Estimation of the Anisotropy of Electric Conductivity via B1 Mapping

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Introduction: The electric conductivity can potentially be used as diagnostic information due to its ability to reflect the grade of tissue damage (see, e.g., [1]). In its general form, the conductivity is given by a rank-2 tensor, including anisotropic cases of conductivity. *In vivo*, anisotropic conductivities can be found in tissue with preferred cell direction, e.g., in muscles and nerves [2]. Measuring anisotropy of the tissue conductivity, characterizing the underlying cell structure, might increase diagnostic information. The recently presented "Electric Properties Tomography" (EPT) is able to determine tissue conductivity *in vivo* by post-processing B1 maps [3]. This study investigates the ability of EPT to estimate also the anisotropy of the conductivity.

Theory: Tissue conductivity $\boldsymbol{\sigma}$ and permittivity $\boldsymbol{\varepsilon}$ can be estimated via [3] (**H**/**E** the magnetic/electric field, ω the Larmor frequency)

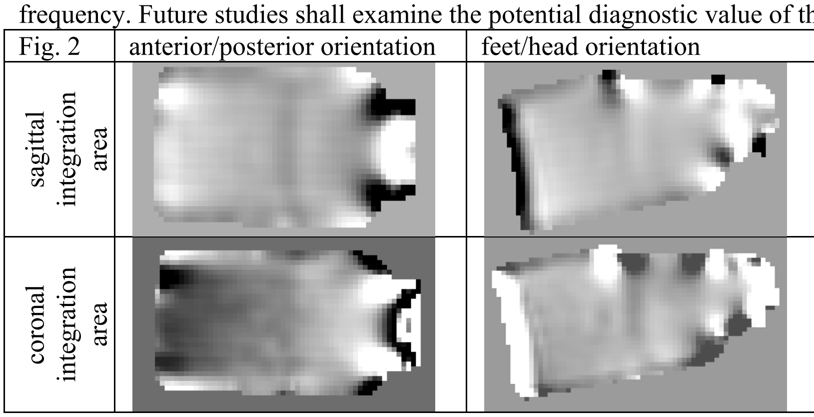
$$\frac{\oint_{\partial A}\nabla\times\mathbf{H}(\mathbf{r})d\mathbf{r}}{\mu_0\omega^2\int_A \mathbf{H}(\mathbf{r})d\mathbf{a}} = \frac{\oint_{\partial A}\boldsymbol{\kappa}(\mathbf{r})\mathbf{E}(\mathbf{r})d\mathbf{r}}{\oint_{\partial A}\mathbf{E}(\mathbf{r})d\mathbf{r}} \approx \frac{\boldsymbol{\kappa}(\mathbf{r})\oint_{\partial A}\mathbf{E}(\mathbf{r})d\mathbf{r}}{\oint_{\partial A}\mathbf{E}(\mathbf{r})d\mathbf{r}} = \boldsymbol{\kappa}(\mathbf{r}) \equiv \boldsymbol{\varepsilon}(\mathbf{r}) - i\boldsymbol{\sigma}(\mathbf{r})/\omega \ . \qquad (1)$$

The assumption of Eq. (1) is valid in regions, where the variation of $\boldsymbol{\kappa}$ (along the boundary ∂A of the integration area A) is significantly smaller than the variation of **E**, e.g., in areas with constant $\boldsymbol{\kappa}$. The resulting $\boldsymbol{\kappa}$ is independent of the choice of A only in the case of isotropic $\boldsymbol{\kappa}$. In the following, a maximally anisotropic $\boldsymbol{\kappa}^{\text{aniso}}$ is considered for demonstration purposes, i.e., $\kappa_{ij}^{\text{aniso}} = 0$ for all $i,j=x,y,z$ except $\kappa_{xx}^{\text{aniso}} > 0$ (x assumed to be the left-right direction). For this case, two different integration areas are compared, a sagittal area A_{yz} and a coronal area A_{xz}. In the sagittal case, the vector $\mathbf{E}(\mathbf{r})d\mathbf{r}$ of Eq. (1) is in the sagittal plane, and multiplication with $\boldsymbol{\kappa}^{\text{aniso}}$ (oriented perpendicular to the sagittal plane) yields a reconstruction result of zero. However, multiplication of $\boldsymbol{\kappa}^{\text{aniso}}$ with a vector $\mathbf{E}(\mathbf{r})d\mathbf{r}$ in the coronal plane yields a finite reconstruction result. The comparison of the two reconstructions reflects the underlying electric anisotropy. A single scan (with arbitrary slice orientation) is sufficient for this approach, i.e., the two reconstructions using A_{yz} and A_{xz} can be applied to the same data set.

Methods/Results: Experiments were performed with a bottle of 500 ml saline (σ = 1 S/m, ε_r = 80) and 1 ml Magnevist (Bayer-Schering Pharma AG, Germany). The lower part of the bottle was completely filled with plastic drinking straws (Ø = 3mm) to achieve electric anisotropy (Fig. 1). The phantom was placed in a transmit/receive head coil of a Philips Achieva 1.5T system (Philips Health Care, Best, The Netherlands). Sagittal B1 maps were acquired for three different phantom orientations using AFI [4] with TE/TR1/TR2=2.3/24/120ms, α = 60°, voxel size 2.5×2.5×3 mm³. The transmit phase was estimated by cutting the phase of the AFI images in half as suggested in [3]. Before, the image phase was corrected for susceptibility effects via a separately acquired B0 map (dual echo sequence, ΔTE = 10 ms). Conductivity reconstructions were performed for the different phantom orientations via Eq. (1) applying a sagittal and coronal integration area (Fig. 2). The quantitative analysis of the reconstruction results are given in the table.

Fig. 1: Phantom with straws in lower part to achieve anisotropic conductivity

Discussion/Conclusion: Electric anisotropy can be estimated by the impact of the EPT integration area on the reconstructed $\boldsymbol{\kappa}$. Particularly, an integration area perpendicular to the major axis of $\boldsymbol{\kappa}$ yields minimal reconstructed $\boldsymbol{\kappa}$. For anisotropic $\boldsymbol{\kappa}$ (with non-zero minor axes), the electric fields in Eq. (1) do not cancel completely, yielding a reconstructed $\boldsymbol{\kappa}$ weighted with the electric fields. This a substantial difference to isotropic $\boldsymbol{\kappa}$, where the electric fields in Eq. (1) cancel completely, yielding absolute values of $\boldsymbol{\kappa}$ [3]. Contaminations from the typically isotropic permittivity are expected to be negligible due to $\boldsymbol{\varepsilon} \ll \boldsymbol{\sigma}/\omega$ for human tissue at Larmor frequency. Future studies shall examine the potential diagnostic value of the electric anisotropy.



straw orientation	anterior - posterior	feet - head	left - right
sagittal int. area	128%	99%	9.1%
coronal int. area	8.3%	102%	77%

Tab. 1: Reconstructed σ of straw compartment, normalized to reconstructed σ of non-straw compartment.

References
[1] Joines W et al., Med Phys 21 (1994) 547
[2] Gabriel C et al., Phys Med Biol 41 (1996) 2231
[3] Katscher U et al., IEEE TMI 28 (2009) 1365
[4] Yarnykh VL, Magn Reson Med 57 (2007) 192