Conductivity mapping using Ultrashort Echo Time (UTE) imaging

Ferdinand Schweser[1,2], Li Huang[1,3], Karl-Heinz Herrmann[1], Martin Krämer[1], Andreas Deistung[1], and Jürgen Rainer Reichenbach[1]

[1]*Medical Physics Group, Institute of Diagnostic and Interventional Radiology I, Jena University Hospital - Friedrich Schiller University Jena, Jena, Germany,* [2]*School of Medicine, Friedrich Schiller University Jena, Jena, Germany,* [3]*Abbe School of Photonics, Faculty for Physics and Astronomy, Friedrich Schiller University Jena, Jena, Germany*

TARGET AUDIENCE

Researchers interested in understanding the origin of phase variations in *ultrashort echo time* (UTE) imaging and finding new applications for UTE sequences, as well as researchers interested in applying MR-based conductivity imaging *in vivo*.

PURPOSE

MR-based *Electric Properties Tomography* (EPT)[1] provides a non-invasive means to assess electric tissue properties, such as conductivity and permittivity. Reflecting the biophysical tissue composition these physical properties are potential candidates for novel diagnostic parameters in oncology and cardiology[1]. EPT is based on the complex-valued B_1^+-field, which may be mapped, in the simplest way, using time-consuming *spin echo* (SE) sequences. Just like SE sequences, the *ultrashort echo time* (UTE) magnitude signal is insensitive to B_0-variations because UTE sequences sample the k-space center immediately after a low flip-angle non-slice selective RF pulse with an extremely short echo-time. While the UTE magnitude contrast is governed by different relaxation properties and proton-density, it was recently shown that both off-resonance effects (B_0) and B_1 phase affect the UTE phase[2]. Off-resonance effects were discussed as a major source of UTE phase contrast in tendons[2]; however, it is so far unclear to what degree these effects also contribute in other body regions, such as the brain. If B_0-effects are small compared to the B_1-contributions in the brain, the UTE phase may be used as an input to phase-based conductivity mapping[3].

In this contribution we investigated the possibility of using UTE phase for *in vivo* conductivity mapping of the brain.

MATERIALS AND METHODS

Data Acquisition: UTE data of the brain were acquired from a healthy volunteer (male, 24 yrs) on a 3T whole-body MRI scanner (Tim Trio, Siemens Medical Solutions, Erlangen, Germany) using a single-channel T_x/R_x birdcage coil and a radial 3D "spikey ball" center-out acquisition (TE =100 µs, TR=5 ms, RF pulse duration 20 µs, FA=7°, 0.66 mm isotropic voxels, 70,428 spokes, 2 averages, TA approx. 11.7 min). Magnitude and phase images were reconstructed by gradient delay compensated state-of-the-art 3D gridding with iterative grid weights estimation[6] and subsequent Fourier transformation.

Data Pre-processing: Phase images were unwrapped with a spatial-domain best-path algorithm[4]. Since in this setup the UTE signal was supposed to contain similar contributions from B_1^+ and B_1^-, the phase was divided by a factor of two.

Conductivity mapping: A conductivity map was calculated from the unwrapped phase images by Laplacian-calculus according to Voigt et al.[5]. The resulting conductivity map was smoothed with a Gaussian kernel (standard deviation 3.3 mm) to suppress noise.

Analysis: Mean and standard deviation of conductivity was assessed in two regions in the center of the ventricles and the temporal white matter, respectively.

