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Nerve Conduction Block Using Combined Thermoelectric Cooling and High Frequency Electrical Stimulation

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Abstract

Conduction block of peripheral nerves is an important technique for many basic and applied neurophysiology studies. To date, there has not been a technique which provides a quickly initiated and reversible “on-demand” conduction block which is both sustainable for long periods of time and does not generate activity in the nerve at the onset of the conduction block. In this study we evaluated the feasibility of a combined method of nerve block which utilizes two well established nerve blocking techniques in a rat and cat model: nerve cooling and electrical block using high frequency alternating currents (HFAC). This combined method effectively makes use of the contrasting features of both nerve cooling and electrical block using HFAC. The conduction block was initiated using nerve cooling, a technique which does not produce nerve “onset response” firing, a prohibitive drawback of HFAC electrical block. The conduction block was then readily transitioned into an electrical block. A long-term electrical block is likely preferential to a long-term nerve cooling block because nerve cooling block generates large amounts of exhaust heat, does not allow for fiber diameter selectivity and is known to be unsafe for prolonged delivery.

Keywords

Nerve block; Nerve cooling; High Frequency Alternating Current (HFAC); Peripheral Nerve; Onset Response; Temperature; Peltier

Introduction

Nerve conduction block is an important technique for use in both basic experimental neuroscience (e.g. for blocking reflex, autonomic or motor pathways) and in applied neurophysiology and neuroengineering research (e.g. therapy development for spasticity and pain). Numerous methods for achieving nerve conduction block have been devised and include techniques which can be categorized into four broad categories: chemical methods,

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thermal methods, electrical methods and methods which involve physical tissue trauma. Chemical blocking methods include the use of denaturing agents which induce a permanent nerve block caused by irreversible axonal damage, and temporary/reversible agents such as channel blockers (Butterworth and Strichartz, 1990). Thermal blocking methods include reversible nerve cooling (Franz and Iggo, 1968) and irreversible thermal ablation. Electrical blocking methods include the use of direct currents (Bhadra and Kilgore, 2004), intermediate frequency stimulation to produce a synaptic depletion block (Wedensky, 1903) or very high frequency stimulation currents to produce a local conduction block (Kilgore and Bhadra, 2004). Methods involving physical trauma are typically irreversible and include surgical section and nerve crush (Kocsis et al., 1982).

Nerve cooling and electrical nerve blocking both have the advantage of being “on-demand” nerve blocking techniques which are fast acting and quickly reversible (tens of milliseconds to tens of seconds depending on the technique) (Bhadra and Kilgore, 2004; Kilgore and Bhadra, 2004; Patberg et al., 1984). Nerve cooling has the additional advantage of inducing conduction block without first inducing a transient activation of the nerve (Patberg et al., 1984). This technique has been proven to be effective in both acute (Franz and Iggo, 1968; Patberg et al., 1984) and chronic preparations (Borgdorff and Versteeg, 1984) for inducing intermittent blockade of neural activity for short periods of time. However, delivery of nerve cooling for periods longer than a few tens of seconds is made difficult by the need to exhaust the heat that is necessarily induced as a by-product of the cooling. For example, Borgdorff and Versteeg utilized a transcutaneous liquid cooling system in their chronic nerve cooling cuff implantation, where the heat producing components were outside of the body (Borgdorff and Versteeg, 1984). Long term nerve cooling (tens of minutes or longer) is also known to cause tissue damage resulting from ischemia and reperfusion injury (Jia, 1998, 1999) and is therefore not appropriate for long-term applications.

