THE INFLUENCE OF THE POSITION OF THE ACTIVE FIBER RELATIVE TO THE MUSCLE BOUNDARY IN COMPUTING SINGLE FIBER ACTION POTENTIALS.

B.K. van Veen, W.L.C. Rutten, W. Wallinga

Biomedical Engineering Division
Department of Electrical Engineering
University of Twente, P.O. Box 217, 7500 AE Enschede, the Netherlands

Abstract.

Single fiber action potentials (SFAP's) were calculated using a volume conduction model which takes into account the microscopic muscle tissue and the microscopic electrical parameters. SFAP's were calculated numerically. The position of the active fiber with respect to the muscle boundary was varied, and SFAP's were calculated at several distances from the active fiber. It appeared, that the presence of the muscle boundary had a considerable effect on the amplitude of the calculated SFAP.

Introduction.

In model studies, volume conduction is often simulated using a macroscopic approach (e.g. Nandedkar & Stålberg, 1983). The model of Albers et al. (1986 and 1988) enables a microscopic, frequency dependent study of SFAP's. However, muscle dimensions were taken to be infinitely big and the active fiber had to be positioned in the center of the model. In general, the amplitude of the recorded SFAP was higher than the calculated one (Albers et al., 1989). In this paper, the model is adapted so that boundary effects of the muscle can be taken into account. Furthermore, the position of the active fiber can be varied through the model. We expect to obtain higher amplitudes of SFAP's through these adaptations, because it is well known that the amplitudes of action potentials may increase due to the presence of a boundary (e.g. Lichtenberg & De Luca, 1979).

Fig. 1: Structure of the microscopic part of the model. In this figure, also the transformation into an electrical network representation is shown. The (extracellular) nodes of the active fiber are indicated with arrows.

Methods.

The active fiber and 8 layers of fibers around it were modelled microscopically, using the model of Albers et al. (1986) (See also fig. 1). Boundary conditions were applied to the boundary of the microscopic part of the model. These boundary conditions followed directly from the potential distribution calculated analytically in an infinite long, but radially bounded cylindrical muscle model (e.g. Plonsey, 1974). So the potential distribution in the fibers surrounding the active fiber could be computed with respect to the microscopic structure and with respect to the presence of the muscle boundary. The active fiber could be positioned at every site within the model (fig. 2).

The 8 layers surrounding the active fiber were modelled using the (microscopic) parameters:

intracellular conductivity:	$\sigma_i = 0.45 (\Omega\text{m})^{-1}$
extracellular conductivity:	$\sigma_e = 2.5 (\Omega\text{m})^{-1}$
membrane capacitance:	$C_m = 0.01 \text{ Fm}^{-1}$
membrane conductance:	$G_m = 1.0 \Omega^{-1}\text{m}^{-2}$
fiber radius:	$A = 25.0 \cdot 10^{-6} \text{ m}$
thickness of extracellular space:	$d = 1.35 \cdot 10^{-6} \text{ m}$
intracellular volume fraction:	$p = 0.9$

For the rest of the model an anisotropic, homogeneous conductivity was assumed, which follows directly from the above parameters (Gielen et al., 1986). In our case, the longitudinal conductivity $\sigma_z = 0.655 (\Omega\text{m})^{-1}$ and the radial conductivity $\sigma_r = 0.131 (\Omega\text{m})^{-1}$. The radius of the total muscle model was taken $1.5 \cdot 10^{-3} \text{ m}$, which was in agreement with the experimental situation (rat m. extensor digitorum longus).

SFAP's were computed according to the method of Albers et al., 1988. A conduction velocity of 5.0 m/s was assumed. SFAP's were calculated at several distances from the active fiber, but only within the microscopic part of the model.

Fig. 2: Total model. In this case, the active fiber is positioned at a depth of 0.5 mm. beneath the muscle surface.

Results and discussion.

We modelled two situations:

- The active fiber 1 mm. from the center of the model (and so 0.5 mm. beneath its surface).
- The active fiber at the center of the model.

SFAP's were calculated at several radial distances from the active fiber and both close to the surface of the model as well as far away from it. In fig. 3, the active fiber is positioned 1 mm. from the center of the model. The decline of the SFAP amplitude V_{tt} is plotted against the distance between the active fiber and the recording site of the SFAP. It appeared, that due to the presence of the muscle boundary the amplitude of the SFAP increases considerably, especially close to the boundary. With the active fiber positioned at the center of the model, hardly any effects caused by the muscle boundary were seen. In experimental situations, the active fiber is often positioned at a depth between 500 and 1000 μm beneath the muscle surface. Therefore, the adaptations made to the model are valuable for the simulations of SFAP's.

Fig. 3: Simulation results. The decline of the SFAP amplitude as a function of the recording distance, with the active fiber positioned 0.5 mm beneath the muscle surface.

References.

- Albers, B.A., Rutten, W.L.C., Wallinga-de Jonge, W. and Boom, H.B.K. (1986) A model study on the influence of structure and membrane capacitance on volume conduction in skeletal muscle. *IEEE Trans., BME-33*, 681-689
- Albers, B.A., Rutten, W.L.C., Wallinga-de Jonge, W. and Boom, H.B.K. (1988) Microscopic and macroscopic volume conduction in skeletal muscle tissue, applied to the simulation of single fiber action potentials. *Med. & Biol. Eng. & Comput.*, 26, 605-610
- Albers, B.A., Put, J.H.M., Wallinga, W. and Wirtz, P. (1989) Quantitative analysis of single muscle fibre action potentials recorded at known distances. *Electroencephalography and clinical Neurophysiology*, 73, 245-253
- Gielen, F.L.H., Cruts, H.E.P., Albers, B.A., Boon, K.L., Wallinga-de Jonge, W. and Boom, H.B.K. (1986) Model of electrical conductivity of skeletal muscle based on tissue structure. *Med. & Biol. Eng. & Comput.*, 24, 34-40
- Lichtenberg, B.K., and De Luca, C.J. (1979) Distinguishability of functionally distinct evoked neuroelectric signals on the surface of a nerve. *IEEE Trans., BME-26*, 228-237
- Nandedkar, S.D. and Stålberg, E. (1983) Simulation of single muscle fiber action potentials. *Med. & Biol. Eng. & Comput.*, 21, 158-165
- Plonsey, R. (1974) The active fiber in a volume conductor. *IEEE Trans., BME-21*, 371-381