spectrum or at specific frequencies.[6] The IP can be mathematically described as a sum of sine waves of different frequencies and expressed according to the power density of the different frequencies. It is common to use frequency in the X axis, and a logarithmic scale of power in the Y axis.[16] Frequencies are expressed in Hz, the range of frequencies goes from zero to 2000 Hz. Power is expressed as -dB. Other useful frequency spectrum descriptors are mean frequency, median frequency and peak frequency. Power can be obtained for individual frequencies, including peak frequency, the total voltage is also expressed as root mean square amplitude or as total power.[17,18]

In this study we ought to analyze time domain and frequency domain variables using superficial EMG for describing the differences between a demyelinating focal neuropathy with normal subjects. Quantitative superficial EMG variables may provide objective values for the evaluation of complete force evaluation of EMG, obtained noninvasively.

## MATERIAL AND METHODS

### Participants

32 patients with electrophysiologic diagnosis of CTS were recruited for this study from April 2019 to March 2020. The bioethics committee approval was obtained. This research was conducted according to the principles expressed in the Code of Ethics of the World Medical Association (Declaration of Helsinki). All subjects gave their signed informed consent for participation.

### Demography

32 patients were included with an average age of 56 years (33-83 years), 25 were female patients (78%)

and seven were male patients (22%). Of the 32 patients, 14 of them presented carpal tunnel syndrome in only one hand (44%) and 18 were bilateral (56%). A total of 50 median nerves (29 right, 21 left) were analyzed. Patients with NCS abnormalities other than median nerve entrapment in CTS were excluded from our study. However, of the 32 patients, five patients had diabetes mellitus (15%), one patient had hypothyroidism (3%), two patients had rheumatoid arthritis (6%), we did not found an association between this comorbidities and NCS values of this patients didn't showed any other abnormalities other than CTS. 17 hands from 14 patients with no symptoms of CTS or electrophysiologic evidence of entrapment were included in the control group, a mean age of 45 years (33-52). An analysis paired by age was also performed, control group was compared with a CTS group of mean age of 50.4 years (range 33-60).

## Procedure

Conventional motor and sensitive NCS for median and ulnar nerves were obtained with a Viking Quest™ 10.2 equipment. Neurophysiological CTS diagnosis was established using international practice guidelines, with an initial SNAP peak latency retardation over 3.8 ms as cut-off value for CTS diagnosis, comparative ulnar-median nerve test was performed for confirmation of diagnosis.[19] CMAP latency at wrist, CMAP amplitude, and motor conduction velocity at palm-wrist segment were analyzed in motor conduction studies. SNAP peak latency and SNAP amplitude were analyzed on sensory nerve conduction studies. With this measurements CTS was classified as mild, moderate or severe: mild when only sensory latency was prolonged, moderate when motor and sensory latency were prolonged, and severe when there was absence of sensory potentials and/or motor latency was delayed and motor amplitude was below normal values.[20]

For the quantitative analysis surface electrodes of 10 mm were placed over *APB* and metacarpophalangeal joint with a 4 cm interelectrode distance, the electromyographic activity of *APB* was recorded during a maximal muscle contraction of 10 seconds. Time domain analysis was obtained from 8-10 epochs of 1 second each. Frequency domain analysis was performed on the first 1 second epoch. Time domain variables analyzed were: turns per second (T), mean amplitude of turns (M), and T/M ratio. A turn was defined as a change of 100 μV. In frequency domain analysis variables included were: mean frequency, median frequency, RMS amplitude, peak frequency, power of peak frequency and the band power of 500 and 1000 Hz.

## Statistical analysis

Two group difference to compare control and CTS group was applied. ANOVA analysis was performed to study differences paired by age between control group, CTS < 60 years and CTS > 60 years. Correlation test was used to evaluate the association between two continuous variables. The quantitative independent variables of latency, amplitude and conduction velocity were correlated with the QEMG measurements as dependent variables. It must be noted that SNAP response was not elicited in 4 patients. In these patients SNAP amplitude was zero and latency values were given the maximum value obtained for other patients only for correlation analysis.

## RESULTS

Differences between control group and CTS group *(Table 1)* were significant for the following time domain variables: mean amplitude of turns was lower in CTS($p < 0.001$), T/M ratio was higher in CTS ($p < 0.001$). Significant differences were found on the following frequency domain variables: RMS was lower ($p < 0.001$) in CTS group than controls. Median frequency was also lower ($p < 0.03$) in CTS group. Other significant differences in frequency domain variables were in the power of peak frequency which was lower in CTS ($p < 0.05$), also the power of 500 and 1000 Hz ($p < 0.05$) was higher for CTS subjects.