Electrical nerve blocking using high frequency alternating currents (HFAC) is of growing interest to both the basic and applied research communities. HFAC block is useful for long term nerve blocking in part, because unlike nerve cooling, it does not require heat-sinking equipment to prevent nerve heating and it can be reversed in a period of milliseconds (Kilgore and Bhadra, 2004). There has only been one study published on HFAC delivery in a chronic animal preparation, and nerve tissue health was not explicitly evaluated (Gaunt and Prochazka, 2009). However, an implantable commercial therapy which utilizes this technique to produce conduction blockade in the vagus nerve has been shown to be safe for chronic implantation in humans (Camilleri et al., 2008). Another attractive feature of HFAC nerve block is that the technique can be used to produce a partial nerve block (Bhadra and Kilgore, 2005) that is likely selective for blocking large fibers (Bhadra et al., 2007). While this technique has many attractive and promising features, delivery of HFAC induces a dramatic transient (tens of milliseconds to several seconds) hyperactivity at the onset of current delivery (Bhadra and Kilgore, 2005). This hyperactivity has been termed the “onset response” of the neural tissue to HFAC (Bhadra and Kilgore, 2005), and it limits the usefulness of this method both experimentally and clinically since activation of the very tissue which is to be blocked is often not desired.

In this study we evaluated the feasibility of a combined method of nerve block which makes use of the contrasting features of two well established nerve blocking techniques: nerve cooling and electrical block using HFAC. The block was initiated with nerve cooling because it does not produce onset response firing, and the block was transitioned into an electrical HFAC because of its suitability for long term delivery. The resulting technique is a nerve conduction block which does not produce an onset response, but that is very likely suitable for long term delivery.

Methods

Experiments were performed in three adult Sprague-Dawley rats and in one adult cat. All protocols involving animal use were approved by our institutional animal care and use committee.

Rodent Surgical Preparation and Experimental Setup

Acute experiments were performed in three adult Sprague-Dawley rats. The surgical preparation is well established and has been previously described in several other HFAC studies in the rat (Bhadra and Kilgore, 2005). The animals were anesthetized with intraperitoneal injections of Nembutal (Phenobarbital sodium). The left hind leg was shaved and an incision was made along the posterior aspect of the hind leg and thigh. The sciatic nerve was exposed from its most proximal aspect, just distal to the sacral plexus, to the popliteal fossa. The common peroneal and sural nerves were severed approximately 1 cm from their respective branch points with the sciatic nerve. The gastrocnemius-soleus muscle complex was dissected, and the calcaneal (Achilles) tendon was severed from its distal attachment at the heel. The ipsilateral tibia was stabilized to the experimental rig via a clamp, and the calcaneal tendon was tethered to a force transducer using a toothed clamp with approximately 1-2 N of passive tension. Body temperature was maintained using a heating blanket.

Figure 1a shows a diagram of the experimental setup. Two electrodes and a thermode were placed on the sciatic nerve as shown in the figure. Both electrodes were silicone rubber nerve cuffs with a J-shaped cross-section and 3 mm × 1 mm rectangular platinum contacts for current delivery (the 1 mm dimension was along the longitudinal axis of the nerve) similar to those which have been used in other HFAC studies (Bhadra and Kilgore, 2005). The proximal electrode was used to generate gastrocnemius-soleus muscle twitches with the delivery of 1.0 Hz, 20 μ sec supramaximal (~600 μ A) cathodic pulses. These pulses were delivered using a Grass S88 (Grass Technologies, West Warwick, RI, USA) stimulator with a current-controlled output stage. The proximal stimulating electrode was placed on the sciatic nerve within 1 cm of the sacral plexus. The distal electrode was used for the delivery of HFAC blocking currents to the nerve. The electrodes were bipolar with a 1.0 mm edge-to-edge contact spacing and 1.0 mm of silicone rubber between the edge of the outer platinum contact and each edge of the cuff (Ackermann et al., 2009). The HFAC waveforms were 40 kHz voltage-controlled sinusoids and were delivered using a Wavetek 395 waveform generator (now Willtek Communications GmbH, Ismaning, Germany). The blocking frequency and amplitude were chosen such that the HFAC onset response was of a reasonably short duration (Bhadra and Kilgore, 2005). Blocking waveform amplitudes of approximately 1.5 times the block threshold amplitude (minimum amplitude required for block (Bhadra and Kilgore, 2005)) were used in each experiment. The thermode was placed approximately 5 mm distal to the blocking electrode on the tibial nerve. A ~1 cm² longitudinal section of the semitendinosus muscle was removed to allow room for placement of the thermode onto the tibial nerve without inducing tension on the nerve.

