1995 IEEE-EMBC and CMBEC
Theme 5: Neuromuscular Systems/Biomechanics

TRIPOLAR NERVE CUFF RECORDING: STIMULUS ARTIFACT, EMG, AND THE RECORDED NERVE SIGNAL

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ABSTRACT

Properties of nerve cuff recording electrodes were analyzed. Tripolar cuff electrodes have to be described essentially different for (propagating) nerve signals inside the cuff, and electrical muscle activity and stimulus artifacts arising from sources outside the cuff. It was experimentally shown that the signals originating outside the cuff are differently and much stronger influenced by the addition of a balancing resistor to the outer cuff electrodes than the nerve signal.

INTRODUCTION

The use of tripolar electrode configurations for the rejection of the electromyogram (EMG) was an important step in the optimization of whole nerve recordings of the electroneurogram (ENG) [1]. But even with tripolar configurations high EMG signals and stimulus artifacts can contaminate the signal [2,3]. A further optimization of cuff electrodes may take advantage of the different modes of operation of the cuff for signals originating internally and externally to the cuff. In this paper we show that for nerve signals the cuff electrode can be regarded as a bandpass filter whereas signals from external origin are linearized inside the cuff. Balancing the cuff within certain limits with an external potentiometer does therefore strongly affect the external signal with only a slight change of the (internal) nerve signal.

THEORY

For internal signals the same (propagating) signal shows up at the different contacts in the cuff at different times. Consider a straight nerve fiber oriented in parallel with the x-axis and a number (N) electrodes at the x-positions x_j, j=1,...,N. Let f=f(t) be the nerve signal as observed by an electrode at x=0. Then, if this signal propagates with a constant velocity v in the positive x-direction, the signal at electrode j will be $f_j(t)=f(t-x_j/v)$. Let g=g(t) be a linear combination of the f_j such that $g(t)=\sum_{j=1}^{N} a_j f(t-x_j/v)$, where a_j, j=1,...,N, are the weights for each of the electrodes. In the frequency domain this reads as G(iω)=H(iω)F(iω), where F and G are Fourier transforms of f and g, and H is given by:

$$(1.)\qquad H(i\omega)=\sum_{j=1}^{N} a_j \exp(-i\omega x_j/v)$$

For an ideal tripolar cuff, with $x_1=0$, $x_2=-d$ and $x_3=+d$, and with weight factors $a_1=1$, $x_2=x_3=-½$ the modulus of (1.) is: $|H_{tripolar}|=1-\cos(\omega d/v)$. The tripolar cuff can thus be regarded as a signal velocity dependent bandpass filter (fig. 1). The weight factors are dependent on a.o., the electrode impedances and the way the electrodes are interconnected.

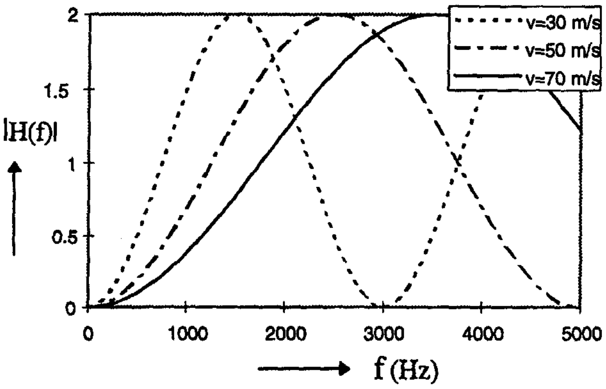

Figure 1 Transfer function |H(f)| for the tripolar configuration for different nerve signal velocities

If the maximum amplitude density is assumed to be at a frequency f_{max} then from (1.) the optimum electrode separation d_{opt} can be calculated. For the given tripole: $d_{opt}=v/2f_{max}$, (e.g., f_{max}=2000 Hz, v=50 m/s, then d_{opt}=10 mm).

External signals are seen by all contacts in the cuff at the same instant. Here the recorded signal is a linear combination of the voltage ΔV across the two cuff-ends (see fig. 2)

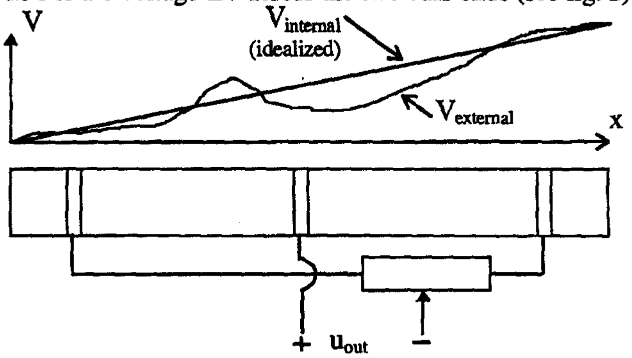

Figure 2 A field outside the cuff ($V_{external}$) and the resulting linear field inside the cuff ($V_{internal}$). A balancing potentiometer is added to the outer electrodes.

