

Power spectrum analysis of compound muscle action potential in carpal tunnel syndrome patients

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ABSTRACT

The objective of using wave-form analysis to assess compound muscle action potential (CMAP) in entrapment neuropathy had not been fully developed. We applied the power spectrum analysis to patients with carpal tunnel syndrome (CTS) for this purpose. 24 patients with CTS were divided into three stages according to Mackinnon's classification, and 50 normal volunteers were examined. CMAP was obtained from the abductor pollicis brevis with supramaximal stimulation to median nerve. Mean and peak frequencies were measured by power spectrum analysis.

The distal latencies of CMAP and the sensory nerve conduction velocities showed some prolongation in CTS patients. Integral values of CMAP were also decreased in CTS patients. Mean and peak frequencies of power spectrum of CMAP in volunteers were 134Hz and 98 Hz, respectively. These values shifted into lower frequencies in CTS patients, namely 102Hz and 61Hz.

Regardless of clinical stage, distal latency of CTS patients correlated with mean frequency.

Key words: power spectrum analysis, compound muscle action potential, carpal tunnel syndrome

INTRODUCTION

When motor nerves are electrically stimulated, the muscles controlled them almost synchronously exhibit compound muscle action potentials (CMAP).^{1, 27} However, the conduction velocity of individual fibers^{12, 21} in the nerve trunk differs, and this temporal dispersion comprises CMAP. Generally, applying Fourier transformation in compound waves, such as waves in electromyograms (EMG), any waveform can be decomposed into sine curves with different frequencies,^{2, 13} and waveforms on EMG can almost be regarded as an aggregate of sine curves. Thus,

analysis of the waveform frequency is used mainly for surface EMG during voluntary contraction, to quantitatively analyze muscles^{17, 23, 29} or muscle fatigue.^{15, 24}

In a recent study, we assumed CMAP to be an average non-synchronously induced single fiber potential.^{3, 9, 26} We also analyzed the frequency for changes in the waveform^{16, 25} of CMAP during peripheral nerve stimulation in patients with carpal tunnel syndrome (CTS)^{19, 22} which is a typical disease of entrapment neuropathy, and compared them with the waveforms of CMAP in healthy volunteers. And we considered the possibility of clinical diagnosis of power spectrum analysis.

MATERIALS AND METHODS

The subjects were 50 healthy volunteers and 24 patients with CTS. The patients comprised 12 patients with mild symptoms, 5 patients with moderate symptoms and 7 patients with severe symptoms. The severity of disorder was divided broadly into the following three categories according to the Mackinnon's classification¹⁴: mild cases were defined as those with intermittent symptoms with a positive Phalen's sign or Tinel's sign; moderate cases as those with decreased muscle strength and a positive Phalen's sign or Tinel's sign without muscular atrophy in the thenar muscles; severe cases as those with muscular atrophy and abnormal findings of sensory symptoms, static 2PD and moving 2PD. We also examined 5 patients who underwent surgical decompression of the carpal tunnel.

The potential was recorded as follows: a surface electrode was placed on the belly of the adductor pollicis brevis at 7 cm proximal to the recording electrode; supramaximum electric stimulation (rectangular waves, duration: 0.2 msec) was applied to the trunk of the median nerve at the wrist, using an amplifier of 50 to 3 kHz to induce CMAP; the obtained potentials were recorded using an electromyogram (model MEM4104, Nihon Kohden Corporation, Tokyo, Japan). We also analyzed the distal latency of CMAP, the integral values, and the frequencies obtained by utilizing the software BIMITUS (Kissei comtec Co., Ltd., Japan), for comparison with those of healthy subjects.