In the three group comparisons categorized by age, differences remained significant on time domain in mean amplitude of turns and TM ratio. Mean amplitude of turns in the control group had a mean of 1385.9 μV (SD 368.9), CTS < 60 had a mean of 716.5, μV (SD 350.4) and CTS > 60 group mean of 465.3 μV (SD 243.4) ($p < 0.001$). T/M ratio in the control group had a mean of 0.2 (SD 0.1), TM CTS < 60 mean of 0.5, (SD 0.2), TM CTS > 60 mean of 0.7 (SD 0.3), ($p < 0.01$). On frequency domain analysis, significant differences were also relevant, RMS in the control had a mean 799.1 μV (SD 199.7), CTS < 60 group had a mean RMS of 358.8 (SD 182.1), RMS in the CTS > 60 group had a mean of 210.9 μV (SD 149.8), ($p < 0.001$). Analysis between groups according to severity classification showed a significant difference between groups for mean amplitude of turns and T/M *(Figure 1)*.

**Table 1: Quantitative variables differences between carpal tunnel syndrome (CTS) group and control group.**

| | Control group | | CTS group | | |
|---|---|---|---|---|---|
| | Mean ± SD | 95% CI | Mean ± SD | 95% CI | p |
| Turns per second | 285.4 ± 21.4 | 274.4-296.4 | 281.0 ± 60.6 | 263.8-298.3 | 0.7 |
| Mean amplitude of turns (µV) | 799.1 ± 199.7 | 696.4-901.7 | 314.4 ± 184.7 | 261.9-366.9 | < 0.001* |
| T/M ratio | 0.2 ± 0.1 | 0.19-0.25 | 0.6 ± 0.3 | 0.48-0.64 | < 0.001* |
| RMS (µV) | 1,385.9 ± 368.9 | 1,196.2-1,575.0 | 641.1 ± 340.1 | 544.5-737.7 | < 0.001* |
| Frequency (Hz) | | | | | |
| Mean | 118.5 ± 10.4 | 113.1-123.8 | 127.2 ± 30.5 | 118.5-135.8 | 0.2 |
| Median | 113.5 ± 13.7 | 106.5-120.6 | 132.8 ± 36.0 | 122.6-143.0 | 0.03* |
| Peak | 104.1 ± 14.2 | 96.8-111.4 | 116.0 ± 35.1 | 106-126 | 0.1 |
| Power (−dB) | | | | | |
| Peak frequency | 10.3 ± 0.5 | 10.1-10.6 | 11.2 ± 1.1 | 10.8-11.5 | 0.003* |
| 500 Hz | 36.1 ± 2.2 | 35.0-37.2 | 32.2 ± 3.9 | 31.1-33.3 | 0.002* |
| 1,000 Hz | 48.6 ± 2.0 | 47.6-49.6 | 46.2 ± 2.6 | 45.5-46.9 | 0.001* |

95% CI = 95% confidence interval. RMS = root mean square amplitude. SD = standard deviation. T/M = turn/amplitude ratio.
* Statistical significance.

Correlation analysis: significant strong correlations ($p < 0.05$) were found between time domain variables and NCS: T/M ratio with CMAP amplitude r = -0.7 and mean amplitude of turns with CMAP amplitude r = 0.7. With frequency domain variables most RMS correlated with Motor CV in palm-wrist segment r = -0.8, but also with CMAP amplitude r = 0.7.

ROC analysis: RMS reached an area under the curve of 0.96 (95% CI 0.93-1.0) with specificity of 92% and sensibility of 100% with a cut value of 580 µV. ROC analysis for mean amplitude of turns reached an area under the curve of 0.93 (95% CI 0.88-0.99),with specificity of 94% and sensibility of 89% with a cut value of 1032 µV. Spectral power of 500 Hz had an AUC of 0.77 (95% CI 0.65-0.89) with specificity of 88% and sensibility of 70% with a cut-off value of 35.5 -dB. Turns per second reached an AUC of AUC of 0.54 (95% CI 0.37-0.64) with specificity of 40% and sensibility of 70% with a cut-off value of 278 turns/s *(Figure 2)*.

## DISCUSSION

Despite clinical use of electromyography exists since the 1920 the evaluation of a full effort is still carried out in many cases with a subjective or qualitative description as a full or incomplete interference pattern using needle EMG.[4] The analysis of recruitment also depends on the experience of the person doing the study[3] and require cooperation of a minimal or submaximal effort from the patient.[21] This methods, either visual or automatic does not evaluate the full amount of motor units available for activation in a muscle.

