Neuroprothetik

1) Vorstellung Neuroprothesen
2) Einführung in die Biologie
3) Das Membranpotential
4) Spannungsgesteuerte Ionenkanäle
5) Die Hodgkin-Huxley-Gleichungen
6) Elektrische Stimulation von Neuronen
7) **Elektrische Stimulation entlang des Axons**

Lernziele:

- Stimulation im externen elektrischen Feld

Neuroprothetik

Wiederholung: Numerische Verfahren

1) Stabilität numerischer Verfahren (A-Stabilität)

2) Genauigkeit der Lösung

3) Plausibilität der Lösung

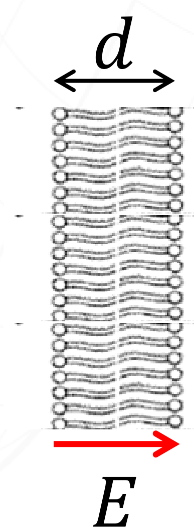
$$\frac{dm}{dt} = \frac{1}{\tau}(m_\infty - m)$$

4) Numerische Realisation
(fixed-point Arithmetik, Zahlenüberlauf, Rundung)

Membrane in electric field

Consider a cell membrane high resistivity with a membrane potential V_m. The membrane potential is proportional to E across the membrane and the thickness d of the membrane.

$$V_m = -Ed$$



$d \approx 7.5 \ldots 10$ nm

Hine, Robert. "Membrane." The Facts on File Dictionary of Biology. 3rd ed. New York: Checkmark, 1999: 198.

Fig. 5: Electric field E across cell membrane with thickness d.

Cylindrical axon in electric field

Consider a simplified axon with a membrane having a very high resistivity and a plasma with high conductivity in a highly conductive extracellular medium. If the axon is running perpendicular to a homogeneous external electric field, *E*, one side of the membrane will become depolarized and the other hyperpolarized with membrane potential:

$$V_m = -Er\cos\theta$$

where *r* is the axon's radius and θ is the angle with the field axis as shown in Fig. 6 below.

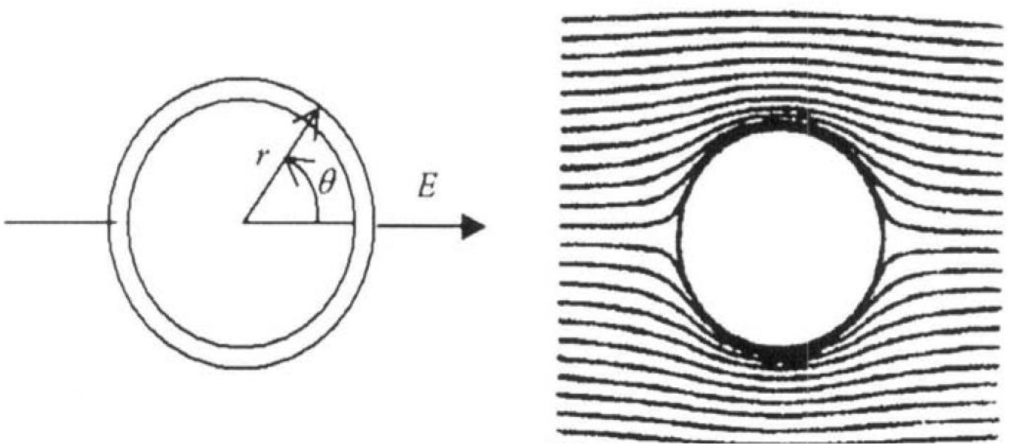
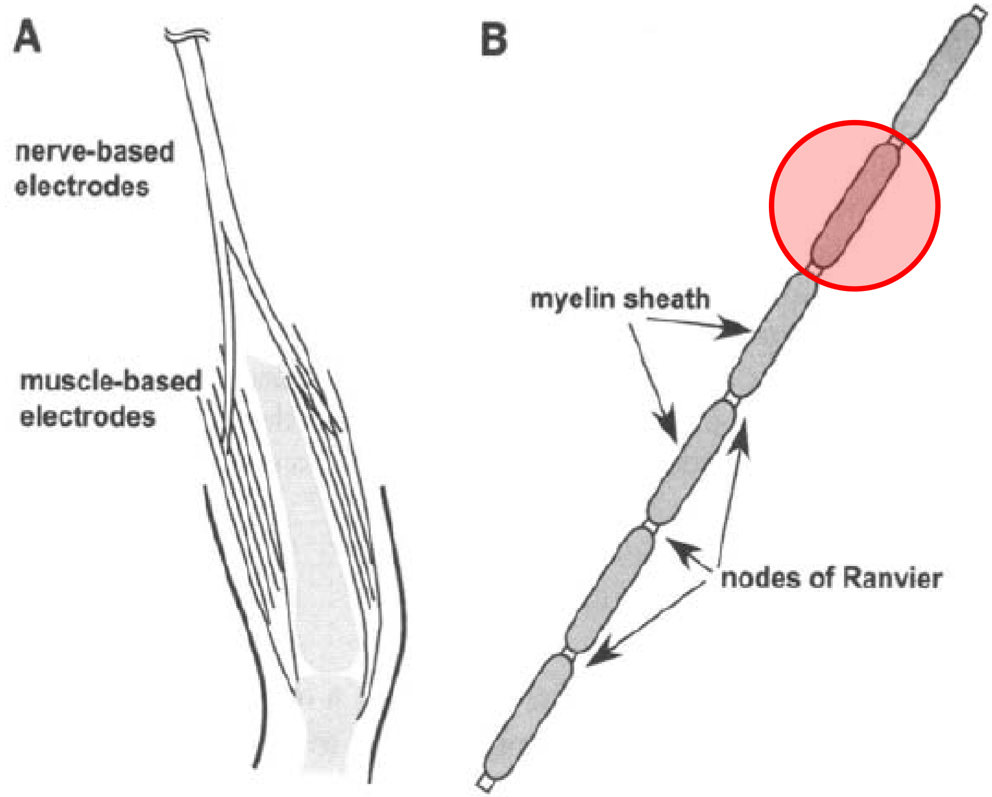