In the analysis of CMAP, the integral value was the sum of the negative and positive portions of a CMAP, with the baseline as the standard. Frequency was analyzed for the whole frequency band up to 2,500 Hz at a sampling frequency of 5 kHz and a frequency resolution of 5 Hz. In order to obtain continuous

waveforms, the Hanning window function was used. A power spectrum was obtained using fast Fourier transformation. The distal latency, sensory nerve conduction velocities (SCV), integral value, frequency of CMAP were compared, and the relationship between distal latency and frequency were evaluated. Statistical significance was accepted at $p < 0.05$. In the statistical analysis, comparison of each group was tested using a one-way analysis of variance (ANOVA) and the Scheffe F-test where significant differences were found. Data are expressed as mean \pm SD. Comparison between groups was made using Student's unpaired t-test. Linear regression lines were obtained to determine correlation coefficients.

RESULTS

The distal latency of CMAP for the median nerves and the SCV were both significantly prolonged in patients (5.1 ± 1.2 (mean \pm S.D.) msec and 38.2 ± 18.5 m/sec, respectively in patients with mild CTS; 6.3 ± 1.6 msec and 41.3 ± 10.5 m/sec in patients with moderate CTS; 6.0 ± 1.4 msec and $38. \pm 8.0$ m/sec in patients with severe CTS) than in healthy subjects (3.5 ± 0.5 msec and 53.8 ± 6.4 m/sec). The differences between the groups were not significant. Significant differences were found in the integral values between healthy subjects (46.5 ± 30.4 msec-mV) and patients (34.5 ± 16.8 msec-mV in patients with mild CTS; 26.7 ± 12.5 msec-mV in patients with moderate CTS; 30.6 ± 19.2 msec-mV in patients with severe CTS).

Next, we compared the peak frequency and the mean frequency in a power spectrum obtained through Fourier transformation (Fig. 1). There were definite

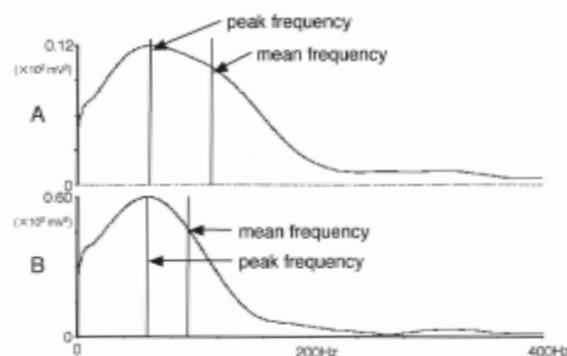


Figure 1 Typical diagram of power spectrum analysis. We compared the peak frequency and the mean frequency in a power spectrum obtained through Fourier transformation. There were definite differences in the power spectrum of CMAP between healthy subjects (A) and CTS patients (B). Peak and mean frequencies shifted to lower values in CTS patients.

differences in the power spectrum of CMAP between healthy subjects and CTS patients: the frequency was lower in CTS patients. The peak frequency was significantly lower in patients (57.4 ± 9.4 Hz) in patients with mild CTS; 58.0 ± 9.7 Hz in patients with moderate CTS; 67.2 ± 17.7 Hz in patients with severe CTS) than in healthy subjects (98.3 ± 31.6 Hz). The differences between the groups were not significant. The differences in the mean frequency were similar: there were significant differences between healthy subjects (133.5 ± 27.2 Hz) and patients (104.6 ± 12.1 Hz in mild CTS patients; 104.1 ± 12.2 Hz in moderate CTS patients; 96.7 ± 12.7 Hz in severe CTS patients).

A negative correlation was found between the distal latency of CMAP and the mean frequency, with a coefficient of $r = 0.31$ at $p < 0.05$ in CTS patients (Fig. 2). This correlation, however, was not found in healthy subjects.

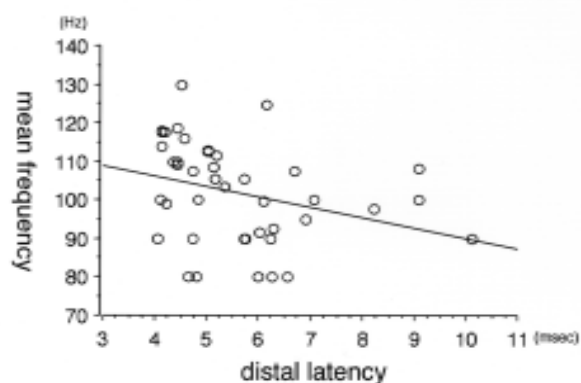


Figure 2 Correlation coefficient between distal latencies and mean frequency. A negative correlation was found between the distal latency of CMAP and the mean frequency, with a coefficient of $r = 0.31$ ($y = -2.72x + 117.22$) at $p < 0.05$ in CTS patients.

