FIBRE SELECTIVE NEURAL STIMULATION USING INTRAFASCICULAR ELECTRODES

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ABSTRACT

Using a nerve stimulation model, areas of excitation can be calculated for different configurations of intrafascicular electrodes. Theory predicts fibre selectivity and recruitment order to depend on the electrode configuration used. This is verified by experiment. These experiments though also reveal two new phenomena indicating that the effect of a stimulus is influenced by preceding stimuli for timeperiods up to several seconds.

INTRODUCTION

Nerve stimulation is a rehabilitation technique which in practical situation is accomplished using extraneural devices. At the University of Twente we're developing a implantable intrafascicular stimulus device that provides a higher degree of fibre selectivity. For a proper dimensional design we need a model to predict the properties of different electrode configurations on the stimulation proces. These properties can be tested by experiment.

THEORY

In first order the electrical equivalent of a myelinated nerve fibre is a lumped network (fig.1). The intracellular fluid between two nodes of Ranvier can be represented as a resistor Ri, the membrane at a node as a resistance Rm and a parallel capacitor Cm [1]. A short rectangular stimuluspuls of time τ induces a change of the membrane potential at node 0:

$$\Delta V_{m,0} \approx \frac{\tau}{R_i \cdot C_m} \cdot (V_{-1} + V_1 - 2.V_0) \qquad \tau < R_i.C_m$$

Vi is the extracellular potential at node i during stimulation.
The fibre is excitated when the membrane potential is raised by a value of about 20 mV. Having a constant value for $\tau/(Ri.Cm)$ and fibres along the z–direction with internode–distance λ, a node at position (x,y,z) is excitated when the activating function

$$f(x,y,z) = V(x,y,z-\lambda) + V(x,y,z+\lambda) - 2V.(x,y,z)$$

exceeds a certain treshold value. If V(x,y,z) during stimulation is known we can calculate the areas of excitation.

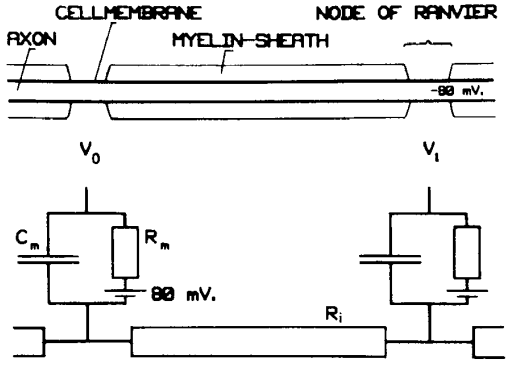

fig. 1
Schematic view of a nerve fibre and its electrical equivalent.

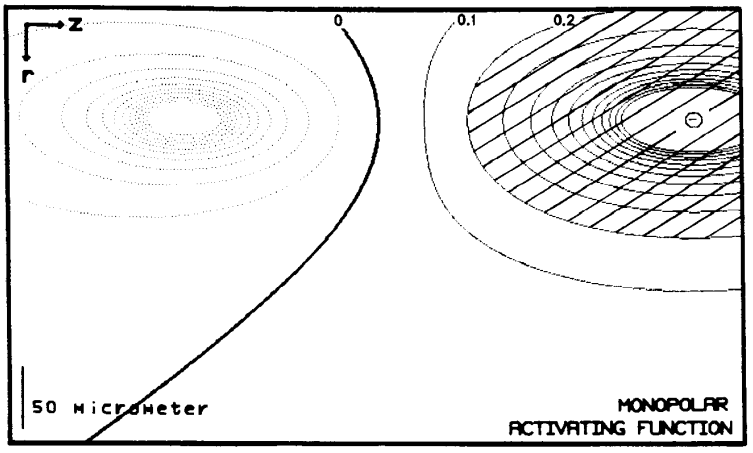

fig. 2 The activating function of a monopole.

$\sigma_x = \sigma_y = 0.1\ \Omega^{-1}.m^{-1}$
$\sigma_z = 0.5\ \Omega^{-1}.m^{-1}$
$I = -50\ \mu A.$

The hatched area is region of excitation for a treshold value of 0.2 V.

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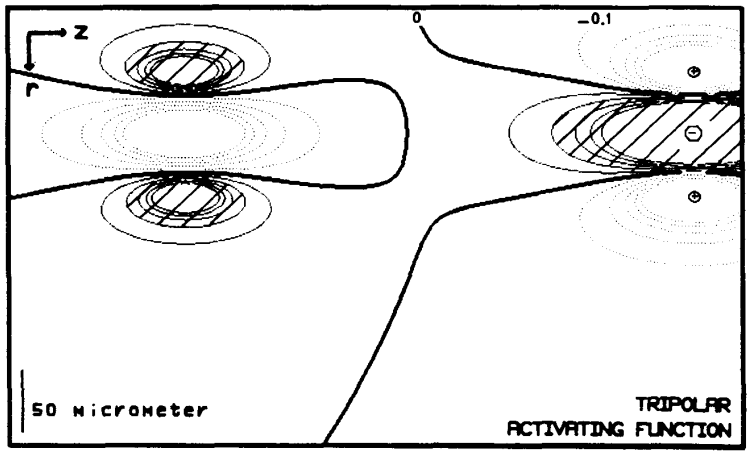


fig. 3 The activating function of a tripole.

