THE EFFECT OF PULSE CONFIGURATION ON THE COMPOUND MUSCLE ACTION POTENTIALS (CMAPs) DURING MAGNETIC STIMULATION

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Abstract

Magnetic stimulation has proven to be effective in diagnostics and treatment in many clinical applications. In these applications, two types of pulse configurations are utilized: bi-phasic and mono-phasic. The former is mostly applied to nerves with high thresholds of depolarization or lying deep within tissue structures, while the latter is used to excite peripheral nerves.

In this paper, the results of applying bi-phasic and mono-phasic pulses and their influences on the compound muscle action potentials (CMAPs) are discussed. The experimental variables are: coil current rate of change (di/dt), coil type (Figure 8 and circular coils), and coil current direction.

Introduction

To our knowledge, the first group to investigate the effects of pulse configuration during magnetic stimulation was McRobbie et al. [1]. They suggested that a "damped sinusoid" pulse(bi-phasic) is more effective than a pulse with a "slow decay" (mono-phasic) and that the threshold of stimuli increased with the increase of pulse decay. Maccabee et al. [2] used a special magnetic stimulator (Cadwell laboratories) which generated mono-phasic and poly-phasic pulses with identical initial phases and different rates of decay. Their results showed that both *in vivo* (median nerve) and *in vitro* (mammalian phrenic nerve) polyphasic pulses can elicit higher responses than those produced by mono-phasic pulses. Recently, Niehaus et al. [3], and Kammer et al. [4] investigated motor threshold amplitudes of CMAPs for different stimulus intensities. Other than the effect when changing the direction of the coil current, most of their findings agreed with the previous studies.

Considering previous work, our group decided to conduct an experiment with the objectives of defining the stimulation site during magnetic stimulation and establishing a quantitative relation between pulse configuration and the resulting neurological response. As the median nerve is well defined, easy to access and its response simple to evaluate, it was chosen as the targeted area for this experiment.

Experiment hardware and software

After a few trials it was concluded that defining the coil optimum position and maintaining it throughout the experiment were critical factors for collecting consistent and reliable data. Electrical stimulation was performed to determine the most effective position for the coil (see the method section). An electrical stimulator (Dantec-Cantata Inc.) was used to deliver single pulses of 200 Fsec. The stimulating pulses were delivered via 8 mm diameter silver electrodes mounted 2.5 cm apart on a plastic bar. To collect the EMG data, pre-gelled disposable surface electrodes were used (Medtronic Inc.). The first electrode was positioned over the thenar eminence to cross the first metacarpal bone perpendicularly at the junction of its proximal and middle thirds. The second electrode was attached over the proximal phalanx of the thumb. The third electrode was attached to the dorsum of the hand. The measured responses were amplified to a gain of 2mv/div and bandpass filtered between 20 Hz and 2 kHz.

A magnetic stimulator (Dantec MagPro) with a Figure 8 coil (outer diameter 10 cm consisting of 2x10 windings) and a circular coil (outer diameter 13 cm consisting of 10 windings) were used for this study. An advantage in using the Dantec system is the flexibility in changing the current direction by a switch located at the front panel, without rotating the coil.

The amplified CMAP responses were collected and sampled at 10 kHz via a data acquisition board guaranteed for 200kS/sec (PCI-6024E a 12-bit acquisition board - National Instruments). To calculate CMAP latency the data were sampled at 100 kHz. The signals were captured by a stand alone algorithm created using Labview software (National Instruments) and Matlab software (Math Works Inc.) The algorithm allows the user to acquire a train of signals, calculate the area and the peak to peak of each pulse, and store the data in ASCII and spreadsheet formats. The algorithm also allows the user to retrieve or re-read the data from the stored files, average and post-process the data.

Method

The study was approved by the ethics committee at St. Joseph's Hospital (Hamilton, Ontario). Ten healthy subjects (8 males and 2 females ages ranging between 19 and 46 years) gave informed consent. Considering that each session lasted one hour to two hours, it was crucial that the subject be relaxed throughout the experiment to ensure successful and reliable recorded data. The subjects were comfortably seated with their arms fully extended and supported by foam and sand bags.