The thermode apparatus (see Figure 1b for labeled photo) consisted of a silicone-sealed Peltier thermoelectric cooler (10 mm × 10 mm 0711 series, Custom Thermoelectric, Inc., Bishopville, MD, USA) which was fixed between two 3.2 mm thick aluminum plates with thermally conductive epoxy. A groove was machined into the top plate to host the nerve. For one experiment a K-type thermocouple was placed within a small-bore hole in the top aluminum plate to monitor plate temperature. The bottom plate served as a heat sink for the Peltier device during the nerve cooling phase. A small ice-filled aluminum cup was fixed to the bottom plate with thermally conductive epoxy and functioned as a simple and effective

heat sink. The thermode was held into position using a small clamp which stood on the experimental rig next to the animal.

Feline Surgical Preparation and Experimental Setup

An acute experiment was also performed in one adult cat. Anesthesia was induced with intramuscular ketamine hydrochloride and maintained with isoflurane. An anesthetic monitoring system (SurgiVet V9200 Advisor Monitor, Smiths Medical PM, Inc., Waukesha, WI) was used to observe ECG, blood pressure, body temperature, blood oxygen saturation and expired pCO₂. The animal was intubated and respiration was maintained by a pressure-regulated respirator (ADS 1000, Engler Engineering Corporation, Hialeah, FL). Saline 0.9% with 8.4 mg/ml sodium bicarbonate and 5% dextrose was administered at 5–20 ml kg/hr IV. Body temperature was maintained using a heating blanket. The left hind leg was shaved and an incision was made along the posterior aspect of the hind leg and thigh. The biceps femoris muscle was reflected to expose the common peroneal nerve from its origin at the popliteal fossa to its insertion in the tibialis anterior. A two inch cutaneous incision was made on the anterior aspect of the distal leg and the tibialis anterior tendon was dissected and severed. The ipsilateral tibia was stabilized to the experimental rig via a clamp, and the tibialis anterior tendon was tethered to a force transducer using a toothed clamp with approximately 1-2 N of passive tension.

The placement of two electrodes and the thermode on the nerve were similar to the placement in the rat experiments and are shown in the schematic diagram in Figure 1a. Both electrodes were silicone rubber nerve cuffs of the type used in the rat experiments, but were in a tripolar configuration (outer contacts tied together) and larger than those used for the rats: 9 mm × 1 mm rectangular platinum contacts for current delivery (the 1 mm dimension was along the longitudinal axis of the nerve). The proximal electrode was placed approximately 2 cm from the sciatic/common peroneal nerve branch point and was used to generate maximum force tibialis anterior muscle twitches with the delivery of 3.0 Hz, 100 μsec, 2.0 mA cathodic pulses. These pulses were delivered using a Surgical Stimulator 207-2 (NeuroControl Corp., Cleveland, OH, USA). The distal electrode was used for the delivery of HFAC blocking currents to the nerve, and was placed approximately 2 cm distal to the proximal electrode. The blocking frequency and amplitude were chosen such that the HFAC onset response was of a reasonably short duration (Bhadra and Kilgore, 2005). The HFAC waveforms were 10 kHz voltage-controlled sinusoids with an amplitude equal to block threshold (5.8 V_{peak-peak}) and were delivered using a model AFG3000 waveform generator at block threshold amplitude (Tektronix, Inc., Beaverton, OR, USA). The thermode was the same as that used for the rat experiments.

Nerve Blocking Protocol

Each demonstration of nerve block using combined HFAC and nerve cooling consisted of three trials. The first trial consisted of HFAC delivery to demonstrate that the HFAC produced an onset response, the second trial used combined HFAC and nerve cooling to block the nerve without onset response, and the third trial was a repeat of the first with HFAC only to verify that the nerve still produced an onset response.