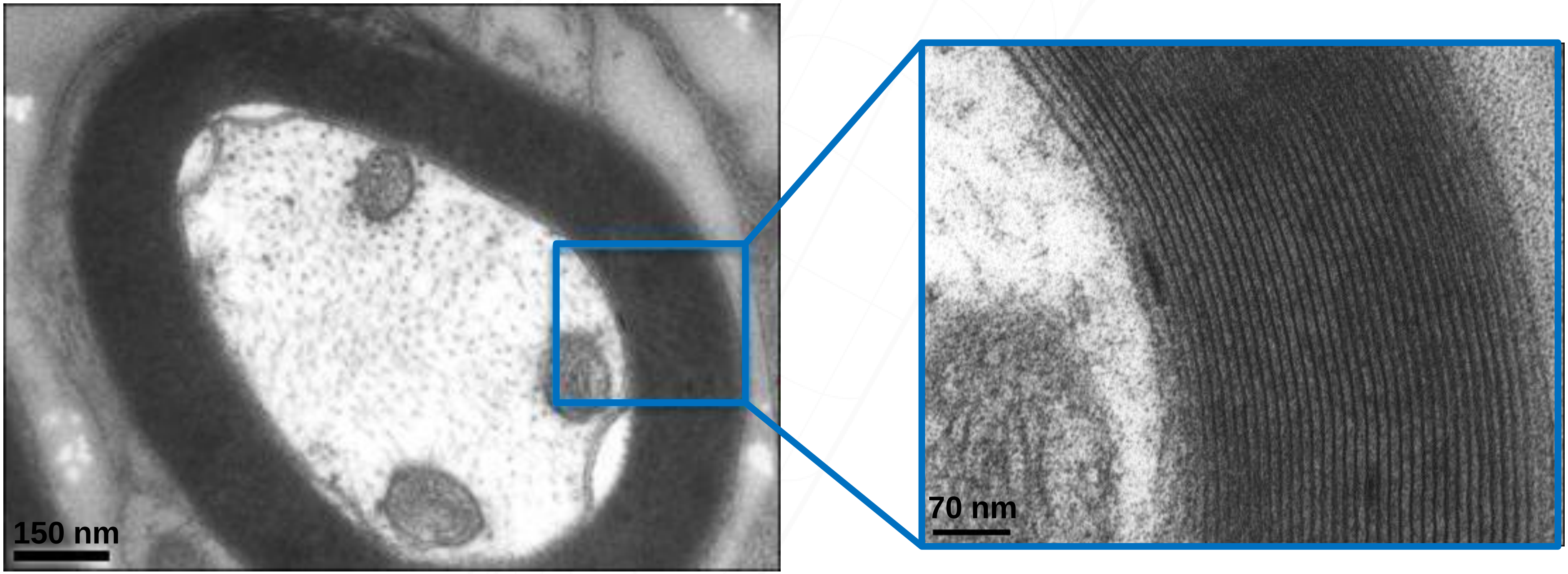
Fig. 6: left: cylindrical axon lying perpendicular to an electric field *E* and definition of angle θ. Right: current flow around axon with very high membrane resistivity.

