Influence of anisotropic conductivity of the white matter tissue on EEG source reconstruction – a FEM simulation study

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Abstract—**The aim of this study was to quantify the influence of the inclusion of anisotropic conductivity on EEG source reconstruction. We applied high-resolution finite element modeling and performed forward and inverse simulation with over 4000 single dipoles placed around an anisotropic volume block (with an anisotropic ratio of 1:10) in a rabbit brain. We investigated three different orientation of the dipoles with respect to the anisotropy in the white matter block. We found a weak influence of the anisotropy in the forward simulation on the electric potential. The relative difference measure (RDM) between the potentials simulated with and without taking into account anisotropy was less than 0.009. The changes in magnitude (MAG) ranged from 0.944 to 1.036. Using the potentials of the forward simulation derived with the anisotropic model and performing source reconstruction by employing the isotropic model led to dipole shifts of up to 2 mm, however the mean shift over all dipoles and orientations of 0.05 mm was smaller than the grid size of the FEM model (0.6 mm). However, we found the source strength estimation to be more influenced by the anisotropy (up to 7-times magnified dipole strength).**

Keywords—**anisotropy, conductivity, FEM, animal model, simulation, EEG**

I. INTRODUCTION

In general the macroscopic neuronal activity is assumed to be represented by electrical current dipoles. Simulations that calculate the electrical surface potential resulting from current dipoles, the forward problem, require a model of the head aside from analytical solutions (e.g. spherical model). The application of such realistic head models is reliant on approximation methods such as the Boundary Element Method (BEM) or the Finite Element Method (FEM). These realistic modeling methods have to take into account volume currents to determine the electric potential. Therefore, the knowledge about tissue conductivity is necessary. Additionally, the conductivity is know to be anisotropic (in particular in white matter structures), however this is usually neglected. The aim of our study was to quantify the influence of neglecting anisotropic conductivity on the electric surface potential and on the source localization in EEG experiments. Therefore a very simple white matter design - a block - was established, to investigate the effect of anisotropy as a matter of principal. A rabbit model was chosen because validation measurements have been performed with such animals.

II. METHODS

In our investigation we applied a high resolution finite element method (FEM) model with cubic elements (633.172 elements, element length = 0.6 mm) of a rabbit head. Four different tissue types were considered (skin $\sigma=0.33$ S/m, skull $\sigma=0.0042$ S/m, gray matter $\sigma=0.337$ S/m, white matter as artificial volume block with an isotropic conductivity of $\sigma_{iso}=0.14$ S/m) as shown in Fig. 1. We quantified the influence of anisotropy by comparing simulated EEG maps using two different type of volume conductors: 1. an inhomogeneous model with isotropic conductivity 2. an inhomogeneous model with a volume block of anisotropic conductivity, which represents the white matter tissue. The white matter block in model 2 was set up with anisotropic conductivity with caudal-rostral orientation and a ratio of 1:10, so that the conductivity in caudal-rostral direction amounted to 0.65 S/m and to 0.065 S/m to this direction. This ratio was established using the volume constraint, so that the volume of an isotropic conductivity tensor which has a conductivity of 0.14 S/m in all directions is equal to the volume of an ellipsoid with the radii 0.65, 0.065 and 0.065 S/m.
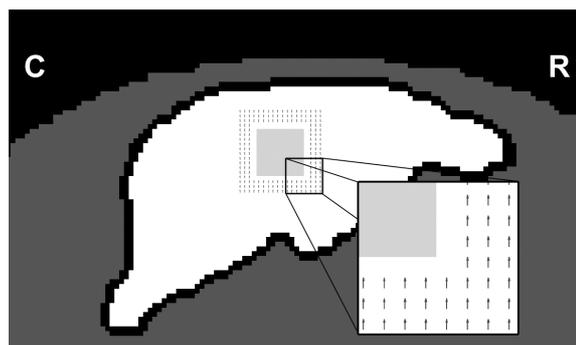

Fig. 1 Sagittal slice of the segmented rabbit head with four different tissue layers (skin, skull, gray matter and an artificial white matter block). The illustration shows the positioning of the dipoles around the anisotropic block, which was modeled with an anisotropic conductivity of 1:10 in caudal-rostral orientation.

A total of 4104 single dipoles were placed around the white matter block with three different orientations with respect to the orientation of the anisotropy of the white matter block in model 2. The orientation of the dipoles with respect to the anisotropy was established for the first set parallel from

caudal to rostral, for the seconds set perpendicular from inferior to superior and for the third set perpendicular from left to right. The electrical potential was simulated using 100 electrodes placed on the top of the rabbit head. The forward simulation as well as the inverse solution was obtained by using the Inverse Toolbox of the Simbio Project [1] including a very fast FEM solver [2,3]. The data derived by the forward simulation using model 1 and 2 were compared by calculating MAG and RDM maps for the electrical potential and magnetic field of every single dipole. To probe the influence of anisotropy on source localization we applied the simulated data derived using model 2 as reference data and performed source localization of a focal dipole using model 1.