Typical waveform timing for a combined nerve block experiment using HFAC and nerve cooling is shown in Figure 2. In each animal, proximal stimulation was initiated at 1.0 Hz (rat) or 3.0 Hz (cat) and continued for the duration of the trial. After approximately 10 seconds, the nerve cooling was initiated by applying a controlled reverse current through the Peltier device using a laboratory bench power supply. Once full nerve conduction block was achieved as determined by a lack of muscle activity, the HFAC current was delivered to the distal cuff electrode. Approximately 3 seconds after the initiation of the HFAC delivery, the

Peltier current was reversed to a forward direction to warm the nerve. The forward current was delivered for a period of time which was sufficient to reverse the cooling block as determined in preliminary trials (e.g. 15 seconds in the cat experiment). The temperature of the nerve cooling apparatus was monitored using the K-type thermocouple described above in one rat experiment to measure the temperature of the nerve during the cooling and warming phases.

Results

Complete nerve conduction block was very readily achieved in each of the four animals without induction of onset activation in the nerve being blocked. Figure 2 shows a typical sequence of three consecutive trials demonstrating conduction block without onset response in the cat. Each trial shows a recording of the muscle force and the timing of the HFAC waveform (indicated by the solid black bar). The muscle force recording in Figure 2a shows a typical onset response for a 10 kHz HFAC waveform. Figure 2b shows the subsequent trial which demonstrates combined use of HFAC and nerve cooling to block the nerve without generation of an onset response. The timing of the cooling and warming phases is indicated by the labeled bars below the trace. At approximately 15 seconds into the trial the nerve cooling is initiated. The nerve is completely blocked approximately 65 seconds into the trial. The HFAC delivery is initiated at approximately 68 seconds into the trial, and the absence of the large onset response indicates that the cooled thermode blocked the onset firing induced by the HFAC. At approximately 71 seconds into the trial the thermode current is reversed and the nerve is warmed. The time required to warm the nerve from the blocked state back to approximate body temperature was typically shorter than the time required to cool the nerve to the blocked state (less energy is required to restore the Peltier device to body temperature than to induce and sustain a deviant temperature). At approximately 84 seconds into the trial the Peltier current was halted. The HFAC delivery was halted one second later and full nerve conduction was restored. Figure 2c shows the following trial in which nerve block is achieved with HFAC only. This trial demonstrates that the nerve cooling did not eliminate the onset response simply by damaging the nerve, and that the block occurred as the result of a transient nerve cooling conduction block. Table I summarizes the results from the cat experiment. This data represents the average over the six trials recorded in the cat.

Figure 3 shows a combined block trial from the rat experiment in which temperature was measured using an embedded thermocouple. In a separate cooling only trial, partial conduction block was found for temperatures below 14° C, and complete nerve conduction block was achieved for temperatures below 6° C in this animal. These temperatures are very consistent with previously published data (Franz and Iggo, 1968). The results of the rat experiments were similar to those demonstrated in the cat; however recovery after cooling block was typically slower than in the cat. Summary results across the three rats are shown in Table I. For animals in which multiple combined block trials were executed, the data represents an average over each of the trials for the animal. These experiments were not explicitly designed to monitor muscle recovery, and data collection was halted before the preparation was allowed to recover completely in Rats 1 and 2.

Discussion

In this study we have demonstrated that two well established techniques for achieving conduction block in a peripheral nerve can be used in a combined fashion to take advantage of the desirable features of each method. In each animal, the distally placed thermode produced a conduction block of the nerve that prevented the onset response activity generated at the HFAC electrode from reaching the muscle. The thermode was then used to warm the nerve back to a conducting temperature, and the conduction block was maintained

using the HFAC. The onset firing generated by the delivery of HFAC is undesirable since it is likely to result in strong activation of musculature in an awake and free moving animal, depending on waveform amplitude and nerve selection. This study demonstrates that by using this combined technique this onset contraction can be eliminated. By combining the contrasting features of the two techniques a nerve block that has attributes that neither have alone is achieved: a quickly reversible, electrically maintained conduction block that does not exhibit a transient onset response and may be safe for long term use.

