Comparing Anodal and AC-Blocking of Peripheral Nerves by Velocity-Selective Recording with a Multi-Electrode Cuff

Schuettler M¹, Seetohul V², Taylor J², Donaldson N³

¹ Laboratory for Biomedical Microtechnology, Department of Microsystems Engineering, University of Freiburg, Germany.
² Department of Electronic and Electrical Engineering, University of Bath, UK.
³ Implanted Devices Group, Department of Medical Physics & Bioengineering, University College London, London, UK.

schuettler@ieee.org

Abstract
We stimulated frog peripheral nerves in vitro under three different stimulation paradigms that allow diameter-selective activation or blocking of nerve fibres. The electrically evoked potentials were analysed applying the method of velocity selective recording with a multiple-electrode cuff, which provides neural activity histograms over a range of conduction velocities. The selectivity of all three stimulation methods was proven. Furthermore, the propagation velocity of the nerve fibres contributing to the compound action potentials was calculated.

1. INTRODUCTION
Blocking of nerve signal propagation is a tool to inhibit the transmission of natural or artificial neural information. It has been shown that this can be reversibly achieved in a nerve by applying a current of specific waveform, e.g. a sinusoidal or square wave of a frequency beyond 1 kHz (AC-block) or by applying large charges (anodal blocking). Both methods are described to be fibre selective so that fast propagating, large diameter fibres are affected by the blocking signal at lower electrical charges per phase than slow, small diameter fibres. However, these two methods have not previously been directly compared. One reason for that is the lack of a tool that displays the activity of the nerve bundle as a function of the conduction velocity. In this study, we evaluate conduction velocity selective recording with an eleven-electrode nerve cuff and use the new method with the two different blocking schemes described above. This is a preliminary study which employs explanted frog sciatic nerves as a model for human peripheral nerves. The authors are aware of the different membrane kinetics in amphibians and humans but want to demonstrate that velocity selective recording with multiple-electrode cuff (MEC) electrodes is a powerful evaluation tool for neuroscientists.

2. METHODS
2.1. Velocity-Selective Recording
An action potential (AP) travelling along a nerve, passing \( N \) electrical contacts equally spaced along the insulating cuff generates an electrical potential at each of the contacts as a function of time and contact position. The resulting electrical pattern that can be recorded from the cuff contacts is specific to the velocity and direction of the action potential propagation (Figure 1).

Figure 1: Recording pattern generated by two action potentials travelling at different velocities along a nerve in an eleven-electrode nerve cuff.

After amplification of the signals using a tripolar amplifier bank the recorded signals are shifted in time against each other by \((n-1) \times dt\) and summed to a single signal, where \( n \) refers the channel number. E.g. channel one is not delayed, channel 2 is delayed versus channel one by \( dt\), channel 3 is delayed by \( 2 \times dt\), etc. In the case that \( dt\) matched the electrode pitch \( p\)
divided by the AP propagation velocity $v$, the signals of all channels add constructively [1]. The amplitude of a $dt$-matched summed signal is up to $N - 2$ times larger than the amplitude after summing with a non-matched time delay (when a tripolar amplifier configuration was used).

2.2 Experimental Setup
The sciatic nerve of Xenopus Laevis frog was explanted over a length of about 8 cm and kept in amphibian Ringer’s solution. A tripolar stimulation cuff “A” was placed at the distal end of the nerve. This cuff was 1.0 mm in diameter, the electrode contacts where arranged at a pitch of 5 mm, were 0.2 mm wide and coated with platinum black (impedance at 1 kHz below 1 kOhm). For AC-block experiments, a second cuff “B” of the same type was wrapped around the nerve with a distance of about 1 cm to cuff “A” (all cuffs used in this study are manufactured using polyimide-based thin-film technology, as described in [2]). For velocity selective recording, a third cuff “C” was placed at the proximal end of the nerve. This cuff had a diameter of 1.5 mm and carried 11 platinum contacts (pitch: 3.5 mm, width: 0.5 mm). This cuff was connected to a custom designed amplifier chip that provided an array of bipolar amplifiers and filters (a follow-up version of [3]). The 10 outputs of this amplifier were monitored by a data acquisition (DAQ) system (DAQCard-6062E, National Instruments), which sampled each channel at 40 kHz with a dynamic range of 12 bit. This data was handled by a LabView program and stored on a laptop computer. Converting 10 bipolar recording channels to 9 tripolar channels, introduction of time delays $dt$ and summation was carried out off-line by a Matlab routine.

