Block of Nerve Conduction Using High Frequency Alternating Current

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Abstract

High frequency alternating current waveforms have been shown to produce a rapidly reversible nerve block in animal models, but the parameters and mechanism of this block are not well understood. A frog sciatic nerve/gastrocnemius muscle preparation was used to examine the parameters for nerve conduction block in vivo. The results indicate that a 100% nerve block of motor activity can be accomplished with a variety of waveform parameters, including sinusoidal and rectangular waveforms at frequencies from 2 KHz to 20 KHz. The block is complete and quickly reversible. The most efficient waveform for conduction block in the frog was a 3-5 KHz biphasic sinusoid. It was demonstrated that the block is not produced indirectly through fatigue. This block may have multiple applications in the treatment of spasticity and pain.

1 Introduction

Unwanted or uncoordinated generation of nerve impulses is a major disabling factor in many medical conditions. For example, unwanted sensory signals can result in peripherally generated pain after cancer treatments or amputation. Uncoordinated motor signals that produce spasticity in stroke, cerebral palsy and multiple sclerosis can result in the inability to make functional movements. There are a variety of other conditions, such as tics, choreas and muscle spasms where involuntary and unwanted movements are produced. If these impulses can be intercepted along the peripheral nerves over which they travel, then the disabling condition can be reduced or eliminated. Existing methods for treating these conditions, such as pharmacological, chemical treatments or surgical intervention all have significant disadvantages and are not consistently successful. Therefore, there remains a widespread clinical need for an effective, reliable and reversible nerve block that does not damage neural tissue.

The use of high frequency alternating current waveforms is one potential method for producing a quick-acting and quick-reversing nerve conduction block. Various investigators have shown these waveforms can produce a nerve block in frog, rat, cat and dog models [1-2,4-7]. However, the mechanism for this type of block was not known, and the reported results appear to be contradictory in some cases. In particular, it is not clear whether high frequency nerve conduction block is due to a fatigue mechanism or to a true conduction block in the nerve membrane. In order to ascertain the true effect of high frequency stimulation on nerve conduction, it was necessary to perform a series of experiments to clarify the reported results, with the goal of determining the true potential of high frequency waveforms to be used as a method for blocking nerve conduction in vivo.

2 Methods

Acute studies have been performed in sciatic nerve/gastrocnemius muscle preparations in adult bullfrogs [3]. The muscle was clamped in a special fixture and the tendon connected to an in-line force transducer to measure tendon tension. Three electrodes were placed on the sciatic-tibial nerve, as shown in Figure 1. Two electrodes are used for stimulation, and the middle electrode is used to deliver the high frequency blocking waveform. In each trial, the stimulation to the proximal electrode was initiated at 0.2Hz and continued through the duration of the trial. After ten to twenty seconds, the conduction block was initiated and typically maintained for 30 to 60 seconds. The block was then stopped and the recovery response of the nerve to the continuing proximal stimulation was recorded for at least ten seconds after the cessation of block. In those experiments where a distal electrode was used, the stimulation to the distal electrode was...
delivered midway through the block. Three distal pulses were applied while the block was maintained. Multiple experiments were performed to evaluate the effect of high frequency AC stimulation on the nerve. The frequency range studied was 600Hz to 20KHz, with the following stimulation parameters: constant-current vs. constant voltage; sinusoid vs. rectangular wave; and bipolar vs. monopolar electrodes.

Figure 1: Block diagram of experimental setup. All experiments included the proximal stimulating electrode and blocking electrode. A distal stimulating electrode was used in some experiments to verify the continued function of the neuromuscular junction. For voltage-controlled waveforms, the direct capacitively-coupled output of the signal generator was used. For current-controlled waveforms, a linear stimulus isolator was used to generate the blocking waveform.

3 Results
A complete and reversible conduction block was achieved in all 34 sciatic nerve preparations tested (18 frogs). Typically, block was achieved using a 3-5KHz sinusoidal waveform with an amplitude of 3-4 volts peak-peak (Vp-p) or 0.3-1.6 ma p-p. For a 5KHz voltage-controlled sinusoidal waveform, the median amplitude for a 100% block was 4.4 Vp-p. At lower amplitude levels (median 2.0 Vp-p), the 5KHz sinusoid either produced a strong tetanic response or did not produce any obvious change in the twitch response. A complete block was achieved in individual preparations at frequencies as low as 1000Hz and as high as 20KHz. In all cases where a 100% block was achieved, the block was maintained at higher amplitudes, up to the highest amplitude tested (10 Vp-p or 5.5mA-p-p).

Figure 2 shows an example of a typical 100% block of frog sciatic conduction using a 3KHz sinusoidal voltage-controlled waveform. This trial shows that the block produces an onset muscle twitch that is nearly identical to the twitch response obtained from the proximal stimulation. The block is essentially immediate, completely eliminating the conduction of the first proximal pulse that occurs two seconds after block initiation. Three pulses were produced by the distal stimulating electrode, demonstrating that the block does not affect the muscle or the neuromuscular junction. The block was maintained for 40 seconds. Typically, the cessation of block also produced a twitch response in the muscle, although this twitch was often of lower amplitude than the onset response. Finally, the block is shown to be completely and instantly reversible. Figure 2 shows that the recovery occurs within 500ms, with no decrease in the twitch amplitude.

4 Discussion and Conclusions
The results of this study demonstrate that high frequency stimulation, when properly delivered, can produce a block of nerve conduction in whole motor nerves. The block is demonstrated to be 100% effective in blocking motor activity and is completely reversible in less than 500ms. Within the parameters tested in the frog, a continuous sinusoidal or rectangular waveform at 3-5 KHz appears to provide the most consistent block at the lowest charge per phase. Typical amplitudes that produced block were 3-5 Vp-p or 0.5-2mA-p-p, although this amplitude is dependent on the electrode surface area, nerve diameter and electrode-nerve interface.

Experiments are ongoing to duplicate these results in mammals and to determine the specific parameters that will be necessary for human use. It will also be necessary to demonstrate the safety of chronic block of nerve using these waveforms. We are in the process of preparing for these chronic studies.
References


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