It is well established that delivery of a nerve cooling block for periods of tens of minutes or longer results in nerve damage (Jia, 1998,1999). HFAC, however has been shown to be safe in a chronic vagus nerve blocking study in humans (Camilleri et al., 2008). Given that HFAC can safely be delivered for long durations, the combined conduction block technique described in this study may also be useful as a method for producing a chronically safe nerve conduction block that does not result in onset firing. Such a combination of attributes would be useful in chronic laboratory studies requiring peripheral nerve block. This technique may also have implications for the clinical deployment of HFAC nerve blocking since a major hurdle to its clinical use is the onset response.

Electrical nerve blocking techniques can provide a partial differential conduction block that preferentially blocks large fibers at low amplitudes and inclusively blocks smaller fibers with increases in waveform amplitude (Bhadra and Kilgore, 2004; Bhadra et al., 2007). A nerve cooling block can selectively block myelinated fibers, maintaining the conduction of unmyelinated fibers; however it does not allow for discrimination within a myelinated population based on fiber diameter (Franz and Iggo, 1968). The combined technique of nerve blocking described in this study may provide a convenient method for utilizing an electrical nerve block which allows for fiber diameter selectivity without producing transient onset firing.

The nerve cooling system utilized in this study would not be suitable for chronic implantation. The largest barrier to developing a system which is implantable is the development of a thermally efficient cooling system that would allow for a small implantable heat sink. This may be possible by integrating a cooling device into a highly thermally insulated cuff with a thermally conductive material at the nerve interface. Unlike the unshielded device used in this study, such a cuff would confine the volume of tissue which is cooled to a small section of nerve. This type of cooling cuff would reduce cooling times for a given Peltier device and could allow for use of a cooler with a minimal heat sinking apparatus (perhaps an exposed metal contact on the outside of the cuff). Such a device could be useful in a chronic laboratory setting, or in a clinical setting for treating disorders involving pathological neural activity (e.g. spasticity, bladder dyssynergia, etc.). Other possible heat sinking options include using a cuff with a large thermal mass or using a remote liquid cooling apparatus. Elaborate heat sinking systems which utilize native vasculature for cooling have also been described in the context of implantable Peltier devices (Saadat, 2004).

Conclusions

We have demonstrated the combined use of two well established nerve block techniques: nerve cooling and electrical block using high frequency alternating currents. This combined method of nerve block makes use of the contrasting features of both nerve cooling and HFAC electrical block. The block was initiated with nerve cooling which did not produce nerve “onset response” activity, a prohibitive drawback of HFAC electrical block. The block was then transitioned into an electrical block. A long-term electrical block is likely preferential to a long-term nerve cooling block, because nerve cooling block generates large

amounts of exhaust heat, does not allow for fiber diameter selectivity and is known to be unsafe for prolonged delivery.