$\sigma_x = \sigma_y = 0.1\ \Omega^{-1}.m^{-1}$
$\sigma_z = 0.5\ \Omega^{-1}.m^{-1}$
$I_{cathode} = -50\ \mu A.$
$I_{anode} = 25\ \mu A.$

The hatched area is region of excitation for a treshold value of 0.2 V.

Fig.2 shows the activating function for a cathode in an infinite homogeneous medium. Two areas can be distinguished. One around the cathode where the activating function is positive and the membrane is depolarised and one at node distance from the electrode where the activating function is negative and the celmembrane is hyperpolarised. The hatched area is area of excitation for a treshold–value in the activating function of 0.2 V. This area broadens in all directions for a stronger stimulus. Overlap between excitation areas of two adjacent cathodes will therefore increase when stimulus current is increased.

Flanking a cathode by two anodes will result in a narrowing of the excitation area (fig.3). This area gets the shape of a disc. Increasing the current will hardly broaden the stimulation region in the direction of the electrode–array. Using this technique we're able to create long narrow areas of excitation which do not overlap and therefore show maximum selectivity.

Also one node away from the anodes regions of excitation are seen. However their volume is much smaller then that of the area around the cathode. f(x,y,z) not only depends on V(x,y,z) but also on λ. Monopolar stimulation highly favours excitation of fibres having large λ: This is the well known phenomenon of inverse recruitment. For tripolar stimulation though recruitment order is more natural. Using low stimulus currents excitation of smaller fibres is favoured.

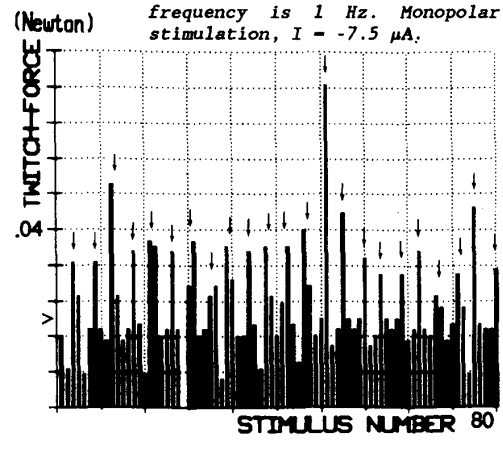
EXPERIMENTS

Experiments were performed in the hindleg of the rat. The Peroneus Communis nerve was stimulated using a silicon device containing an array of twelve electrodes. Twitch forces of the EDL muscle were measured isometrically [2].

Stimuli at two different electrodes C1 and C2 result in twitch forces F1 and F2. Taking a short time between these two stimuli (5 ms.) only one twitch is seen having force $F1,2 = F1 + F2$ [2]. When interstimulus time is shortened below 2 ms., fibres in the overlapping region only will be stimulated once, due to their refractory properties. F1,2 will decrease. This decrement is a measure for overlap and therefore also indirectly for selectivity. For monopolar cathodal stimulation an electrode separation of 200 μm. was needed for small currents to ensure no overlap. For tripolar stimulation experiments are still in progress.

According to our ideas of nerve stimulation F1,2 always should be larger or equal to F1 and to F2. Preliminary

fig. 4 Twitch force measured sometimes shows a clear rhythmic response. Each bar represents one twitch, its height being the force measured. Stimulus frequency is 1 Hz. Monopolar stimulation, I = -7.5 μA.



results for tripolar stimulation though show that F1,2 can be noticeably smaller. Experiments indicate that this phenomenon is not a result of RC overlap (loading of the membrane capacity).

Stimulation of the nerve with small stimuli at low frequency (1 Hz.) often causes the twitch force of the muscle to vary between two or more levels. When a nerve fibre is at treshold it will only fire occasionally. Therefore a discrete value to the twitchforce is added randomly. For tripolar stimulation these values are found to be generally smaller then for monopolar stimulation. Units of 0.05 grams are seen. Since small motorunits are associated with thin nerve fibres (having small λ) this indicates a different recruitment order.

Not always twitch force varies randomly. During some experiments the force shows a rhythmic variation (fig. 4). The rhythm is not influenced by stimulus shape (monophasic, biphasic), but the relative frequency decreases with decreasing stimulusfrequency (0.7 Hz. at 2 Hz. stimulus frequency, 0.025 Hz. at 0.2 Hz. stimulus frequency).

[1] McNeal D, IEEE Trans. on BME 23: 329–337 (1976)

[2] Rutten WLC, Proc. 10th An. Conf. of the IEEE Eng. in Med. and Bio. Soc.: 1688–1689 (1988)