THE INFLUENCE OF ELECTRODE CONFIGURATIONS OF MINIATURIZED IMPLANTABLE STIMULATORS OVER THE GENERATED FIELD AND CURRENT DISTRIBUTIONS AND THEIR POSSIBLE EFFECT ON OPTIMUM FUNCTIONAL STIMULATION[x])

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Summary:
Implantable stimulators as investigated in this work, in a simplified manner consist of a self-contained, hermetically sealed generator and a pair of electrodes of different or equal size and geometry (fig.1), By varying a and 0, the investigations show, that the distance á and the length â of the stimulator configuration are the controlling factors of efficient stimulation. Further it is shown that for stretching the stimulation region in fibre direction, a has to be increased, herewith altering the effective electrode surface area â according to an associated function of á

Introduction

Transcutaneously operable miniaturized electrical stimulators for functional muscle stimulation (fig. 1) are to be implanted into well-defined regions of preselected sceleton muscles. The self-contained stimulator including its electrodes is, for anatomical reasons, preferentially arranged in parallel to the bulk of the muscle fibres to be stimulated. Maximum stimulation is achieved for the parallel current density vector. Therefore in analyzing the effectiveness with respect to muscle stimulation,the distribution of the parallel-(z)

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components of current density is especially considered and plotted (fig. 3). For estimating possible corrosive deteriorations of the electrodes, current density at the outer electrode surfaces was evaluated additionally (fig. 2).

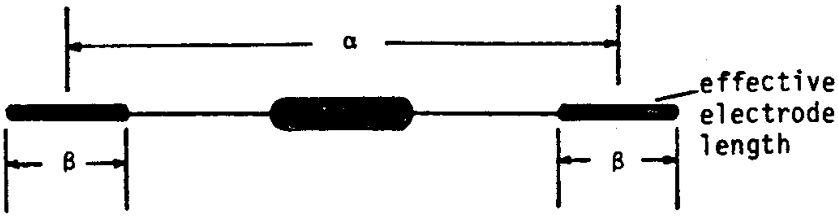

Fig. 1: Principle form of the generator

<u>Rotational symmetric fields of implantable stimulators</u>

The mathematical procedures for calculating the electrical field strength and potential in biological mediums are the following:
The first equation we used for homogeneous mediums is:

equ. 1 $$\Delta\phi = 0$$

For the boundaries one obtains:

equ. 2 $$\operatorname{div} \vec{S} = \operatorname{div} \kappa\vec{E} = - \operatorname{div} (\kappa(\operatorname{grad} \phi)) = 0$$

and hence noting that

$$T_M = 2 (\kappa_2 - \kappa_1)/(\kappa_2 + \kappa_1)$$

we obtain:

equ. 3 $$\Delta\phi + ((\operatorname{grad}\kappa)/\kappa \operatorname{grad} \phi = \Delta\phi + T_M \vec{n} \operatorname{grad} \phi = 0$$

- κ : Conductivity
- $\vec{E}$: Vector of the electrical field strength at the boundaries
- $\vec{n}$: Normalvector of the boundary surface
- ϕ : Electrical-Potential

At all points of the field which are free of charge we obtain the potential by using Laplace's equation (equ. 1). Equation 3 allows the calculation of the potential at the boundary of two mediums, where usually charges are distributed over the surface.
For solving equ. 3 and under consideration of $\vec{E} = -\,\mathrm{grad}\,\phi$ we obtain:

equ. 4 $$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + T_M\left(\frac{\partial \phi}{\partial x} n_x + \frac{\partial \phi}{\partial y} n_y\right) = 0$$

Assuming that the surrounding muscle tissue is approximately homogeneous the stimulator is generating an electrical field of rotational symmetry. The three-dimensional field distribution can then be calculated in zylindrical coordinates:

equ. 5 $$\frac{\partial^2 \phi}{\partial r^2} + \frac{\partial^2 \phi}{\partial z^2} + \left(\frac{1}{r} + T_M n_z\right) \frac{\partial \phi}{\partial r} + T_M n_z \frac{\partial \phi}{\partial z} = 0$$

Equat. 5 numerically solved, allows the calculation of potential fields of arbitrary stimulator configurations, produced by arbitrary potential distributions on the electrodes under consideration of quasistatic conditions. We determined the absolute value and the direction of the field strength and with $\vec{S} = \kappa\vec{E}$ the current density-vectors.

Further we calculated the total current I_t of the stimulator and the current density distribution on the electrodes surfaces with:

equ. 6 $$I = \int \vec{S}\, d\vec{A}$$

Thus we obtain the following equation by integration over the cross section in the middle of the generator housing:

equ. 7 $$I = 2\pi\kappa \int_0^{ro} E_z\,(r,z)\,r\,dr$$

Numerically, we solved the problem as follows:

equ. 8 $$I_t = 2\pi\kappa \sum_{i=o}^{i=n} r_i\, E_{zi}$$

The conductivity of the muscle tissue is $\kappa = 2\ 10^{-3}\ (\mathrm{Ohm\ cm})^{-1}$.

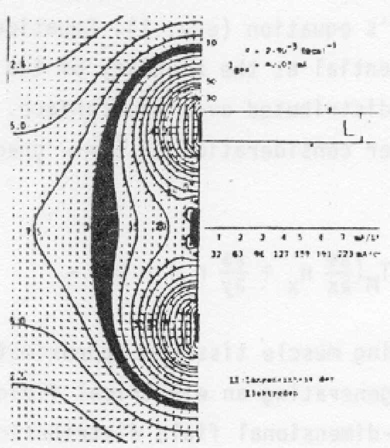

Fig. 2: Distribution of the electrical field strength (left) and current density distribution on the electrode surface of an implantable stimulator (right).