Electrical stimulation was performed above the median nerve at two sites: the cubital fossa and the wrist. To achieve maximum stimulation, the exact placement of the stimulating electrodes was defined by searching the placement that gave the lowest stimulus threshold for the thenar motor units as previously described [5]. Five pulses were applied at each site and their recruited M-waves were measured and averaged. The cathode position at each site was marked and the distance between the two positions was measured. By measuring this distance and calculating the difference of the M-wave latencies, the nerve conduction velocity was obtained. This value was used during magnetic stimulation to define the stimulation site (the position of the virtual cathode) and to calculate any shift in its placement. A self adhesive tape was used to mark the exact placement of the cathode (cross mark). The coil position was maintained manually as precisely as possible throughout the entire experiment and consequently consistent reliable measurements were collected. With the help of a laser pen, it was found that maximum stimulation was achieved when the projection of the center for the Figure 8 coil matches that of the cathode for the stimulating bar.

During magnetic stimulation, the influence of pulse configurations and coil current directions were investigated for different stimulus intensities. The intensities were varied from 30% to 80% of the maximum stimulator output with a 10% step increase. At each step, ten consecutive stimuli were applied and their responses collected and averaged. To ensure that the same energy was supplied for all stimuli within one step the di/dt value, displayed at the front panel, was monitored throughout the experiment. The above procedure was followed for all subjects using Figure 8 and circular coils at the elbow and the wrist.

Results

A) <u>Defining stimulation site</u>: Figure (1) shows the averaged M-waves when electrical stimulation was applied to the median nerve at the elbow and wrist. Table (1) illustrates the averaged CMAP peak latencies resulting from electrical and magnetic stimulations. Considering that the conductive velocity of myelinated nerve fiber is about 50 m/sec, a latency of 1 msec in the data presented in table (1) translates to a 5 cm shift in cathode position.

Table 1

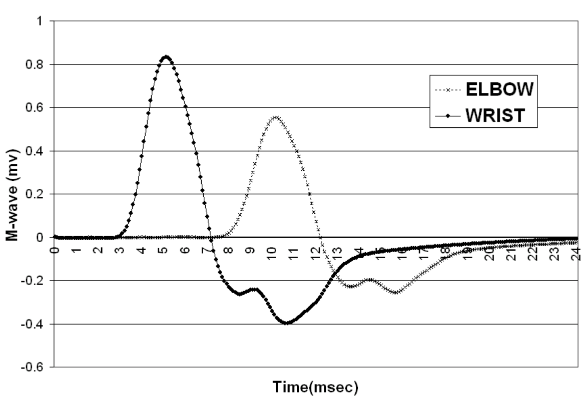

Fig. 1: M-wave responses using electrical stimulation.

Summary of the CMAP peak latencies

Stimulus Type	El (msec±s.d.)	Wr(msec±s.d.)
Electrical	10.09±0.71	5.63±0.42
Figure 8 - Bi	10.11±0.78	6.64±0.87
Figure 8 - Mono	10.26±0.83	6.55±0.76
Circular - Bi	10.41±1.02	6.93±0.54
Circular - Mono	10.50±0.83	6.79±0.82

The results in table (1) show that the average shift in position between the virtual and electrical cathodes is smaller at the elbow than that at the wrist.

B) <u>The effect of pulse configuration</u>: Figure (2) shows CMAP responses of a bi-phasic waveform with the Figure 8 coil placed at the elbow. These responses were collected as the stimulating intensities were increased in steps of 10% from 30% to 80% of the maximum output. Comparable responses with proportional amplitudes and different latencies were obtained at the wrist.

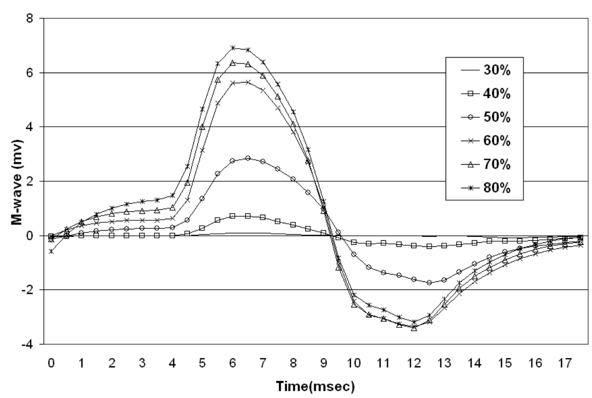

Fig. 2:M-wave responses for different intensities using Figure 8 coil at the elbow. The starting point of the time axis was selected to accommodate the figure size.

The M-waves in figure (2) clearly indicate that the rate of change in the CMAP decreases at higher stimulating intensities (an indication that the number of motor units recruited approaches its maximum at these intensities).

