Analysis of Dorsal Column Stimulation

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ABSTRACT

Computation of field potentials and activating functions in an infinite, homogeneous medium was taken as a first approach to investigate the effect of several electrode combinations on nerve fibers with different orientations in the spinal cord. Secondly, the cervical spinal cord and its surrounding tissues were modeled as an inhomogeneous, anisotropic volume conductor. It was concluded that cathodal stimulation, medio–dorsally in the epidural space, can recruit longitudinal fibers, but may block dorso–ventral ones With anodal stimulation the opposite will occur. Parameters that mostly affect the potential distribution in the dorsal columns, are the width of the subarachnoid space and inhomogeneities in the epidural space near the electrodes.

INTRODUCTION

Spinal Cord Stimulation (SCS) has been applied in the treatment of various neurological diseases for more than two decades. Yet little progress has been made on the improvement of this method. This is mainly due to the fact that little is known about the underlying neurophysiological mechanisms and about the way SCS affects different nerve pathways in the spinal cord.

To assess the influence of electrode configurations on the membrane potential of nerve fibers with different orientations in the dorsal column, we calculated field potentials in a spinal cord volume conductor model. In a more basic approach we calculated field potentials and activating functions in a homogeneous medium. The activating function [1,2] is proportional to the initial change of fiber membrane potential and is defined as the second order difference of the imposed field along the fiber.

HOMOGENEOUS MODEL

In the homogeneous model, electrodes were represented by equidistant point sources located at the L–axis of a cartesian coordinate system at intervals z (Fig.1). Field potentials were calculated analytically and activating functions were determined in longitudinal (S_l), radial (S_r) and tangential (S_t) directions for several electrode combinations. It was shown that at cathodal stimulation, S_l and S_t had identical positive peaks while S_r had a negative peak twice this value. Therefore longitudinal and tangential fibers will be depolarized, while fibers in radial direction will be hyperpolarized at cathodal stimulation. At anodal stimulation opposite effects were obtained.

INHOMOGENEOUS MODEL

Longitudinally the model was composed of 40 layers consisting of identically wedge shaped volume elements, each of which was given an (an)isotropic specific conductivity. The model (fig 3a) comprises white matter

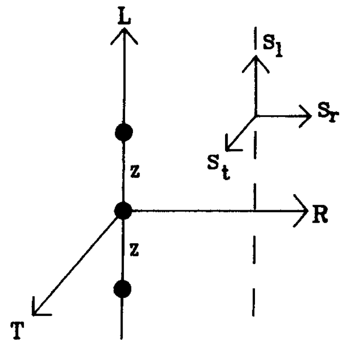

Figure 1

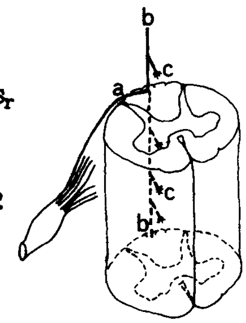

Figure 2

(wm) (conductivity: 0.006/Ωcm transversally and 0.00083/Ωcm longitudinally), grey matter (gm) (0.0023), epidural fat (0.0004) and cerebrospinal fluid (0.017). Conductivities were taken from literature [3] except for csf, which we measured from three subjects. Dura mater and arachnoid were not modeled [4]. Vertebral bone, muscle, fat and other tissues in the neck were represented by a single layer with low conductivity. The width of the subarachnoid space varies largely with the set of the head. The saggital diameter of the cord was taken 7.5 mm.

Field potentials were computed using the variational principle [5] with dirichlet boundary conditions (fixed potentials at the electrodes and zero potential at the surface of the model). From the field potentials activating functions were computed in three orthogonal directions.

RESULTS

Monopolar and bipolar electrodes were located medio–dorsally in the epidural space (fig.3a). Electrode length was 3 mm and separation 6 mm. It was shown that field potentials in the dorsal columns were mainly affected by changing the width of the csf–layer (an increase from 0.7 to 1.4 mm. decreased the potentials by 30%) and by inhomogeneities of the epidural space near the electrodes. At monopolar stimulation field potentials in the dorsal columns were about twice as high as with bipolar stimulation. Therefore sensitivity to conductivity changes of dorsal column potentials was also higher at monopolar stimulation.

