MODELLING AND TESTING OF MULTIPOLAR INTRANEURAL STIMULATION

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ABSTRACT

A nerve stimulation model has been developed to predict the stimulation characteristics of intrafascicular electrode configurations.
Two configurations were experimentally tested. The experiments verified the predicted change in recruitment order but also revealed that stimuli can influence the response of succeeding stimuli for time periods up to several seconds.
Single fibre signals could be measured by subtraction of the C(ompound) A(ction) P(otential)s corresponding to two different (discrete) force levels of the activated muscle.

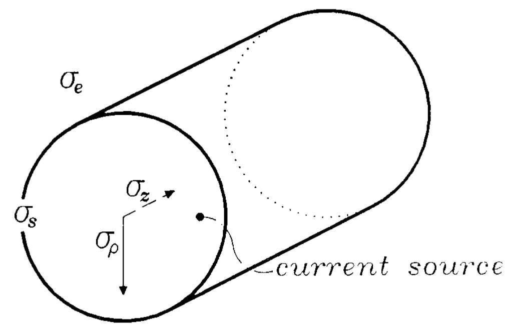

fig. 1 The cylindrical model of the fibre bundle and its surroundings.

INTRODUCTION

Conventional nerve stimulation techniques used in F(unctional) E(lectrical) S(timulation) put major restrictions on a proper control of the muscle forces. It is believed that the low fatigue resistance and insufficient open-loop control at low muscle forces, associated with convential electrodes, can be circumvented using intraneural stimulus electrodes that in principle provide a higher degree of spatial selectivity. This stimulation by intraneural electrode configurations has been modeled and the predicted stimulation properties were tested by experiment.

THEORY

The nerve stimulation model consists of two parts.
The first part is the calculation of the potential field inside the nerve's fascicle due to the intrafascicular electrodes. The fascicle is idealised as an electrical homogeneous and infinitely extending cylinder having an radial conductivity σ_ρ and a longitudinal conductivity σ_z (fig. 1). The cylinder is surrounded by a layer that represents the thin perineurium. It has a sheeth-conductivity σ_s. The environment of the fascicle is represented by a homogeneous, infinite and isotropic medium with conductivity σ_e. Stimulation electrodes are idealised as current point sources and can be positioned anywhere in the fascicle.

Using the cylinder symmetry an analytical expression for the potential field was found, written as an expansion of Bessel functions.
The second part is the calculation of the response of the nerve fibres to the potential field. For subthreshold conditions the fibre can be represented by a lumped electrical network [1]. An analytical solution of the network response to an imposed time-varying external field allows the calculation of the regions where the nodes of Ranvier are stimulated above threshold.

MODEL APPLICATIONS

Several multipolar electrode configurations have been analysed and were compared with monopolar cathodal stimulation. Special interest was given to stimulation by a linear tripole, positioned inside the fascicle, transverse to the fibre direction. The tripole consists of a cathode, flanked by two anodes each supporting half the cathodal current (fig. 2). Qualities of this configuration are an improved spatial selectivity, a more orderly recruitment and a decreased dependence on the conductivities of the fascicle's surrounding media (σ_s and σ_e). Moreover, an appropriate stimulus device for an one-dimensional electrode configuration can be made more easily as for a two- or three-dimensional configuration.

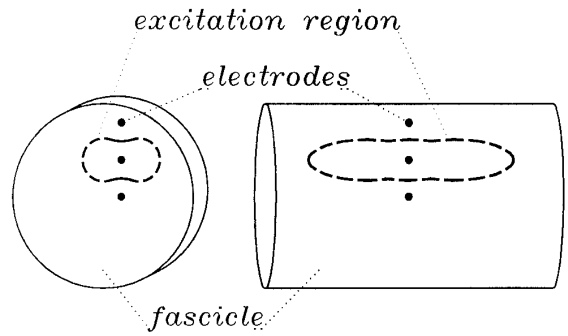

fig. 2 Using a linear tripole that consist of a cathode, flanked by two cathodes each supporting half the cathodal current, results in a long and flattened excitation region around the cathode.

EXPERIMENTS

In the hindleg of rat the exposed peroneal nerve was stimulated using a silicon stimulation device, containing an array of twelve electrodes (50 μm interelectrode distance). Twitch forces of the E.D.L. were measured isometrically [2].
Analysis of the recruitment data supported the prediction that for a tripole stimulation is more localised and that the recruitment is more orderly as it is for a monopole.
To test the spatial selectivity the overlap between the groups of motor fibres stimulated by two different electrode configurations was measured using the refractory properties of the fibres and the values of the twitchforces elicited by single stimuli [2]. These experiments revealed that stimuli can inhibit the excitation of fibres by succeeding stimuli over periods of several seconds. This phenomenon is probably due to the strong electrical fields that are locally induced and prevented a proper measurement of the overlap . Strong electrical fields can bring about a temporarily breakdown of the transmembrane ionic gradient. Therefore reduction of the field strength can become an important parameter in the design of a proper electrode configuration.
Sequencies of stimuli of constant amplitude can result in twitches with a non constant force value. Some experiments showed a clear rhythmic variation that is presumably related to activity-dependent after-effects on the threshold.
Discrete levels in twitch force could be seen as a result of the activation of a discrete number of motorunits. When the ENG was measured (using two stainless steel hook electrodes, 3 mm. apart, placed distally to the stimulus device) and when force varied between two levels, for each level an corresponding CAP could be recorded. Subtracting these signals sometimes revealed the single fibre signal corresponding to the motorunit that caused the force variation. The fact that this signal was not always seen indicated that not all the active fibres were reflected in the CAP. Principally therefore, recording of the ENG signals is unsuited as a "monitor" of the stimulation proces.

PRESENT RESEARCH

Present research is aiming at the development of a three dimensional "nail-bed" stimulation device as well as techniques to bring this device inside the nerve's fascicle. Apart from stimulation such a device also enables the spatial selective recording of action potentials, thereby hopefully providing an appropriate "monitor" of the activation of single nerve fibres.

[1] J.H. Meier, W.L.C. Rutten and J.H.M. Put, "Fibre selective neural stimulation using intrafascicular electrodes", Proc. 11th An. Conf. of the IEEE Eng. in Med. and Bio. Soc., pp. 988-989, 1989
[2] W.L.C. Rutten, J.H. van Wier and J.H.M. Put, "Sensitivity and selectivity of intraneural stimulation using a silicon electrode array", accepted IEEE Trans. on Biomed. Eng.