III. RESULTS

All results were plotted their corresponding source position. Six transversal slices were selected to show the results. Three slices with dipoles above and three slices with dipoles below the anisotropic tissue block (cf. Fig. 2).
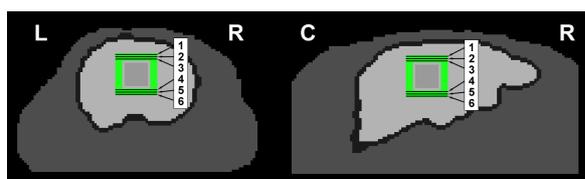

Fig. 2 Transversal and sagittal slice of the segmented rabbit head showing the position of the result maps.

The RDM between the potentials with and without taking into account the anisotropy was less than 0.009. The values in the MAG maps ranges from 0.94 to 1.04. Despite this weak influence of the anisotropy, it is clearly shown, that the influence depends on the distance to the anisotropy. Furthermore, the dipoles below the anisotropic block are more influenced than dipoles above the block. This holds true for the RDM as well as the MAG. The pattern of the RDM maps of the perpendicular oriented dipoles are similar and differ from the pattern of the RDM maps of the parallel oriented dipoles. The RDM maps show the strongest influence close to the corners of the anisotropic block in case of perpendicular oriented dipoles, while in the parallel case the influence is strongest on the middle part of the left and right sides. In all three orientations we can observe positions with low RDM values, despite of a short distance to the anisotropic block. Obvious, the symmetry of the geometric alignment leads to opposed influence and diminishes the influence of anisotropy. This effect was found distinct using dipoles above and below the center of the block in inferior superior direction, as shown in the middle row of the RDM maps, but also next to the center of

the edges in case of dipoles oriented from left to right, as shown in the right column of the RDM maps.

The MAG maps in Fig. 3 show similar pattern for the parallel (left column) and the left-right (right column) oriented dipoles, where a strong influence over and below the center of the block can be observed. In contrast the inferior-superior oriented dipoles (middle column) show an effect next to the edges of the block, however only on the edges which are perpendicular to the orientation of the anisotropy.
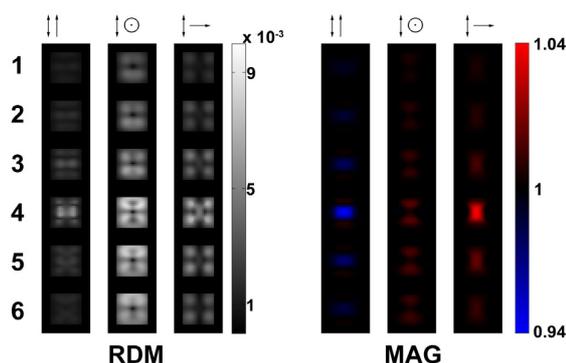

Fig. 3 RDM and MAG maps of the upper (1-3) and lower (4-6) planes in which dipoles were placed. The annotations above the maps show the orientation of the dipoles with respect to the anisotropy. Anisotropy is depicted as double arrow.

The reconstructed dipoles using the isotropic model with potentials derived by employing the anisotropic model, where compared by means of dipole shift and change of dipole magnitude. Fig. 4 shows shifts and magnitude changes maps which corresponds in their position to the maps in Fig. 3. The maps show an influence on the inverse solution mostly in the lower planes (4-6), which is distinguishable from the numerical uncertainty of the inverse solution.
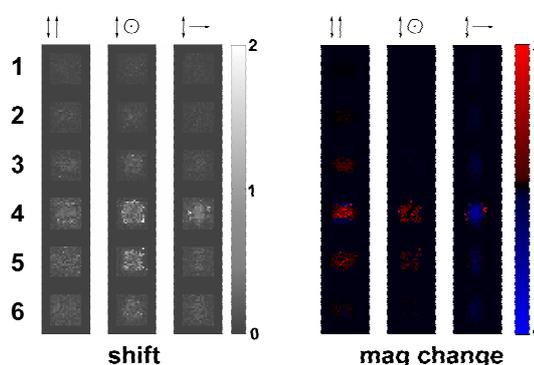

Fig. 4 Mapping of the shifts and magnitude changes between the dipoles used as source in the anisotropic model and the reconstructed dipole employing the isotropic model. The positions of the planes are shown in Fig.2 and correspond to the planes in Fig. 3.

IV. DISSCUSION

The results of the source reconstruction show that the influence of the anisotropy on EEG source localization is mostly within the principal accuracy of the localization procedure. This is in accordance to a previous study [4]. Furthermore, we can observe a stronger influence of anisotropy to source strength estimation. In further studies we have to investigate the influence of anisotropy to MEG source localization. In face of the relatively simple anisotropic model we observed a complex correlation between the position and orientation of the sources with respect to the anisotropy. Thus, it is difficult to make a prediction of the influence of complex anisotropic models. This has to be investigated in further studies using diffusion tensor imaging, which provides tensorial conductivity information using the effective medium approach.

ACKNOWLEDGMENT

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