Figure 3b shows isopotential lines in the mid–saggital section of the spinal cord at bipolar stimulation. In fig.3c isolines of the longitudinal activating functions are shown (lines close to the electrodes were not plotted). Positive

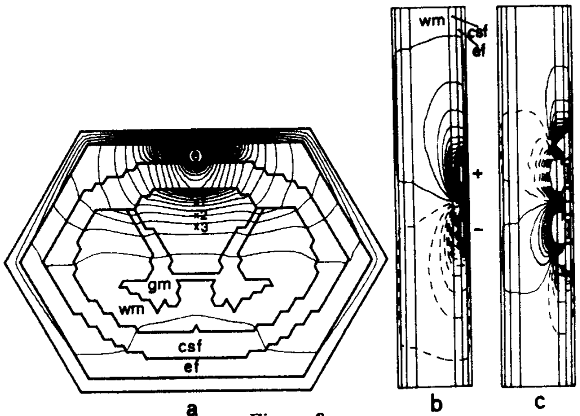

Figure 3

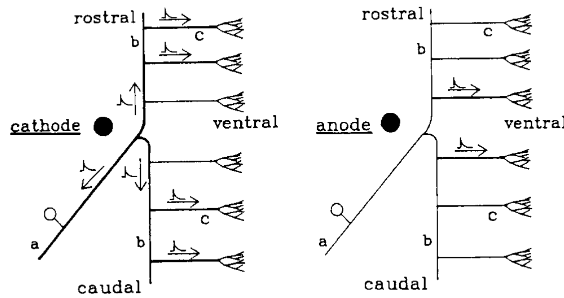

Figure 5

values are represented by solid lines, negative values by dashed lines.

In figure 4 plots of the bipolar radial (4a) and longitudinal (4b) activating functions are shown. The digits 1, 2 and 3 in the plots correspond with those in figure 3a, where the positions of the longitudinal lines are indicated (x) at 0.7, 1.4 and 2.1 mm from the dorsal column boundary. The values of the radial activating functions are about 8 times higher than the longitudinal ones, while in the homogeneous model this was only a factor two. This difference is mainly due to the anisotropy of the dorsal columns

CONCLUSIONS

The models predict that cathodal stimulation recruits ascending and descending fibers in the dorsal columns as well as dorsal root fibers in which antidromic propagation will occur. Dorso–ventral (radial) collaterals can be blocked. The models also predict that anodal stimulation can be used for selective recruitment of collateral fibers (figures 2 and 5).

Because of the sensitivity of dorsal column potentials (and activating functions) to changes in the width of the csf–layer and the large variations of this width at cervical levels at different head positions, recruitment of fibers in the dorsal columns will vary a great deal and therefore cervical spinal cord stimulation will not be very stable.

Due to the relatively high sensitivity for variations in conductivity of the epidural space, potential distribution can be disturbed by inhomogeneities near the electrodes.

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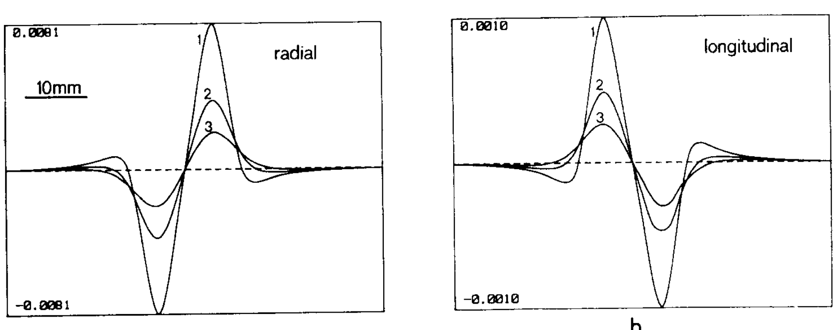

Figure 4