Electrical stimulation of peripheral nerve fibers



(A) Electrodes for stimulation of peripheral nerve fibers may be placed in or on the skeletal muscle (muscle-based electrodes) or in, on, or around the peripheral nerve trunk (nerve-based electrodes). Note that muscle-based electrodes do not activate the muscle directly, but stimulate the terminal nerve fibers that, in tum, activate the muscle. (B) The basic structure of a myelinated nerve fiber consists of a tube of membrane, surrounded over most of its area by the myelin sheath. The myelin sheath is interrupted at regular intervals by exposed sections of membrane called nodes of Ranvier.

Electrical stimulation of peripheral nerve fibers

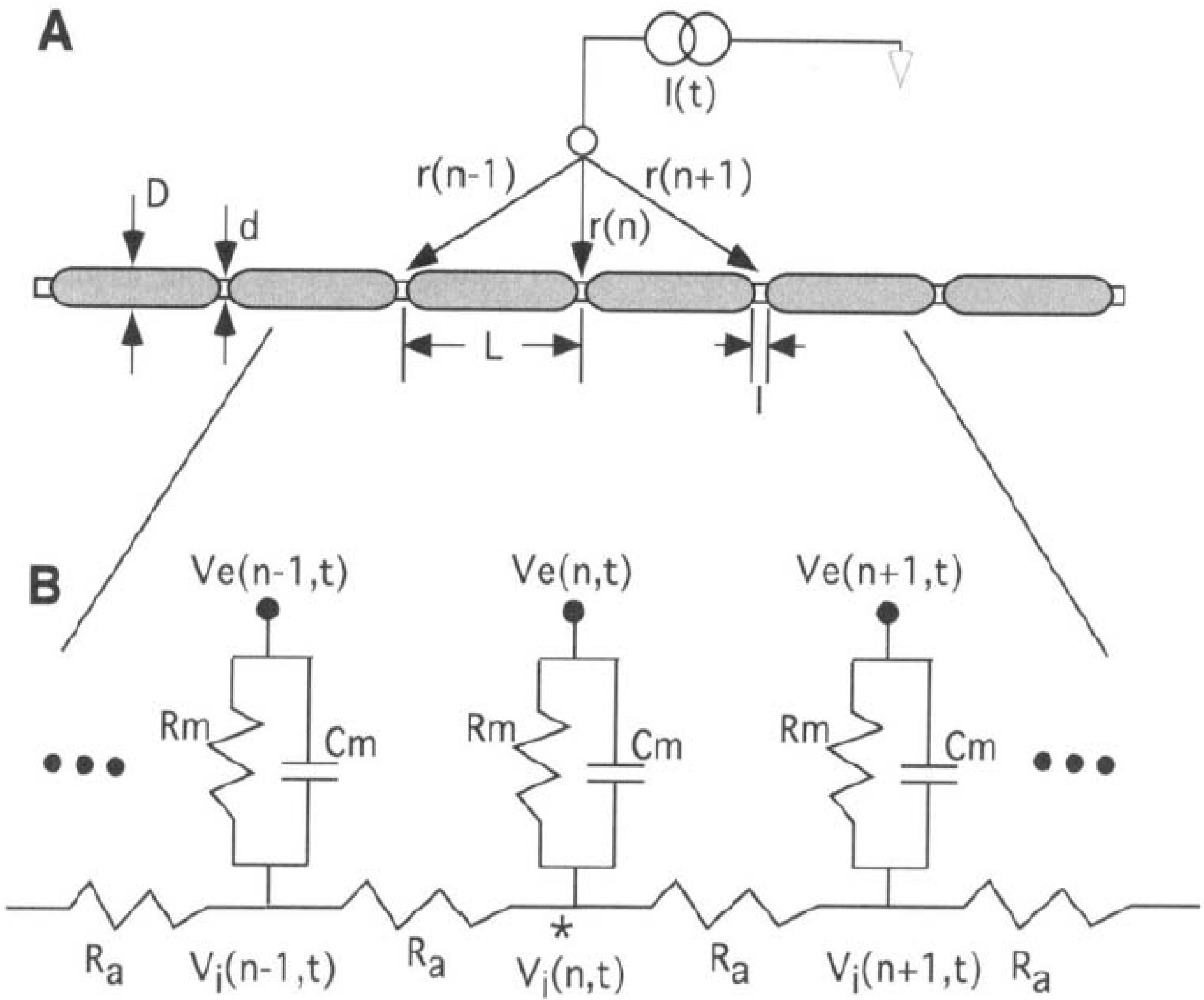