Quantitative electromyography offers objective numerical values of the full effort phase of EMG, however, there is no consensus or enough clinical evidence for its clinical application, despite these being available in most electromyography equipment. Our study shows that time and frequency domain analysis of the IP obtained with a superficial electrode have significant differences with healthy subjects and has correlation with common NCS.

Mean amplitude of turns, T/M ratio and RMS were the more relevant quantitative variables that showed significant correlations with CMAP amplitude, these variables depend on the voltage of the muscle activity and may be explained because of a lower amount of motor units available as the axonal loss increases in the pathology. We also found that demyelinating variables such as CV was associated with RMS, the more severe the focal retardation the total voltage of the IP is affected. Myelin loss and secondary axonal loss, can be studied in a sustained contraction of muscle activity with quantitative tools, however It is difficult to isolate primary demyelination from the secondary axonal loss.

Regarding the frequency domain, the spectral analysis of muscle activity has been mostly used in studies of fatigue.[22] However we describe the

relationship of these variables with an entrapment neuropathic syndrome. RMS has been mentioned, but we also found differences in the power of peak frequency where controls showed a higher power, and in the power of high frequencies of the spectrum, with normal subjects showing lower values in 500 Hz and 1,000 Hz, in this manner, a neuropathic disorder show a lower value of peak frequency power with a higher power of higher frequencies between 500 and 1,000 Hz, this may be explained by a desynchronization of the axonal activity. Desynchronization is expected after an insult to the nerve and it has been studied with near nerve needle recording.[23,24] So we propose that in the spectral analysis of motor muscular activity, desynchronization of the axonal and muscular activity diminish the power of peak frequency and increase spectral power of high frequencies. Total voltage of muscle electrical activity expressed as the root mean square amplitude is diminished in neuropathic disorders.

Changes in mean frequency had been reported with needle electrodes[18] and surface electrodes.[25] The surface electrodes studies showed an increase of mean frequency with upward changes in force output, decreased time tolerability to continuous effort expressed as fatigue it's been shown to slower mean frequency.[22,26,27] In our study the neuropathic pattern was associated with higher median frequencies. We found that median frequency was higher in the