Prolongation of the distal latency, which contributes to diagnosis of CTS, was divided into 3 groups: 5 msec or less, 5 to 6 msec, and 6 msec or more, to prepare a box plot of the SCV and the mean frequency. The chart clearly indicated that both SCV and the mean frequency decreased with prolongation of the distal latency. In particular, the mean frequency significantly differed between CTS patients and healthy subjects, even in patients with a prolongation of 5 msec or less (Fig. 3). Both the mean frequency and the peak frequency improved soon after an operation for CTS, with the mean frequency being 128.8 ± 18.6 Hz, and the peak frequency 95.2 ± 19.6 Hz. The differences, however, were not significant, probably due to the small number of cases.

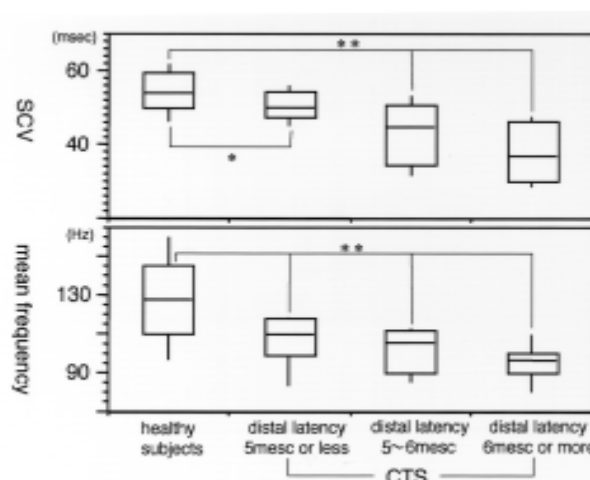


Figure 3 Scattered diagram of SCV and mean frequencies in CTS patients divided into three groups according to distal latencies. Prolongation of the distal latency, which contributes to diagnosis of CTS, was divided into 3 groups: 5 msec or less, 5 to 6 msec, and 6 msec or more. The chart clearly indicated that both SCV and the mean frequency decreased with prolongation of the distal latency. In particular, the mean frequency significantly differed between CTS patients and healthy subjects, even in patients with a prolongation of 5 msec or less. ** $p < 0.01$, * $p < 0.1$.

DISCUSSION

Peripheral SCV and distal latency of CMAP have been known to be useful as parameters^{8, 18, 20} for EMG in CTS patients. CMAP of CTS patients are likely to exhibit prolonged distal latency and changes in the waveform. In the past, researchers⁴ examined changes in integral values, paying attention to changes in the waveform. Changes in the waveform, however, may be a poor parameter for diagnosis, because of the great standard deviation in individual patients, despite the significant differences between healthy subjects and CTS patients, as were observed in our study.

Generally, compound waves, such as waves on EMG, can be decomposed into an aggregate of sine curves with different frequencies through a Fourier transformation of potential.^{16, 25} Further, contribution to formation of a waveform at individual frequencies can be obtained through calculation of a power spectrum. CMAP may be regarded as a compound wave, an average of non-synchronously induced CMAP. Through power spectrum analysis, both the mean frequency and the peak frequency significantly decreased, accurately reflecting changes in the waveform. Changes in the waveform are generally known to comprise temporal dispersion¹² due to

conduction disturbance in the entrapped site. For example, as in Case 1, which exhibits clinical symptoms of CTS, prolongation of distal latency of as short as 4.1 msec and a normal SCV of 56.3 m/sec, the form of CMAP has changed. Frequency analysis of such cases as Case 1 revealed a definite decrease in the mean frequency (90.0 Hz) and the peak frequency (50.0 Hz), and it is possible to evaluate and reflect temporal dispersion (Fig. 4). The effect of physiological temporal dispersion may not have to be considered, because of the short distance between the stimulation point and the recording site in CTS patients. Changes in the waveform accurately reflect temporal dispersion due to delayed conduction at the entrapped site.