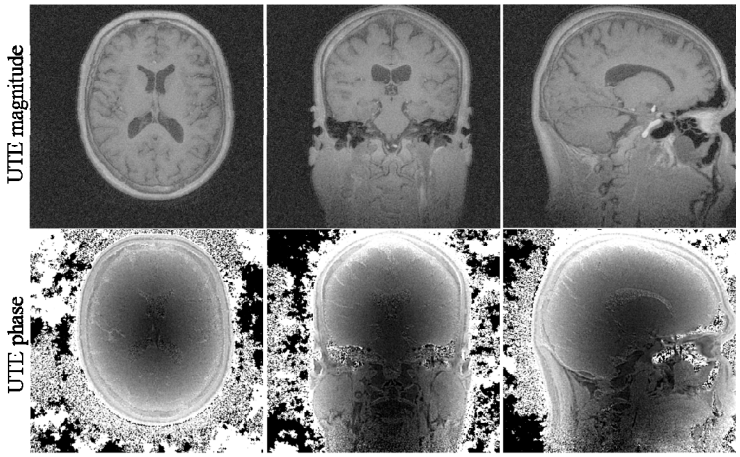

FIGURE 1. **Top**: UTE magnitude images. **Bottom**: UTE phase images [from black to white: 1.1 rad to 2.5 rad].

RESULTS

Figure 1 shows representative UTE magnitude images (top row) and the corresponding unwrapped UTE phase (bottom row) images, respectively. The phase images show B_1-phase behaviour typical for 3 Tesla with minimum phase in the center and increased phase values at the edges of the head. Figure 2 illustrates the conductivity maps calculated from the UTE phase. Average conductivity was (1.81 ± 0.65) S/m in the CSF and (0.48 ± 0.14) S/m in the white matter.

DISCUSSION – Off-resonance effects cannot explain the observed UTE phase in the brain (Fig. 1-bottom) because, first, CSF is virtually invisible on B_0-maps (such as susceptibility weighted phase images)[9] and, second, susceptibility variations cannot produce a large-scale phase minimum in the center of the brain[10]. Consequently, it is likely, that off-resonance contributions to the UTE phase are negligible *in vivo* compared to B_1-effects and play a major role only in extreme cases such as in highly anisotropic and heterogeneous meniscus specimens[2]. We demonstrated that i*n vivo* conductivity mapping of the human brain based on UTE phase images is possible. The conductivity map had an appearance similar to those presented in literature[5-7] and conductivity values were in good agreement with literature values of approximately 2 S/m for CSF and 0.6 S/m for white matter tissue[8]. However, to assess the applicability of UTE for conductivity imaging more thorough analyses and validation are required using dedicated B_1-mapping sequences such as DREAM[11]. In particular, the relative contribution of B_0-related effects to the UTE phase *in vivo* needs further analysis

CONCLUSION – Reasonable conductivity maps may be obtained from UTE phase images, indicating that B_1-effects dominate the UTE phase signal. However, validation with a dedicated B_1-mapping sequence and further research on the relative contribution of off-resonance effects is required.

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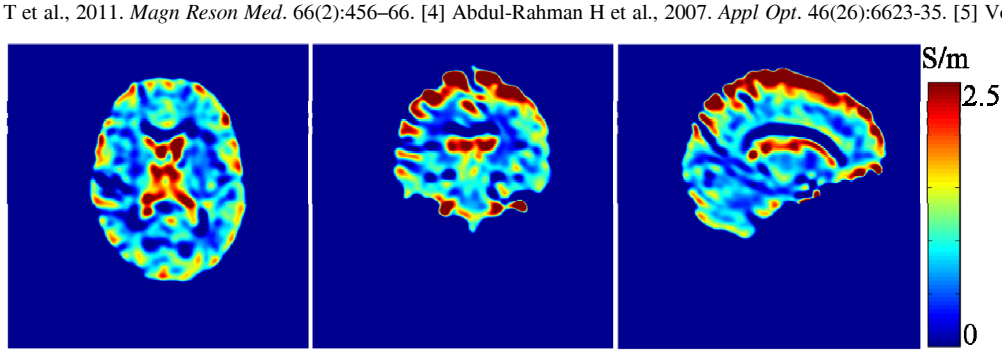

FIGURE 2. Conductivity maps corresponding to the slices in Fig. 1.