Left: Cross-section of a myelinated osseous spiral lamina fibre (peripheral axon from a type I neuron). Within the axon, 3 mitochondria and numerous microtubules are seen (scale bar: 150 nm).

Right: The myelin sheath is formed of 35 layers (scale bar: 70 nm)

Rémy Pujol, http://www.cochlea.eu/en/cochlea

Models of the Axon



Cable model of a myelinated nerve fiber. (A) Schematic representation of a myelinated nerve fiber in the presence of an extracellular stimulating electrode. (B) Electrical circuit equivalent of a section of a myelinated nerve fiber. In this simplified representation all membrane conductances are lumped into Rm.

Models of the Axon

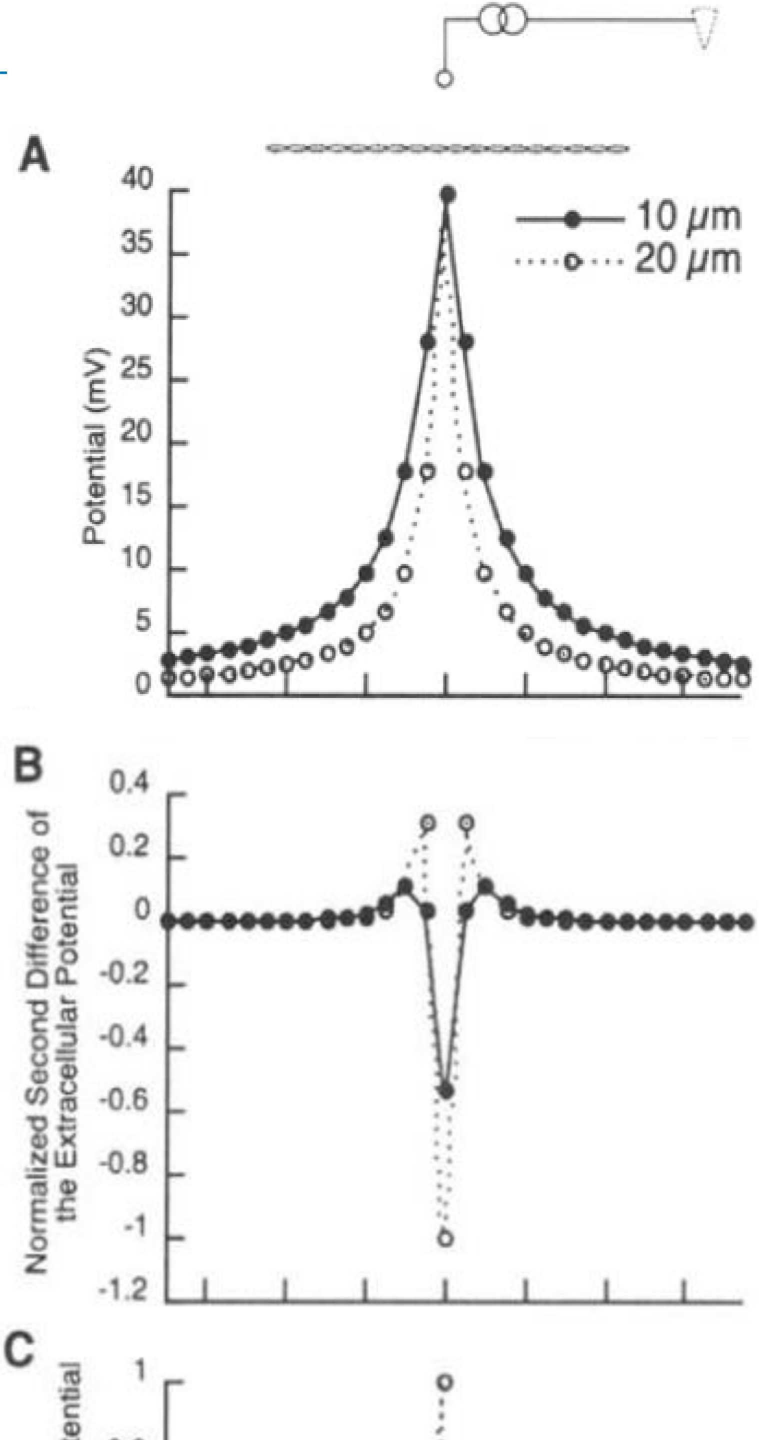
$$\frac{[V_i(n-1,t)-V_i(n,t)]}{R_a}+\frac{[V_i(n+1,t)-V_i(n,t)]}{R_a}+\frac{[Ve(n,t)-V_i(n,t)]}{R_m}+Cm\frac{d[Ve(n,t)-V_i(n,t)]}{dt}=0 \tag{17}$$

