Designing coils to minimize the maximal induced electrical field amplitude in a patient

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INTRODUCTION Peripheral nerve stimulation (PNS) due to the electrical field $\vec{E}$ induced in the patient body limits the increase of the drive field amplitude and thus the imaging field of view (FOV) and speed [1-4]. In order to maximize the drive field amplitude, the minimization of the normalized maximal induced electrical field amplitude (nMIEFA) [5] is done during the design of x-, y- and z-drive coils.

MATERIAL AND METHODS The coil design can be formulated as a problem minimizing the dissipated power P_{QCQP} and constraining the field quality [6], typically called quadratically constrained quadratic program (QCQP). To minimize the nMIEFA, a Second-Order Conic Program (SOCP) problem is introduced and formulated as

$$\min_{\vec{s}} \max_{k}(\|\overrightarrow{E_k}(\vec{s})\|)$$
$$\text{subject to: } P_{SOCP} \leq n\, P_{QCQP}$$

with $\vec{s}$ the surface current density, $k = 1, \dots, K$ with K the number of considered surface elements forming the patient model, P_{SOCP} the dissipated power for the solution and n an integer equal to 2, 4, 6 or 8. Additionally, the same constraint on the field quality is applied as the one used for the QCQP problem. All problems are solved using the YALMIP toolbox [7] and the MOSEK (7.0, Mosek ApS, Denmark) solver.

The induced electrical field is evaluated according to [8].

A cylindrical surface with a diameter of 0.640 m and a length of 0.4 m is discretised in 400 triangles and is used as support for the coil.

The surfaces of two patients are modelled either from photos or via the segmentation of the body/air interface from a whole body MRI acquired with a voxel size of 0.8x0.8 mm², a slice thickness of 5 mm and a distance between slices of 5.5 mm. The mesh coming from the MRI acquisition is segmented using 3DSlicer [9]. Both meshes are then post-processed using Meshmixer (v10.7.84, Autodesk Inc, USA) to obtain fully connected meshes.

RESULTS The nMIEFA on 2 human models are calculated at 22 different positions for 3 magnetic field topologies und 5 different optimisation problems resulting in 660 optimisations. The results for the optimisation of y-drive coils in relation with the MRI-based model is presented in Fig. 1. Four surface current densities are shown in Fig. 2, which illustrates the variation of the coils.

CONCLUSION An nMIEFA reduction of up to 50 % for a given position can be expected for a coil optimised to minimize it. This result is patient and position dependent. The technical difficulties associated with such coils may outweigh the reduction of PNS and the increase of FOV.

ACKNOWLEDGEMENTS The authors gratefully acknowledge the financial support of the German Federal Ministry of Education and Research (BMBF, grant number 13N11090) and of the European Union and the State Schleswig-Holstein (Programme for the Future – Economy, grant number 122-10-004).

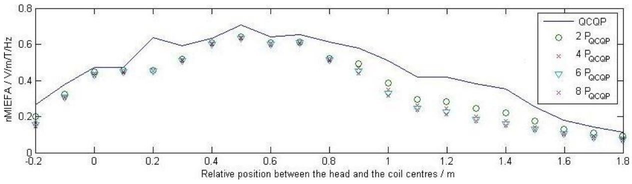

Figure 1: nMIEFA for 5 y-drive coil optimisations on the mesh based on an MRI acquisition of a human subject.

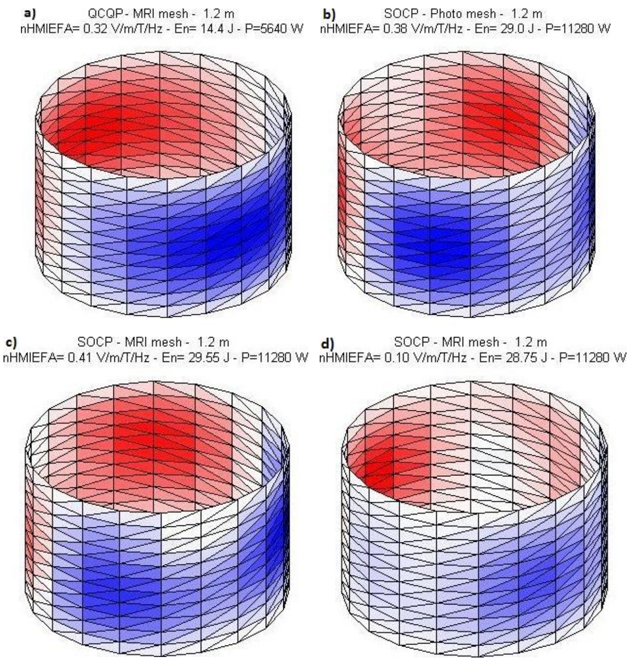

Figure 2: Surface current density for y-drive coils obtained from QCQP (a) and SOCP (b, c, d) problems at position 1.2 m (a, b, c) or 0.5 m (d) from photo (b) and MRI (a, c, d) based meshes.

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