Ideally, if the cuff diameter is small compared with the length, the cuff linearizes the external field (note that be-

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cause of the electrode impedances -not drawn- the cuff is by no means short-circuited if the outer electrodes are connected). For a perfectly symmetrical tripolar configuration (including the electrode impedances) the signal of any external source will vanish. Any asymmetry, or capacitive coupling (also by the wires) will destroy this perfect attenuation. But part of the asymmetry may be reduced by adding a balancing potentiometer to the outer electrodes (see fig. 2). Since this adds noise with an rms value of $9.3\ \mathrm{nV}/\sqrt{\Omega}$ and this gives rise to a signal amplitude drop, values of the potentiometer should be below 1 kΩ.

METHODS

Initial experiments were performed in New Zealand White rabbits to verify the strong influence of the cuff's balance on external signals. A 2 mm inner diameter and 20 mm long split cuff type [4] electrode was implanted around the tibial nerve. The rabbits were anaesthetized with dormicum 2 mg/kg and hypnorm 0.3 ml/kg subcutaneously. During anaestesia supplementary doses hypnorm were administered. Cuff material was silastic and three platinum foil band electrodes of 2 mm wide were used with an electrode separation of 10 mm. Data were taken at day 5 after the implantation and the experiments were part of a more extensive protocol. The amplitude of the reflex EMG, due to mechanical stimulation (indentation) of the foot sole, and the amplitude of the stimulus artifact due to electrical stimulation with a bipolar electrode in the ankle were measured with the tripolar cuff electrode.

RESULTS

In fig. 3 the absolute value of the amplitude of the stimulus artifact is drawn as a function of the potentiometer position. the potentiometer had a resistance of 100 Ω.

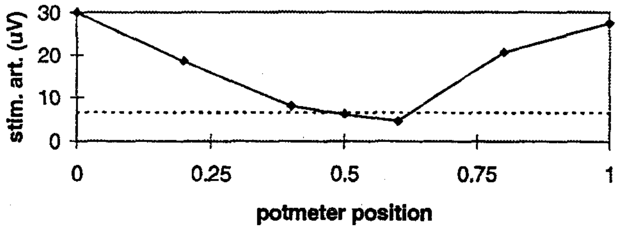

Figure 3 Stimulus artifact vs. potmeter position. 0: entirely left, 1: entirely right, 0.5: in the middle. Potmeter 100 Ω. Dashed line: value of stimulus artifact without potmeter.

With the potentiometer it was possible to obtain a slight decrease of the artifact (29 %). With the potmeter in the extreme positions the amplitude went up by approximately a factor 5. The signal amplitude, however, did not change more than 3 % over the full range. The resistance between the left outer electrode and the central electrode was 1.37 kΩ and between the right and central electrode it was 1.43 kΩ, measured at 1 kHz. The dashed line gives the amplitude of the stimulus artifact with the outer electrodes interconnected. Figure 4 illustrates the influence of cuff balancing on the recorded EMG. An unbalanced cuff clearly gives rise to a much higher EMG contamination of the signal.

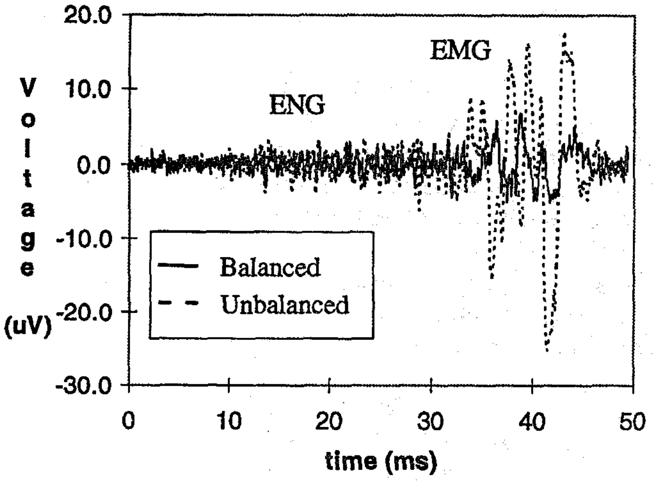

Figure 4 Reflex-EMG contaminating the nerve signal during mechanical stimulation.

CONCLUSIONS

It is possible to influence the recording of signals external to a tripolar cuff by balancing the outer electrodes, while this changes the recorded nerve signal only slightly. Although we have shown a relatively small improvement of the rejection of external signals in the initial experiments the results encourge further investigation on the use of this method.

For the neural signal the cuff electrode can be regarded as a signal-velocity dependent filter. For different signal propagation velocities the optimum electrode separations can be derived from equation (1.) for given electrode configurations. It may also be possible to use equation (1.) to design new electrode configurations for selective recording of signals from nerve fibers within a given diameter (and thus propagation velocity) range.

Acknowledgement: We thank Ole Sørensen and Torben Madsen for their technical assistance in the experiments.

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