AC Nerve Blocking: in-vivo tests & potential applications

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Abstract

Sinusoidal currents can produce localized and dynamically reversible conduction blockade in peripheral nerve. Waveform parameters can be selected so that localized blockade occurs without activity induced in the nerve.

Using a rat nerve/muscle preparation we have demonstrated localized and selective blockade. We suggest how this form of block may be combined with electrical stimulation to provide selective blockade, selective stimulation and unidirectional stimulation. Potential applications for bladder and bowel are indicated.

1 Introduction

Alternating currents have been proposed for nerve blockade, see for example [2, 3, 4, 6]. Based on our initial studies involving computer modelling and in-vivo studies [1, 5] we suggest that a range of waveform parameters can be used to obtain localized block. However, parameters outside this range can produce uncertain combinations of neuromuscular endplate depletion, collision and localized blockade. In this paper we report on our in-vivo demonstration of localized blockade. In another IFESS2004 presentation are in-vitro results [7].

2 Methods

Five female rats (307 +/- 40 g) were tested. Each rat was anaesthetized with an intraperitoneal injection of 45 mg/kg pentobarbital sodium (Somnotol). After initial anaesthesia, pentobarbital sodium (45 mg/kg ip) was administered in a 1:5 dilution to maintain general anaesthesia. The trachea of each rat was cannulated, and mechanical ventilation assistance was applied for one animal. The body of each rat was warmed during the tests by radiant heat from above and a heating pad beneath.

The left sciatic nerve was exposed in each rat. The ipsilateral knee was held in place using a stereotaxic frame. Each ipsilateral muscle groups, other than the tibialis anterior, was denervated. The tendon from the tibialis anterior was cut and tied to a strain gauge. Force was amplified and viewed on a Tektronix dual time base storage oscilloscope (model 5441), and monitored continuously on a Gould 1200S pen recorder. The force from the muscle was recorded under different stimulus conditions.

A bipolar cuff electrode, constructed of Silastic tubing (inside diameter 1.98 mm outside diameter 3.18 mm, length 6 mm, contacts of 15 strand Cooner wire symmetrically and longitudinally spaced by 4 mm) was placed around the sciatic nerve at the most distal site from the muscle. An intramuscular electrode, made by bared ends of Teflon coated fine silver wires (75 μm), was inserted near the motor point of the tibialis anterior in a position most proximal to the muscle. A symmetrical tripolar cuff electrode (inside diameter 1.98 mm outside diameter 3.18 mm, length 6 mm, contacts of 15 strand Cooner wire symmetrically spaced by 2 mm) was placed around the common peroneal nerve approximately halfway between the other two electrodes.

Action potentials and muscle firings were produced using unipolar 50 μs pulses produced by a Grass generator and connected to the bipolar and intramuscular electrodes. The amplitude of the pulses was set to cause the maximal force single muscle twitch from the muscle. Pulses could be generated independently from the bipolar and intramuscular electrode, or the timing of the pulses could be synchronized. In tests to demonstrate the localized nerve block, the muscle twitch produced by the intramuscular electrode typically preceded the muscle twitch from the cuff electrode by one second. In some tests, only the bipolar electrode was used to generate action potentials.

The centre contact of the cuff was connected to a variable frequency, variable amplitude sinusoidal generator. The two outer contacts of the tripolar cuff electrode were connected to the common (ground) of a sinusoidal stimulator. The waveform generator used an analogue control to vary the frequency between 3 and 20 kHz. The magnitude of the first harmonic of the waveform, the largest frequency domain component of noise, was attenuated by 38 dB, measured on a Hewlett Packard digital storage oscilloscope, Model 54600A. A schematic of the experimental arrangement is shown in figure 1.

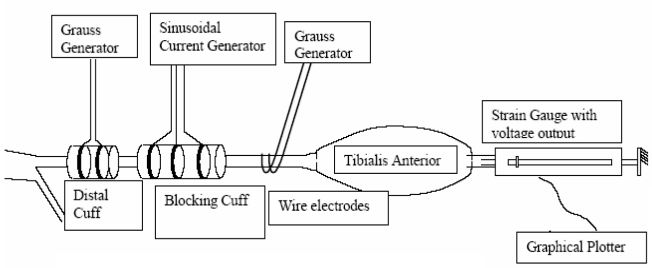

Figure 1: *Experimental set-up.*

3 Results

The blocking current was applied in 15s bursts. Conduction was blocked in 4 out of 5 animals from the first burst and after the twelfth burst in the 5th rat. Figure 2 shows a typical trace.

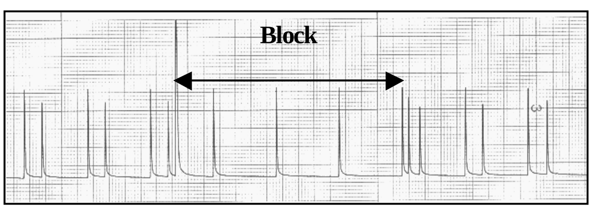

Figure 2: *Typical muscle force record for block above 10 kHz. To the left, the first muscle twitch was due to the intramuscular electrode and the second twitch the proximal cuff electrode. A larger twitch is observed on turning on the block after which only twitches due to the intramuscular electrode are seen. After block switch-off both stimulus twitches immediately resume.*

Selective stimulation is indicated by figure 3.