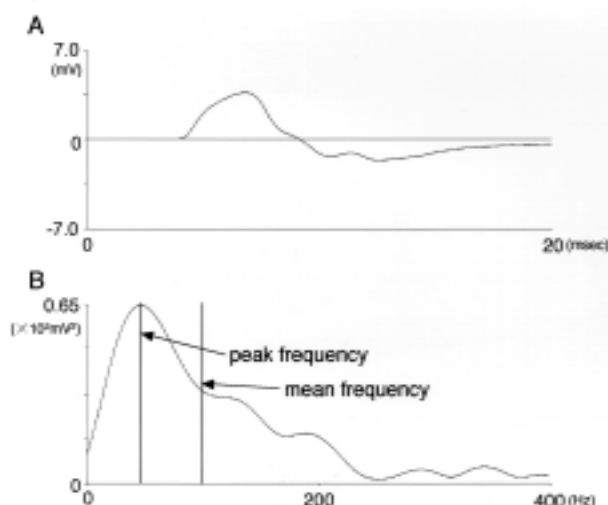


Figure 4 Case 1: 53 years, male. The clinical symptoms of CTS were obvious in this case. Although CMAP (A) indicated temporal dispersion, the values of SCV and distal latency of CMAP were within normal criteria. Mean and peak frequencies of power spectrum analysis (B) shifted to lower values.

As for the postoperative changes, although the symptoms of the patients who underwent an operation improved, the follow-up period was short, and the distal latency was prolonged for 4.9 msec on average. By this time the waveform has changed. Frequency analysis revealed a greater mean frequency and a greater peak frequency than those before operation, reflecting the changes in the waveform at an early period.

In cases where the site distal to the entrapped site developed Wallerian degeneration due to prolonged entrapment, or where muscular atrophy developed, a CMAP with a form different from that of a normal

CMAP is obtained, even when the stimulation point is moved proximally or distally. The order of discharge of motor neurons observes the size principle proposed by Henneman⁵: it is known that, in a weak contraction in the early stage of voluntary movement, the type I muscle fibers are discharged, and then the type II muscle fibers are involved in a strong contraction.^{6, 28} Generally, it is considered that the type II muscle fibers are fast muscle fibers that are easily fatigued, have a sharp action potential, and act at a high output, and correspond to the high frequency component, whereas the type I muscle fibers are slow muscle fibers that are not easily fatigued, have a gentle action potential, and are involved in the low frequency component.^{10, 11} It is also known that the type II muscle fibers easily decrease with muscle fatigue and muscular atrophy.⁷ In cases where muscular atrophy is involved, decrease of the type II muscle fibers may have lowered the frequency. The fact that the type II muscle fibers are controlled by thick axons, which are subjected to pressure at the entrapped site, must also be considered.

Thus, analysis of frequency of CMAP may accurately represent changes in the waveform in CTS patients with less physiological temporal dispersion, and reflect temporal dispersion or changes in the component of muscle fibers. And we thought that an early diagnosis was possible also in the subclinical case by using power spectrum analysis.

CONCLUSIONS

1. We recorded CMAP in 50 healthy subjects, 25 CTS patients (42 limbs), and 5 CTS patients who underwent surgical decompression of the carpal tunnel, to analyze frequency.
2. The frequency of CMAP was significantly lower in CTS patients than in healthy subjects, but no correlation was found between the frequency and the severity of the disease. The patients recovered from these changes soon after the operation.
3. There was a significant correlation between the distal latency and the mean frequency of CMAP in CTS patients, but not in healthy subjects.
4. Analysis of frequency of a CMAP may accurately represent changes in the waveform in CTS patients with less physiological temporal dispersion, and reflect temporal dispersion or changes in the component of muscle fibers.
5. We thought that an early diagnosis was possible in the subclinical case by using power spectrum analysis.

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