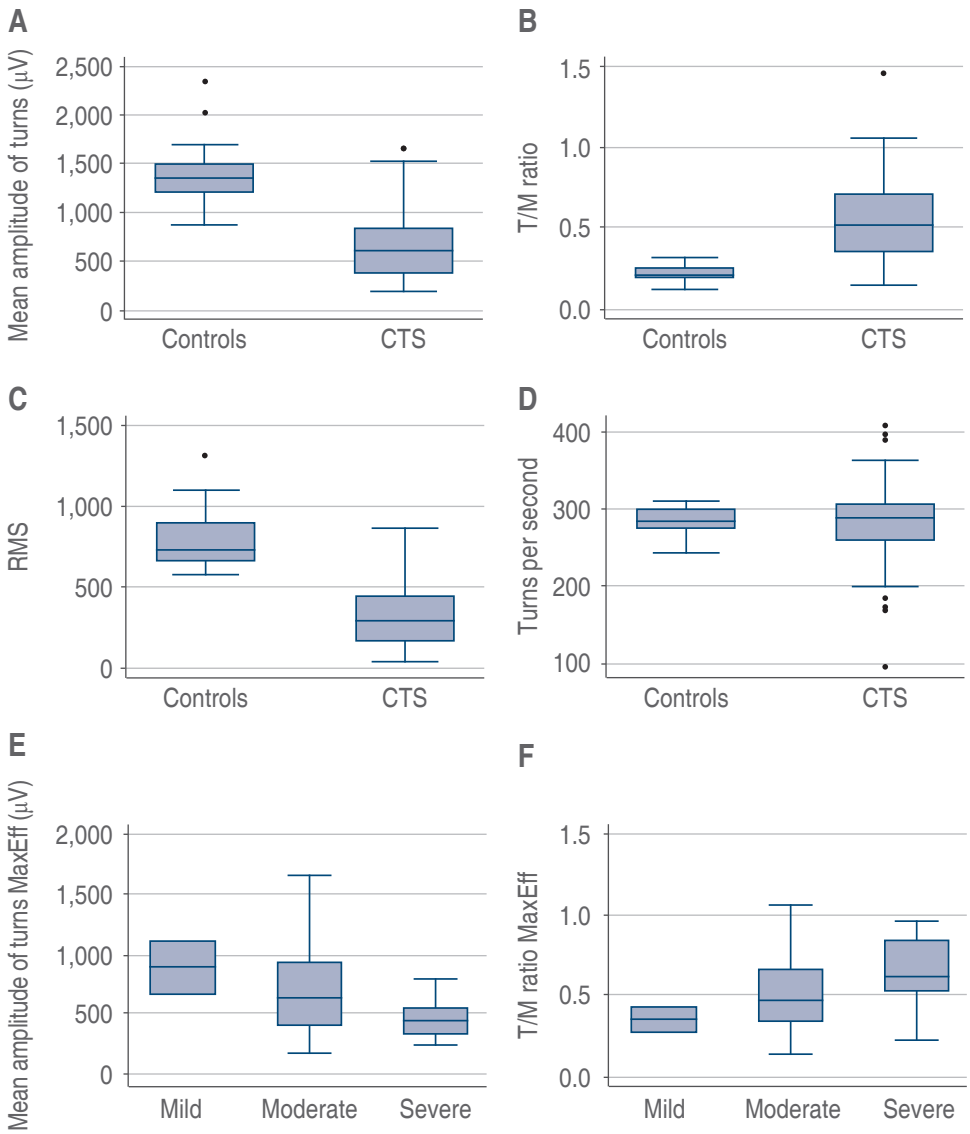


**Figure 1:**

**A-D)** Two group differences of relevant time domain and frequency domain variables. **E-F)** carpal tunnel syndrome severity groups differences on mean amplitude of turns and T/M. CTS = carpal tunnel syndrome. RMS = root mean square amplitude. T/M = turn/amplitude ratio. $p < 0.05$.

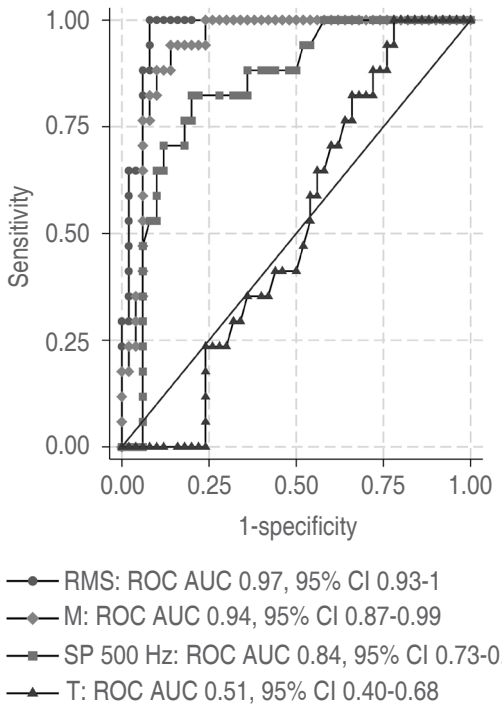


**Figure 2:** ROC AUC analysis of root mean square amplitude (RMS).
AUC = Area Under the Curve. M = mean amplitude of turns. RMS = Root Mean Square amplitude. ROC = Receiver Operating Characteristic. SP = Spectral Power of peak frequency. T = turns per second.

neuropathic pattern, but no differences or correlations were found with mean frequency in our study.

This study was performed with a surface electrode which has been described as a reliable method for studying muscle activity. The main advantages are that the number of fibers evaluated is greater, because of the bigger collection radius and it is less painful and more accessible. Its main disadvantages is less specificity and is more susceptible to noise and other artifacts if the setup is not managed correctly. Different bibliography[28,29] considers the use of surface electrodes may reflect the general state of the muscle instead of needle electrode, nonetheless the finding of pathologic changes may be more difficult to analyze. The use of surface electrodes continues to develop and may favor the diagnostic capability of this techniques.[30]

## CONCLUSION

This study describes the possible use of quantitative measures of surface EMG during maximal voluntary muscle contraction in the description and possible diagnosis of a demyelinating neuropathy with secondary axonal loss. RMS and mean amplitude had a high diagnostic accuracy in this pathology. At this moment surface QEMG is only proposed as a complementary approach to the diagnosis of nerve pathologies, as for carpal tunnel syndrome it is necessary to demonstrate focal sensory delay in nerve conduction studies for diagnosis.[19] However the results of this study are encouraging to continue studying surface QEMG in neuromuscular pathologies due to the high diagnostic accuracy observed in some variables and the advantages described earlier such as being more comfortable for the patient than needle EMG, offers objective numerical values, and is easy to perform.

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