We then apply definition of reduced transmembrane voltage Vm(n,t)=Vi-Ve:

$$\frac{[V_m(n-1,t)-2V_m(n,t)+V_m(n+1,t)]}{R_a}+\frac{[V_e(n-1,t)-2V_e(n,t)+V_e(n+1,t)]}{R_a}-\frac{V_m(n,t)}{R_m}-Cm\frac{d[V_m(n,t)]}{dt}=0 \tag{18}$$

$$Cm\frac{d[V_m(n,t)]}{dt}+\frac{V_m(n,t)}{R_m}-\frac{[V_m(n-1,t)-2V_m(n,t)+V_m(n+1,t)]}{R_a}=\frac{[V_e(n-1,t)-2V_e(n,t)+V_e(n+1,t)]}{R_a} \tag{19}$$

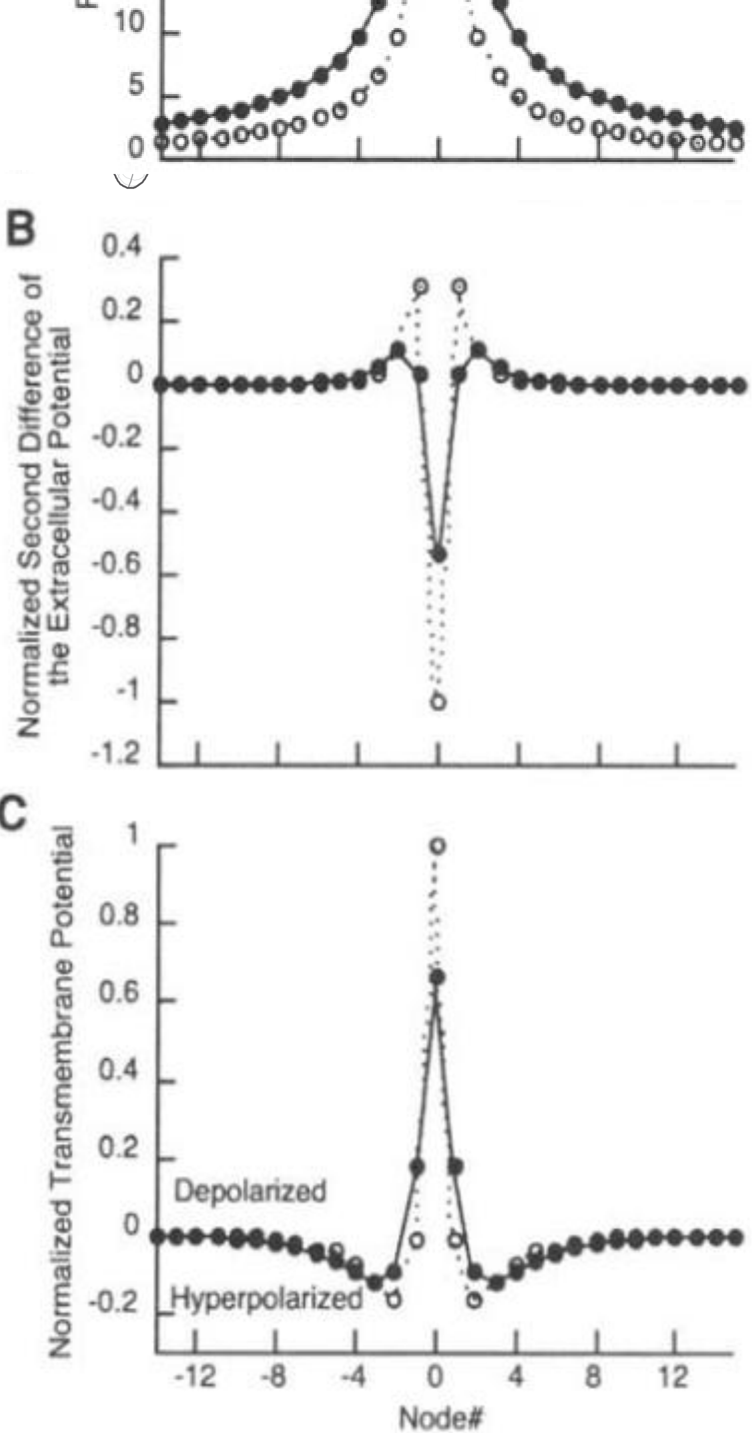
!!! Bitte im Script S 330-335 korrigieren (Gleichung 18,19, 24) !!!