2.2 Experimental Protocol
At first, only cuff “A” and “C” were installed. The stimulation intensity of a charge-balanced, current-controlled pulse was gradually increased while the neural response was monitored by cuff “C” and the DAQ system.

The second experiment involved the third cuff “B”, which was used to inhibit propagation of APs excited by cuff “A”. While cuff “A” stimulates the nerve above threshold level, a sinusoidal current (20 kHz) was fed into cuff “B”. This current was gradually increased in amplitude while the electrical signals picked up by cuff “C” were monitored.

The third experiment focused on evaluation of anodal blocking of nerves. Anodal blocking pulses are not purely inhibiting nerves but provide a so-called “blocking window” in which only small fibres are excited while large fibres are electrically blocked. This window is a function of charge. Outside the blocking window either only the large fibres are stimulated or large and small fibres. In this experiment, the intensity (charge) of the anodal blocking pulse was gradually increased and the neural response was monitored.

For all experiments we generated propagation velocity profiles that show the maximum amplitude of the rectified signal after time-shifting and summation of the 9 tripolar channels over the propagation speed and the related time delay $dt$. The delay domain is also converted to the velocity domain by calculating the velocity $v = p / dt$. The parameter $p$ represents the recording electrode pitch.

3. RESULTS
At a low stimulation charge of 0.13 µC, only fast fibres (A: 35 m/s) were activated. Increasing the charge to 1.01 µC led to an increased activity of fast fibres but also excited slower fibres (B: 14 m/s), which contributed with a lower amplitude to the velocity profile, shown in Figure 2.

A different nerve gave a similar profile when stimulated at super-threshold level, as shown in Figure 3 (dashed line). Applying a sinusoidal wave of 10 mA amplitude allowed the complete block of the propagation of the compound action potential (CAP). Furthermore, a smaller...
amplitude (4 mA) inhibited predominantly fast fibres (A: 35 m/s) while the slower fibres (B: 14 m/s) presented increased activity compared to the CAP.

Anodal blocking was carried out on a third nerve applying pulses of 550 µs width that had an exponential decay of a duration of 1 ms. The charge balancing phase was limited to 9 µA. The length of this phase depended on the amplitude of the first phase, which was gradually increased to 620 µA. Figure 4 shows that the stimulation amplitude of 140 µA was outside the blocking window, at 430 µA anodal blocking was achieved: The fast fibres (A: 23 m/s) are blocked and slow fibres (B: 11 m/s) are firing. Increasing the current to 620 µA led to inhibition of fast and slow fibres.

4. DISCUSSION AND CONCLUSIONS

All three experiments show that the method of velocity selective recording based on MEC is capable of providing information on the distribution of fibre activity. Not only the propagation velocity of the fibres was identified, but also the direction of CAP propagation: no increased activity can be found in the negative velocity range in Figures 2, 3, and 4. However, the method is limited in resolution (delay \(dt\) domain) by the sampling frequency. At 40 kHz, the smallest \(dt\) is 25 µs. This causes the profiles to be coarse for high velocities and provides a increasing definition with decreasing velocities.

The obtained velocity profiles match the report of fibre activities given by literature: Gradually increasing an electrical stimulus in intensity, leads to “inverse recruitment”, as shown in Figure 2. This stimulus selectively stimulated fast fibres first. AC blocking at low intensities blocks fast fibres but stimulates slower fibres [4]. Anodal blocking also stimulates fast fibres at low amplitudes, increasing the amplitude caused inhibition of fast fibres while slower fibres were excited [5].

References


Acknowledgements

This work was supported in part by the German Academic Exchange Service (DAAD) and by the Engineering and Physical Sciences Research Council (EPSRC) UK.