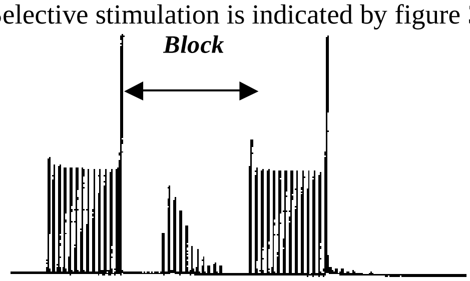

Figure 3*: Twitches are generated at 5s intervals by proximal stimuli. Block is applied at maximum current is initially maximum with an initial high force twitch. Block current is then reduced and then progressively increased to maximum and held until switch-off (note smaller switch-off twitch).*

4 Discussion and Conclusions

These initial results suggest that a selective and localized blockade can be established in rat nerve. The onset and recovery times are short, typically less than 10ms. Sinusoidal blocking currents were typically less than 2.5mA and suitable for existing electrode and implant technology. In the present arrangement we observed a single twitch induced when the AC block is applied and sometimes when it is removed. Our nerve/muscle model does not enable us to determine if any activity was induced in any sensory axons. AC block can be combined with electrical stimulation to as shown in Figure 4.

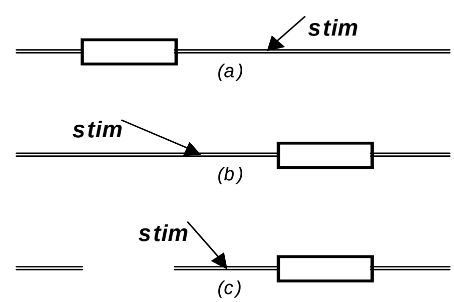

Figure 4: *Possible stim/block combinations*

Figure 4(a) enables uni-directional activation in larger axons. Block current is set to maximum. The stimulus induces action potentials that propagate to the right. All propagation blocked to the left. The stimulus intensity determines the population of axons activated.

Figure 4(b) The stimulus generates action potentials bi-directional in a population of axons determined by the stimulus intensity. The sinusoidal current can be adjusted to selectively block propagation to the right in the larger axons.

Figure 4(c) is used to establish uni-directional activation only in the smaller axons. For propagation to the right, the left block current is set to maximum and all traffic in that direction will be stopped. The right block current is adjusted to stop propagation to the right only in the larger axons. The stimulus intensity is set sufficient to activate the smaller axons, which are free to propagate only to the right. Vice versa for propagation to the left.

Because the block is highly localized, the blocking and stimulating electrodes may be placed in close proximity.

AC block and ENG amplification may allow selective recording from smaller axons by first blocking activity the larger axons as indicated in Figure 5.

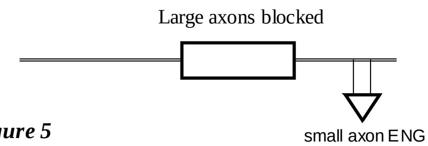

Figure 5

AC blocking potentially extends FES applications, for example, spasticity may be suppressed to improve movement or bladder/bowel control. Because the blockade does not induce activity it is unlikely to cause discomfort and may thus be used where sensation is preserved.

For example, a blocking cuff electrode could be positioned on the pudendal nerve to transiently block activity in the sphincters, which may be used assist micturition or defecation. The same cuff could also double-up as a stimulating electrode to provide low-level neuromodulation during the filling phases to reduce hyperactivity in the detrusor or rectum.

Extradural sacral root AC blocking and stimulation, may be possible to restore control the neurogenic bladder. The blocking cuff could be positioned extradurally on the mixed sacral root (typically S2) as shown in Figure 6 using similar surgical access to that used in the "Barcelona" technique [8]. A stimulating electrode system could be positioned distally. With the proximal block fully on the stimulus is applied in bursts to provide post-stimulus voiding similar to that used in the Finetech-Brindley SARS system. The AC block would temporarily disrupt the reflex arc during micturition thus avoiding detrusor-sphincter-dyssynergia. During the filling phase the block is switched off and a low-level stimulation applied to provide neuromodulation to reduce detrusor hyperreflexia.

An additional refinement would be to use a combination that includes a second blocking electrode placed distally as shown schematically in figure 4(c). In this arrangement selective contraction of the detrusor with blockade of the sphincter provides low pressure voiding i.e. during micturition the proximal block would be set to maximum and the distal block set to block the larger efferents to the urethral sphincter. In both arrangements the requirement for posterior rhizotomy may be avoided and the extradural surgery is less risky than intradural approaches.

Unidirectional stimulation can also be implemented using anodal blocking techniques such as those described in [9]. However, AC blocking has the advantage that no action potentials are induced and any activation, deliberately induced by stimulation, can be blocked upstream from reaching central sensory pathways. This may enable applications to be extended to cases with sensory sparing such as incomplete spinal injuries or MS.

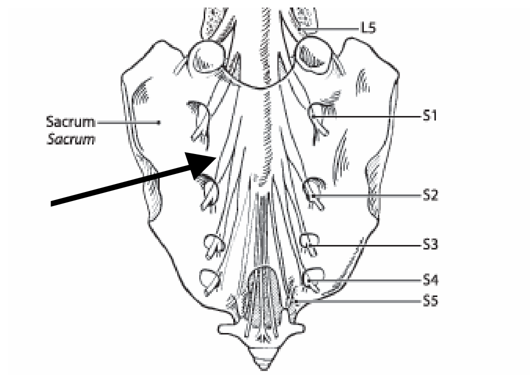

Figure 6: *The block/stimulation electrode system of figure 4 (a) or (c) may be positioned extradurally and bilaterally on the mixed sacral roots. The approximate location for S2 cuff electrode system is indicated*

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