Influence of Anisotropic Blood Vessels Modeling in the EEG/MEG Forward Problem Using MRI.

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Target Audience: Researchers interested in patient-specific MRI processing, EEG/MEG source localization, and anisotropic conductivity forward modeling.

Purpose: The electroencephalogram (EEG) measures potential at electrodes over the scalp of a human head over a period of time. These potential differences are generated by electrical activity inside the brain that turn out to be dependent on the conductivities of the tissues of the human head. We study the influence of neglected important tissues of the head, with special consideration on the anisotropic blood vessels within the EEG source localization problem. To this end, we consider four different patients. Information about anisotropic areas of the white matter is extracted from Diffusion Weighted Imaging (DWI) data. Similarly, we used spatial gradients to estimate the anisotropic eigenvectors of blood vessels.

Methods:

Data Acquisition: Images of the head were acquired on a General Electric Signa HDxt 3.0T MR scanner using the body coil for excitation and an 8-channel quadrature brain coil for reception. Imaging was performed using an isotropic 3DT1w SPGR sequence with TR=8.7ms, TE=3.2ms, TI=400ms, NEX=1, acquisition FOV=260mm, matrix=320x160, resolution=1x1x1mm, flip angle=12, and an IDEAL T2 sequence with TR=3000ms, TE=81.9ms, NEX=6, FOV=260mm, acquisition matrix=320x160, flip angle=90, and a Time of Flight (TOF) sequence consisting of 8 volumes with 6 slices overlap and TR=20ms, TE=2.1ms, NEX=1, acquisition FOV=224mm, matrix=224x224, resolution=1x1x1mm, flip angle=15.

Tissue Model Generation: Image preprocessing was carried out using 3D Slicer built-in modules. The preprocessing steps included: MRI bias correction (N4 ITK MRI bias correction) and registration (BRAINS) for movement correction. We obtained detailed tissue models from the T1-weighted and TOF volumes by using the pipeline described in [1,2]. These models contained WM, GM, CSF, skull, eyes, muscle, fat, arteries and skin. The arteries segmentation mask was processed in order to estimate the direction of blood flow, obtaining a normalized vector map describing the maximum anisotropy inside the arteries.

Forward Modeling: We used the anisotropic finite difference reciprocity method (AFDRM) [3] to solve the Poisson equation in the volume conductor for realistic head models. $\nabla(\sigma\nabla V_h) = -\nabla J_a$ Ec 1., where σ is a conductivity tensor holding the anisotropic behavior of the current tissue. The MRI segmentation holds 9 different tissues with different conductivity values (given in (S/m)) (scalp, 0.33 S/m; fat = 0.4; muscle = 1.1112; skull = 0.020; eye = 0.0505; CSF = 1.538; GM = 0.3333; WM = 0.14; blood vessels = 0.28) [4]. It is well known that skull and white matter have strong anisotropic behavior [5]. In the case of the skull, we used a 1:10, radial:tangential anisotropic setup, based in the volume constrain of the isotropic value. On the other hand, for the anisotropic white matter, DWI was corrected for motion, eddy currents and field inhomogeneities using FSL. Diffusion tensor images (DTI) were reconstructed with Diffusion-Toolkit. Finally, registration of DTI images to the anatomical T1 image space was performed with FSL using the preprocessed DWI b0 image [6].

Anisotropic Blood Vessels Modeling: We adapted the anisotropic blood vessel model to the AFDRM algorithm [7] setting a local affine transformation A pointing towards the local eigenvector of the found gradient of the vessels. The anisotropic conductivity of the blood at maximum movement was defined as $\hat{\sigma} = diag(\sigma_b, \sigma_a, \sigma_b)$, where σ_a = 0.21 S/m, and σ_b = 0.49 S/m. For the local to global transformation we applied $\sigma = A\hat{\sigma}A^T$ [8].

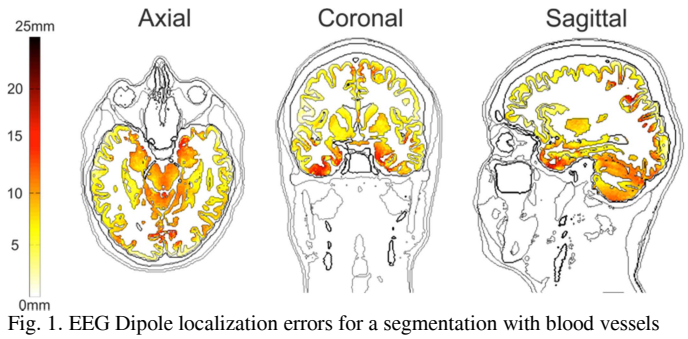

Fig. 1. EEG Dipole localization errors for a segmentation with blood vessels reference model against a simplify head model.

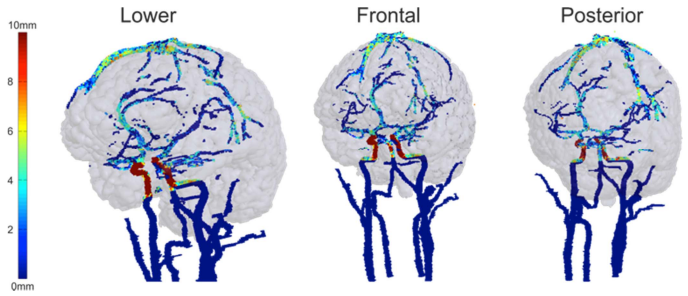

Fig. 2. 3D OpenGL graphic of EEG Dipole localization errors as result of neglect the anisotropic blood vessels.

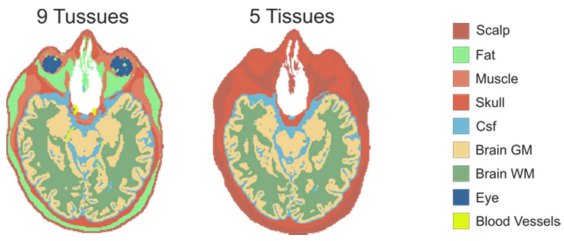

Fig. 3. Image Segmentation

Results: We compared four different patients choosing the most complex head model as reference, holding 9 tissues and including anisotropic skull, white matter and blood vessels. The comparison was made with a simplest 5 tissues model (Fig. 3), holding only scalp, skull, CSF, grey and white brain, including also anisotropic skull and white matters. The results showed errors larger than 30mm in the deepest zones of the brain, an also errors larger than 20mm in intercortical areas of the grey matter (Fig. 1). Similarly, we compared a reference head model with anisotropic blood vessels, against the same model neglecting the vessels segmentation. Regarding this experiment, we obtained errors larger than 67mm in zones near to the Willis polygon, a mean error of 4mm inside the brain (Fig. 2).

Discussion: Forward modeling impacts directly in the EEG source localization, thus, the realistic head modeling with anisotropic capacity is needed for more accuracy detection of neuronal sources. The AFDRM technique allows faster calculation supporting anisotropic conductivities. The results show that neglected important tissues of the human head, like eyes, muscle, fat and anisotropic vessels directly influence the dipole estimations with errors larger than 67mm. On the other hand, consider an anisotropic blood vessels modeling is important for deep sources analysis.

Conclusion: Tissue segmentation in forward realistic head models has a direct influence in the EEG dipole localization.
Anisotropic blood vessel modeling shows that these tissues can influence the dipole estimation, especially in deep brain areas.
Temporal and inferior behavior was affected in terms of accuracy. It could potentially be an important drawback for source localization in focal temporal epilepsy.

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