The response of myelinated nerve fibers to extracellular stimulation.

(A) Extracellular potentials at each node of Ranvier in 10 µm and 20 µm diameter nerve fibers from a point source electrode positioned 1mm above the central node of the fibers. The extracellular potential was calculated using V(r)=Iρ/4πr, where I is the stimulating current (0.1 mA), p is the resistivity of the extracellular medium (500 Ω cm), and r is the electrode to node distance.

(B) Magnitude of the source term driving membrane polarization, i.e., the right hand side of Eq. 19, for the 10 um and 20 µm fibers as a function of the node number. The magnitudes of the second difference of the extracellular potentials were normalized to the peak value for the 20 µm fiber to illustrate that the source term is smaller in the smaller diameter nerve fiber. (C) Profile of transmembrane potential generated in the 10 µm and 20 µm nerve fibers. Again, the transmembrane potentials were normalized to the peak value in the 20 µm fiber to illustrate the difference between the two diameters.



The response of myelinated nerve fibers to extracellular stimulation.

(A) Extracellular potentials at each node of Ranvier in 10 µm and 20 µm diameter nerve fibers from a point source electrode positioned 1mm above the central node of the fibers. The extracellular potential was calculated using $V(r)=I\rho/4\pi r$, where I is the stimulating current (0.1 mA), p is the resistivity of the extracellular medium (500 Ω cm), and r is the electrode to node distance.

(B) Magnitude of the source term driving membrane polarization, i.e., the right hand side of Eq. 19, for the 10 um and 20 µm fibers as a function of the node number. The magnitudes of the second difference of the extracellular potentials were normalized to the peak value for the 20 µm fiber to illustrate that the source term is smaller in the smaller diameter nerve fiber. (C) Profile of transmembrane potential generated in the 10 µm and 20 µm nerve fibers. Again, the transmembrane potentials were normalized to the peak value in the 20 µm fiber to illustrate the difference between the two diameters.

Conduction velocity: **CV=6 m/s/µm**

The velocity at which action potentials travel along myelinated nerve fibers is proportional to the fiber diameter. This relationship arises from the correlation between fiber diameter and internodal spacing (L=100D). Since larger diameter fibers have larger internodal spacing, the action potential travels further as it moves from node to node (salutatory conduction) in large diameter fibers than it does in small diameter fibers.

Neuroprothetik

1) Vorstellung Neuroprothesen
2) Einführung in die Biologie
3) Das Membranpotential
4) Spannungsgesteuerte Ionenkanäle
5) Die Hodgkin-Huxley-Gleichungen
6) Elektrische Stimulation von Neuronen
7) **Elektrische Stimulation entlang des Axons**

Lernziele:

- **Stimulation im externen elektrischen Feld**