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References

- Ackermann D, Foldes E, Bhadra N, Kilgore K. Effect of Bipolar Cuff Electrode Design on Block Thresholds in High Frequency Electrical Neural Conduction Block. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*. 2009; 17:469–77. [PubMed: 19840914]
- Bhadra N, Kilgore KL. Direct current electrical conduction block of peripheral nerve. *IEEE transactions on neural systems and rehabilitation engineering : a publication of the IEEE Engineering in Medicine and Biology Society*. 2004; 12:313. [PubMed: 15473193]
- Bhadra N, Kilgore KL. High-frequency electrical conduction block of mammalian peripheral motor nerve. *Muscle and Nerve*. 2005; 32:782. [PubMed: 16124008]
- Bhadra N, Lahowetz E, Foldes S, Kilgore K. Simulation of high-frequency sinusoidal electrical block of mammalian myelinated axons. *J Comput Neurosci*. 2007; 22:313–26. [PubMed: 17200886]
- Borgdorff P, Versteeg P. An implantable nerve cooler for the exercising dog. *European Journal of Applied Physiology and Occupational Physiology*. 1984; 53:175–9. [PubMed: 6542517]
- Butterworth JFI, Strichartz GR. Molecular Mechanisms of Local Anesthesia: A Review. *Anesthesiology*. 1990; 72:711–34. [PubMed: 2157353]
- Camilleri M, Toouli J, Herrera MF, Kulseng B, Kow L, Pantoja JP, Marvik R, Johnsen G, Billington CJ, Moody FG, Knudson MB, Tweden KS, Vollmer M, Wilson RR, Anvari M. Intra-abdominal vagal blocking (VBLOC therapy): Clinical results with a new implantable medical device. *Surgery*. 2008; 143:723–31. [PubMed: 18549888]
- Franz DN, Iggo A. Conduction failure in myelinated and non-myelinated axons at low temperatures. *Journal of Physiology (Paris)*. 1968; 199:319.
- Gaunt R, Prochazka A. Transcutaneously coupled, high-frequency electrical stimulation of the pudendal nerve blocks external urethral sphincter contractions. *Neurorehabil Neural Repair*. 2009; 23:615. [PubMed: 19109445]
- Jia. Cold injury to nerves is not due to ischaemia alone. *Brain*. 1998; 121:989. [PubMed: 9619199]
- Jia. Cold nerve injury is enhanced by intermittent cooling. *Muscle*. 1999; 22:1644.
- Kilgore K, Bhadra N. Nerve conduction block utilizing high-frequency alternating current. *Medical and Biological Engineering and Computing*. 2004; 42:394–406. [PubMed: 15191086]
- Kocsis JD, Waxman SG, Hildebrand C, Ruiz JA. Regenerating Mammalian Nerve Fibres: Changes in Action Potential Waveform and Firing Characteristics Following Blockage of Potassium Conductance. *Proceedings of the Royal Society of London. Series B, Biological Sciences*. 1982; 217:77–87.
- Patberg WR, Melchior HJ, Mast JG. Blocking of impulse conduction in peripheral nerves by local cooling as a routine in animal experimentation. *Journal of Neuroscience Methods*. 1984; 10:267–75. [PubMed: 6748738]
- Saadat, V. USPTO. , editor. Apparatus and Methods for Cooling a Region Within the Body. US Patent #: 6,746,474. 2004.
- Wedensky N. *Pfluger's Arch*. 1903; 100

Figure 1.

Schematic representation of the experimental setup showing the nerve with proximal stimulating electrode, high frequency blocking electrode and Peltier thermode. The muscle is instrumented with a force transducer. Insert: Photo of nerve cooling apparatus with components labeled. A: Top aluminum plate; B: Machined groove for nerve; C: Peltier device; D: Wire for thermocouple entering hole in top aluminum plate; E: Bottom aluminum plate; F: Aluminum cup for holding ice.

Figure 2.

Sequence of three consecutive trials demonstrating block of the onset response with common peroneal nerve cooling in the cat. Each trial shows a recording of the muscle force, the timing of the HFAC waveform (indicated by the solid black bar) and the timing of the proximal stimulation (indicated by the grey line with diamond ends). a) Muscle response to a 40 kHz HFAC waveform. Onset response indicated by block arrow. b) Muscle response to combined delivery of HFAC and nerve cooling/warming. The timing of the cooling and warming phases is indicated by the labeled bars below the trace. c) Muscle response to a 40 kHz HFAC waveform.

Figure 3.

Combined thermal and HFAC conduction block trial from Rat 3 experiment. Muscle force, thermode temperature and HFAC amplitude are displayed. This plot shows that the thermode effectively blocks the HFAC onset response.

Table

Summary Data For All Experiments

An. #	# Attempts	# Successes	HFAC Freq. (kHz)	HFAC Amp.	Cooling Time To Block (sec)	Total Cooling / Warming Delivery Time (sec)	% Complete Block	% Recovery (Post Block force/Pre Block Force)
Rat 1	2	2	40 kHz	9 V _{pp}	29	35 / 22	100%	0.92
Rat 2	1	1	40 kHz	9 V _{pp}	18	20 / 62	100%	0.83
Rat 3	2	2	40 kHz	8.4 V _{pp}	47	51 / 32	100%	1.02
Rat Avg.	5	5	40 kHz	8.8 V _{pp}	34	38.4 / 34	100%	0.94
Cat 1	6	6	10 kHz	5.8 V _{pp}	36.5	46.5 / 23.7	100%	1.07