On the Influence of Cancellous Bone Structure Upon the Electric Field Distribution of Electrostimulative Implants

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Abstract

At the University of Rostock, a new electrostimulative total hip revision system is being developed [1]. This system utilizes the accelerating effect of electromagnetic fields on bone regeneration as it has been characterized by Bassett et al. in 1974 [2]. Though this effect is already utilized in several medical applications to enhance bone regeneration after fractures or bone diseases, there is only a partial understanding of the underlying biological effects.

In previous works the macroscopic field distribution around the implant has been investigated in a layered bone model. All the biological tissues (cancellous bone, cortical bone, blood etc.) have been defined as homogenous material with homogenous electrical properties. Nevertheless, especially cancellous bone is not a homogenous tissue. It is a complex material consisting of inorganic material (hydroxylapatite), organic material (collagen) and fluids forming a trabecular structure. Thus the electric field varies accordingly within this structure. This is investigated in the present work.

The basic idea is to correlate the density of the different materials with the electrical properties. Therefore, the density data of a cylindrical bone sample (radius: 6 mm, height: 13 mm) has been determined with a Micro-CT (voxel size of 26 μm). The processed gray scale values of this Micro-CT-scan are imported into COMSOL Multiphysics® and used as a position-dependent parameter within a cylindrical domain to define the conductivity mathematically. The electrical properties of collagen and hydroxylapatite are taken from literature and are each assigned to a certain gray scale value. For the correlation of all the other gray scale values different mathematical approaches are tested. For example, figure 1 shows the conductivity distribution of the exponential approach. In addition, a linear and a sigmoidal approach have been simulated.

To resolve the 83 million voxels of the Micro-CT-scan different mesh types have been tested with a convergence analysis. The electric field within the sample is impressed by defining the upper and lower boundary with 0.455 V and -0.455 V, respectively. Using these voltages, a homogenous material would be stimulated with 70 V/m. Since this is the upper limit for the stimulation system, we are interested in the location of overstimulation within the inhomogeneous tissue. Figure 2 shows the electric field of the example of figure 1 and it can be seen, that there

is overstimulation especially in the areas of the non-conducting hydroxylapatite.

Reference

1. Carsten Potratz et al., Multiobjective Optimization of an Electrostimulative Acetabular Revision System, IEEE Transactions on Biomedical Engineering, Vol. 57, No. 2, pp. 460-468 (2010)
2. C. Andrew Bassett et al., Acceleration of fracture repair by electromagnetic fields. A surgically noninvasive method, Annals of the New York Academy of Sciences, Vol. 238, pp. 242 -262 (1974)

Figures used in the abstract
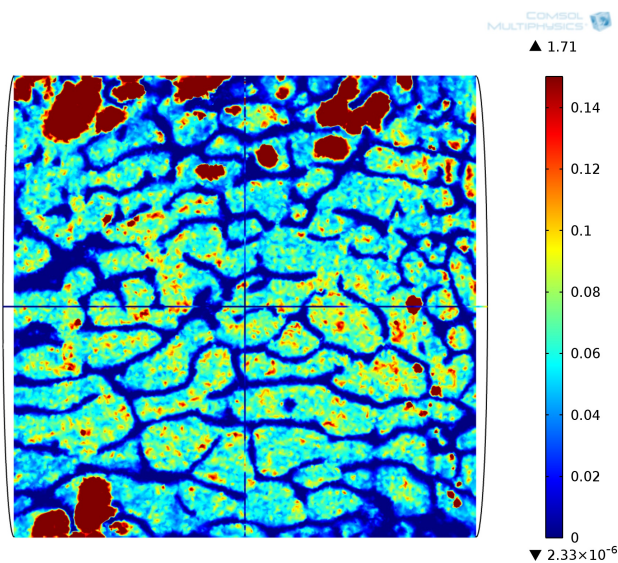
Figure 1: Conductivity in S/m using an exponential approach for the correlation of gray scale value and electric conductivity within the bone sample.
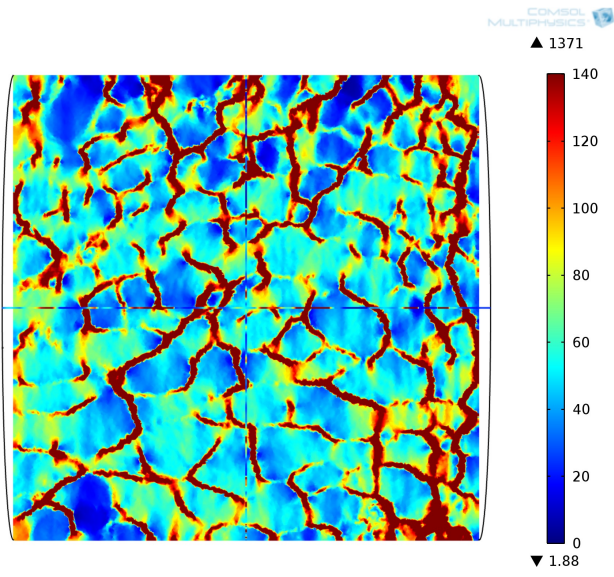
Figure 2: Electric field in V/m within the stimulated bone sample