Improvement of Stimulation Effects by using Electrical Field Analysis in Biological Inhomogeneous Mediums

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Important for electrical stimulation is the charge-density ($\mu C/cm^2$), which means the charge transport normal across the area unit. Between the electrical charge density and the field intensity and the current density, a mathematical relation is existing. By calculation of the field intensity $\vec{E}$, we get the current density by multiplying $\vec{E}$ by the conductivity κ. So it is possible to analyse the effectiveness of electrical stimulation. Furthermore, corrosion of implantable electrodes as well as their influence on the tissue can by observed by field analysis.

In this paper we are presenting a procedure which allows the calculation of the potential and field intensity distribution in the human body under consideration of the conductivity and the dielectric constant of different body tissues. We have neglected the influence of the magnetic induction on the field intensity (quasistationary field) (3).

The field calculation in the biological medium will be done for the first, as if the inhomogeneities were homogeneous in their interior area. So we can calculate the potential in this area by Laplace equation.

The analysis of an electrical field is often faciliated by use of an auxiliary function known as potential. Under neglection of the time varying effects in the field at every point of space the stationary vectors satisfy the system:

(1) $\quad \mathrm{rot}\ \vec{E} = 0$ $\qquad$ (3) $\quad \mathrm{div}\ \vec{B} = 0$

(2) $\quad \mathrm{rot}\ \vec{H} = J$ $\qquad$ (4) $\quad \mathrm{div}\ \vec{J} = 0$

If first the medium was considered as homogeneous and isotropic, with κ and μ independent of field intensity we obtain:

(5) $\vec{E} = -\mathrm{grad}\ \phi$

(6) $\vec{J} = \kappa\vec{E}$

With: $\vec{E}$: Electric field intensity
$\vec{H}$: Magnetic field intensity
$\vec{B}$: Magnetic flux
$\vec{J}$: Current density
ϕ : Electric potential (arbitrary scalar function of position)
κ : Conductivity

Under consideration of the boundary conditions between two mediums of different conductivity, we then introduced free charges to the boundary surface, which can be determined from the material constants κ and with known surface normals in every field point of the boundary we calculated the potential under consideration of equ.5 and 6.

(7) $\mathrm{div}(\kappa \mathrm{grad}\ \phi) = 0$

By multiplying equ. 7 with κ/κ we obtain:

(8) $\mathrm{div\ grad}\ \phi + T_m\ \mathrm{grad}\ \phi = 0$

With $T_m = \mathrm{grad}\kappa/\kappa$

After quantisation of gradκ

(9) $T_m = 2\ \vec{n}\ (\kappa_1 - \kappa_2)/(\kappa_2 - \kappa_1)$

we obtain:

$$\Delta\phi + T_m\ \vec{n}\ \mathrm{grad} \quad = 0$$

Equ. 10 allows the calculation of the potential at the boundary of two mediums where usually charges are distributed over the surface.

In our study, subcutaneous fat, muscle tissue, muscle facies, bones, blood vessels, and tendines were introduced as inhomogeneities. As source of the electrical field, we used two and four stimulation electrodes with potentials of ± 10 volts.

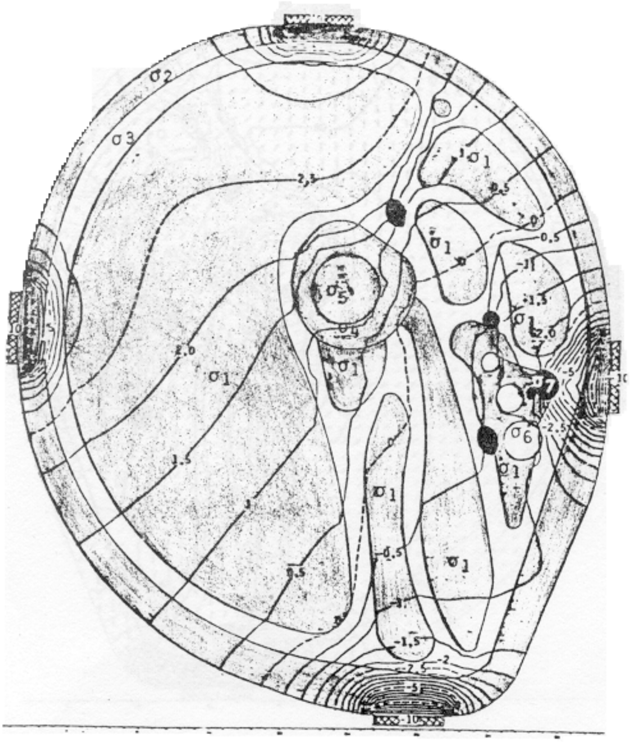

Figure 1:

Field potential distribution in an arm cross section. The solid lines indicate regions of equipotential. The dimension of the parameters is volt. The potentials of the electrodes are indicated in the figure. In the arm cross section we introduced muscle (σ_1), subcutaneous fat (σ_2), muscle fascies (σ_3), bones (σ_4), fat (σ_5), blood vessels (σ_6), and tendines (σ_7).

In this paper, we calculated fields in an arm cross section (x,y) with an infinity extension in z-direction. The exterior border of the cross section and the boundary of the interior inhomogeneities were determined by computertomographic pictures (2). We have put different stimulation electrode configurations on the surface of the arm cross section.

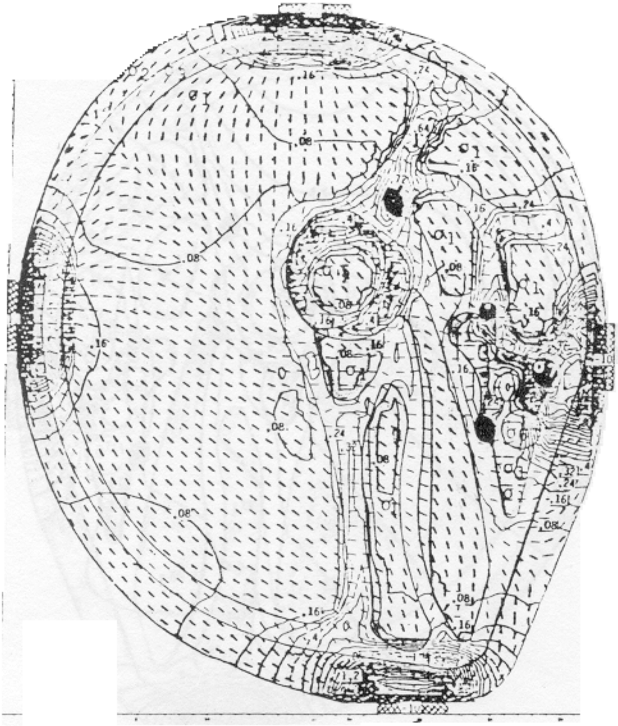

Figure 2

Field intensity distribution in an arm cross section, vectorially represented by modulus and direction. The solid lines indicate regions of constant field strength while the arrows show the direction. The dimensions of the parameters are volt/length unit. The potentials of the electrodes are indicated in the picture.
In the arm cross section we introduced muscle (σ_1), subcutaneous fat (σ_2), muscle fascies (σ_3), bones (σ_4), fat (σ_5), blood vessels (σ_6), and tendines (σ_7).

The results of the representation are potential fields and field intensity distributions in a predetermined cross section area; the latter is vectorially represented by modulus and direction parameters (fig. 1, fig. 2).
In order to facilitate the analysis of stimulation influences, we have connected the points of equal field intensity by means of a line. In every field point, the direction of the field intensity was indicated by a small arrow.

It can be shown, that the knowledge of the stimulation current density distribution by modulus and direction enables a more effective electrical stimulation.
The field analysis makes it possible to optimize the stimulation effect in a predetermined therapy area by changing the electrode position and its potential.

Literatur:

(1) Meyer-Waarden K., Hansjürgens H.J., Friedmann B.
Darstellung elektrischer Felder in inhomogenen biologischen
Medien. Biomedizinische Technik, Bd. 25, 1980

(2) Gambarelli J. et.al.
Ganzkörper-Computer-Tomographie.
Springer-Verlag, 1976

(3) Plonsey R.
Bioelectric Phenomena.
McGraw-Hill Company, New York, 1969

(4) Simonyi K.
Theoretische Elektrotechnik.
Deutscher Verlag der Wissenschaften, 1969