Table (2) summarizes the CMAP responses of different waveforms using Figure 8 and circular coils at the elbow.

Table 2
Summary of the results using different coils at the elbow

Stimulus intensity	Figure 8 coil (P-P±s.d.(mv))		Circular coil (P-P±s.d.(mv))	
(A/Fs)	Bi	Mono	Bi	Mono
46.3	0.4±0.4	0.2±0.2	0.4±0.3	0.1±0.2
62.5	1.4±1.7	0.4±0.3	0.8±0.7	0.3±0.4
77.7	2.3±1.3	1.4±0.5	1.2±0.8	0.4±0.5
90.8	4.3±1.8	2.4±1.8	2.3±1.3	0.5±0.7
106.6	7.5±3.0	3.6±1.9	3.2±2.8	0.6±0.8
121.5	8.5±5.4	5.4±2.6	4.9±3.1	0.8±1.1

C) The effect of changing current direction:

Figure (3) shows the M-waves of one subject while Table (3) summarizes the average responses of all subjects. These results were collected and averaged using 50% of the stimulator output.

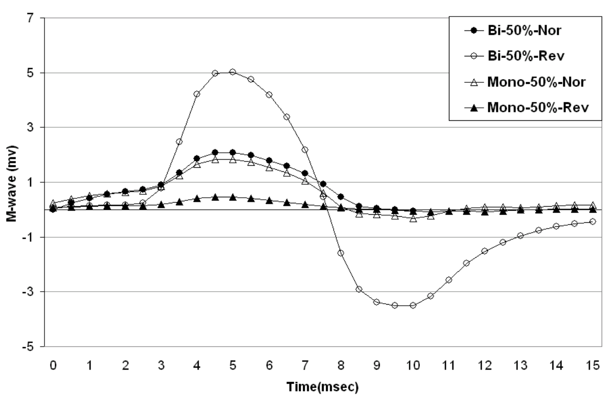

Fig. 3: M-wave responses for various waveforms and current directions using a Figure-8 coil at the elbow.

Table 3
Summary of the results when changing current direction

Site-Coil type	Bi-phasic		Mono-phasic	
	Normal	Reverse	Normal	Revers
wr-Fig.8	2.0±1.2	1.5±1.2	1.5±0.9	1.2±1.0
wr.-Circ.	1.0±1.1	1.2±1.7	0.4±0.3	0.4±0.4
el.-Fig.8	2.3±1.3	4.5±2.9	1.4±0.5	0.4±0.5
el.-Circ.	1.2±0.8	0.9±0.8	0.4±0.5	0.3±0.4

From figure (3) and table (3), it is evident that changing the current direction resulted in different responses for both waveforms.

It is important to clarify two critical points related to the results presented in this section. First, the data for the "normal" current direction were collected while the coil was placed along the arm with its handle pointing toward the subject hand. Second, the "normal" direction represents the default output of the Dantec MagPro stimultor, while "reverse" direction should be set by the user.

Discussion

This paper has outlined the results of an experiment to investigate the influence of pulse configurations during magnetic stimulation on the compound muscle action potential (CMAP). The key findings of the study are:

1) The average shift in position between the virtual and electrical cathodes was substantial especially at the wrist and/or when using circular coil. However, a smaller average shift was noticed at the elbow. These findings disagree with Nilsson et al. [5] Maccabee et al. [6] results. The differences could be attributed to the shape of the pulse applied and/or to the model of the coil used.
2) Using the same stimulating intensity, bi-phasic stimuli result in higher elicited CMAPs than that achieved with mono-phasic. This holds true for different stimulus intensities, when changing the current direction, and using different coils. The reason for the different responses can be explained by either nerve hyperpolarization-depolarization phenomena [7] or by the difference in current rate of change within the second and third phases of the two waveforms (work in progress).
3) For both pulse configurations, regardless of coil type or current direction, the increase of stimulus intensity or di/dt results in non-linear increases in the CMAP response.
4) Changing the direction of coil current results in different responses for both pulse configurations. This can be attributed to the change in the population of the excited neurons.
5) The use of different pulse configurations and the change in current directions (especially at the elbow) have little effect on the CMAP latencies. One solution to precisely quantify these latencies is to repeat this experiment using electrical stimulation.
6) Maintaining the stimulus coil in the same position (which is defined by electrical stimulation) for each subject is extremely critical. This includes projecting the coil focal point on the targeted area, coil orientation, and coil tilting.

Acknowledgment

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