Influence of anisotropic conductivity measured using DTI on the EEG forward solution: a whole human head sensitivity analysis

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Introduction:
The quality of source reconstruction based on EEG data depends on the one hand on the quality of the EEG data and on the other hand on the quality of the model, which is used to reconstruct the source. The acquired EEG data are usually improved by advanced hardware. The quality of the model matches with how realistic the model reflects the electromagnetic properties of the subject. Besides increasing the resolution of the model consideration of anisotropy is one step forward to more realistic models. Tuch et al. [1] has shown that the conductivity tensor and the diffusion tensor measured by diffusion weighted MRI share the same eigenvectors and experimental verification was performed recently [2]. The goal of this study was to find regions which are highly influenced by anisotropic conductivity employing a realistic high resolution FEM (finite element method) model.

Material and Methods:
High resolution isotropic T1 and T2 weighted images (1 mm³, FOV=256 mm) were acquired to generate a FEM model with 5 different tissue types (skin/extra, csf, white and gray matter, bone). Most of the head below the brain was cropped to reduce the size of the model. Nevertheless, the model consists of 3.2e6 cubic elements with an element size of 1 mm. We assigned a conductivity tensor to each element which belongs to white matter tissue. The conductivity tensors were artificially generated by using the eigenvectors of the co registered diffusion tensor data and a fixed anisotropy of 1:10. That means that we assigned a conductivity value to the largest eigenvector which was ten times larger than the values assigned to the other two eigenvectors. In this high resolution model we placed over 25,000 dipoles perpendicular to the white matter surface in the cortical area with an approximate distance of 1.5 mm to the white matter surface. For each of these dipoles we calculated the forward solution employing the full isotropic and the model with anisotropic white matter tissue. The results were compared by means of relative difference measure (RDM) and magnitude difference (MAG). These values were finally mapped on the inflated white matter surface of the head model to receive a qualitative impression of cortical areas, where the EEG forward solution is strongly affect by anisotropy.

Results:
We found RDM values with a max of 1.74 and MAG values within a range of -5.7 up to 1.46. Assuming an exponential distribution for the RDM values we got a mean RDM of 0.16±0.03. For visual inspection of the results, RDM and MAG values for each dipole position were mapped to the closest vertices on the white matter surface and finally smoothed to obtain values for vertices, which did not get an RDM or MAG value assigned to, since the density of white matter surface vertices was higher than the density of dipole positions. These maps were than placed on the inflated white matter surface as shown in Fig.1.The regions, which are highly affected by white matter anisotropy are almost equal for RDM and MAG and very similar for the right and left hemisphere. Overall, medial regions in particular the cingulate, the parietooccipital and the calcarine sulcus are more effected than lateral regions (cf. Fig 1b and 1d). Nevertheless, we also observed a strong influence on RDM and MAG for dipoles in the posterior part of the lateral sulcus, the superior temporal sulcus, the postcentral sulcus and in the transverse occipital sulcus as shown in Fig. 1a and c. Also positions in the precentral and central sulcus, which are interesting for motor functions, are influenced by anisotropic conductivity of the white matter tissue.

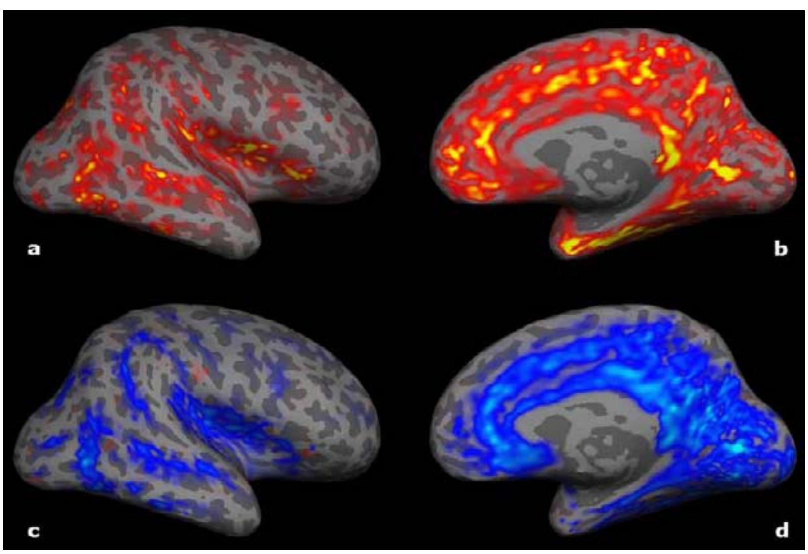

Fig.1: Mapping of the RDM (a and b) and MAG (c and d) values on the right hemisphere (lateral view a and as well as medial view b and d) for each processed dipole by assigning the corresponding value to the closest vertex of the white matter tissue surface and a subsequent smoothing to obtain values for vertices, which did not get value assigned to. RDM as well as MAG are shown using the heat color map (ranging from white to yellow with blue and red to indicate sublevels).

Discussion:
We demonstrated the influence of white matter tissue conductivity to the EEG forward solution in a very high resolution FEM model human head model. Whereby, the anisotropy information was derived from DTI data. To the best of our knowledge this is the first study, which investigates the influence of conductivity anisotropy for the whole human brain. The results of this extensive work should sensitize people performing EEG source localization using ECD (equivalent current dipole) models with dipoles placed in regions which are highly influenced by anisotropic conductivity to perform the localization with models which do consider anisotropic conductivity. Future work on this topic will investigate the influence on the inverse solution.

References: [1] Tuch DS et al. Proc Natl Acad Sci U S A. 2001;98(20):11697-701 [2]Oh, et al., ISMRM 2006, p3034