Results:

We find, that in the interesting area, the total current I_t is for β = constant nearly independent of the distance α

$$\frac{\Delta I_t}{\Delta \alpha} = 0{,}08\ \%/\mathrm{cm} \qquad (\Delta I_t\ \text{:Variation of}\ I_t),$$

while a doubling of α results in a doubling of the total current I_t.

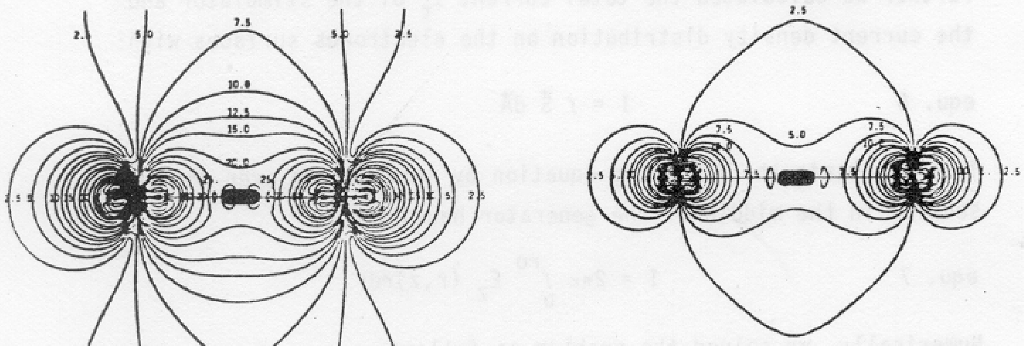

Fig. 3: Distribution of the electrical field strength of 2 generator configurations under consideration of only the z-component of the vector. The solid lines indicate regions of constant field strength (Volt/cm).

By varying the distance α and the effective electrode length β, it could be shown that β is the controlling factor for efficient stimulation. In that way highest possible uniformity of stimulation current density in direction of the muscle fibres (z-direction) is approached.

The electrode length β depends on some parameters as follows:

equu. 9 $$\beta = f(\alpha, S_{ts}, Z_0, D_0, U_0, \kappa)$$

S_{ts} : Threshold current density of stimulation

Z_0, D_0 : Extention of the stimulation region

U_0 : Potential of the electrodes

First assumptions were introduced for simplification of the problem:

$$U_0 = \text{constant}$$
$$\kappa = \text{constant}$$

Furthermore the stimulation region was assumed to be cylindrical (D_0, Z_0) and homogeneous.

Because there will be always a nonstimulated area (fig.3) close to the middle of the stimulating electrodes, it is efficient to determine this cross-sections for the lid planes of the stimulation region respectively of the defined cylindrical form. So we obtain for $\alpha > 0{,}2\beta$:

$$Z_0 = \alpha$$

With these assumptions, we get an optimum relationship between Z_0 and D_0, independent of the actual extension of the generator and on the threshold stimulation current density as shown in fig. 4 $D_0/Z_0 = 2/3$:

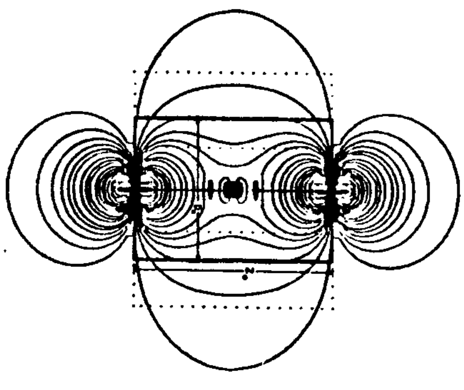

Fig.4: Optimum relationship between Z_0 and D_0: $D_0/Z_0 = 2/3$.

Finally we obtain a simplified form of equation 9, shown in fig. 5.

equ. 10 $$\beta = f\ (\alpha, S_{ts})$$

Hence we can determine β in relation to the threshold stimulation field strength, or with $\vec{S} = \alpha\ \vec{E}$, in relation to the threshold stimulation current density S_{ts}.
This empirically determined graphical function can also be used for other defined stimulation regions. The deviation of the electrical field intensity distribution is indicated in fig. 4.

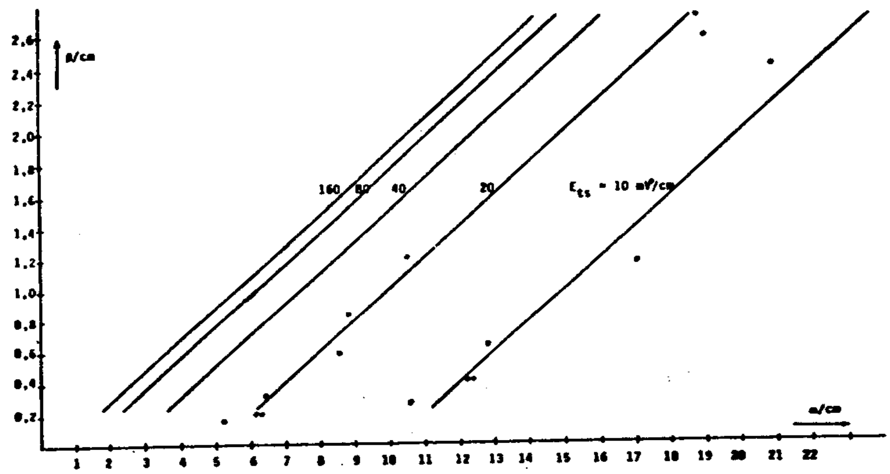

Fig. 5: Relation between the effective electrode length β and the length of the stimulation region α.

<u>Literature:</u>

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