Imaging Electrical Properties of Human Head with Tumor Using Multi-channel Transceiver Coil at UHF: A Simulation Study

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Introduction Determination of tissue electrical properties (EP, conductivity σ and permittivity ε) using MRI has aroused great interests due to its significance for diagnostic purpose and patient-specific real-time SAR calculation. Complex B^+_1/ B^-_1 field map is necessary to derive electrical properties as well as electrical field in order to estimate SAR. However, it becomes challenging to estimate the phase of complex B^+_1/ B^-_1 field as field strength increases. A previous study has introduced a rigorous method of complex B^+_1/ B^-_1 field mapping at ultrahigh field using a multi-channel transceiver coil on samples with approximately elliptical symmetric geometry [1-2]. In the present study, we investigate, by computer simulation, the feasibility of imaging electrical properties on a realistic geometry head model with cancerous tissue, which breaks the symmetric structure.

Principle According to Magnetic Gauss's Law and principle of reciprocity [3], ignoring H_z component, we can modify the dual-excitation algorithm [4] by combining the H_x and H_y components into B^+_1 (eq. [1]). With at least two independent measurements, we can calculate the complex permittivity ($\varepsilon_c = \varepsilon - j\sigma/\omega$) pixel-wisely by solving eq. [1].

$$-\nabla^2 H_1^+ = \omega^2 \mu_0 H_1^+ \varepsilon_c - (\partial H_1^+/\partial x - j\partial H_1^+/\partial y)[(\partial \varepsilon_c/\partial x + j\partial \varepsilon_c/\partial y)/\varepsilon_c] \quad [1]$$

Method Sixteen complex B^+_1 and B^-_1 field maps (with both magnitude and absolute phase) for each coil element can be derived following the protocol in the previous study [1], given the measurements of $|B^+_1|$, proton density biased $|B^-_1|$ ($PD\times|B^-_1|$) and the relative phase of B^+_1 and B^-_1 to a reference channel. Simulated solutions of magnetic and electric field at frequencies corresponding to 7 T and 9.4 T were carried out using software ANSYS (ANSYS Inc., PA, USA) on an anatomically accurate human head model with resolution of 2×2×2.5 mm^3. The electrical properties of tissues at different frequencies were chosen according to the 4-Cole-Cole Model [5]. Asymmetry was introduced by simulating a tumor (see red box, Fig. 1C) in the brain unilaterally with literature reported electrical property values [6], which are ≥ 20% bigger than surrounding tissues. Relative proton densities were assigned according to [7]. One single coil element was excited independently at a time. The electrical properties were reconstructed according to eq. [1].

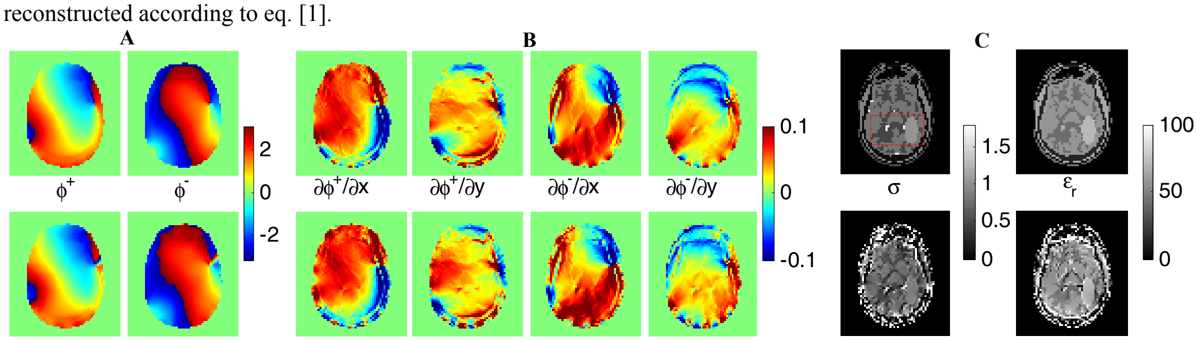

Figure 1. Top row: target; bottom row: reconstructed. (A) Absolute phase, (B) gradient of absolute phase, and (C) electrical properties. An elliptical "tumor" is simulated unilaterally within the ROI of red box (C).

Results Fig. 1 shows the reconstruction results (bottom) of absolute phase (φ^+ and φ^-), gradient of phase and electrical properties from one slice in the tumor head at 7 T in comparison with the target distribution (top). Gradient of phase is critical to reconstruction because ε_c is calculated pixel-wisely in eq. [1]. Table 1 illustrates and compares the relative error (RE) and correlation coefficient (CC) of reconstructed electrical properties within ROI (Fig. 1C) between symmetric normal head and asymmetric head with a tumor, as well as the REs of gradient of reconstructed phase. The average differences of REs and CCs of reconstructed electrical properties between symmetric and asymmetric heads are ≤ 1% and 0.01, respectively. The method at 9.4 T outperforms 7 T in both reconstructions of electrical properties and gradient of phase.

Table 1. Relative errors and correlation coefficients of EP and phase gradient reconstruction on both normal and tumor head model at 7 T and 9.4 T

REs/CCs		7 T REs		7 T CCs		9.4 T REs		9.4 T CCs	
		Normal	Tumor	Normal	Tumor	Normal	Tumor	Normal	Tumor
WM	σ	36%	38%	0.89	0.90	35%	36%	0.90	0.92
	ε_r	24%	28%	0.94	0.93	16%	18%	0.97	0.97
GM	σ	20%	20%	0.94	0.93	20%	19%	0.91	0.90
	ε_r	14%	15%	0.97	0.97	11%	12%	0.98	0.98
Tumor	σ	--	17%	--	0.99	--	18%	--	0.99
	ε_r	--	10%	--	0.98	--	8%	--	0.99
Average		23%	22%	0.94	0.95	19%	19%	0.94	0.95

REs phase gradient est.	7 T		9.4 T	
	Normal	Tumor	Normal	Tumor
$\nabla\phi^+$	28.4%	27.9%	22.4%	24.5%
$\nabla\phi^-$	21.1%	22%	17.4%	19.1%
Average	24.8%	25.0%	20.0%	21.8%

Conclusion In the present study, we conducted complex B^+_1/ B^-_1 field mapping at ultrahigh field on simulation data of both symmetric and asymmetric geometry using the method proposed previously, and tested the influence of this method on reconstruction of electrical properties of asymmetric geometry. The present simulation results show that realistic asymmetric head structure in a pathological case does not degrade the performance of reconstruction of electrical properties at ultrahigh field and suggest the practical value of this method for diagnostic purpose and patient-specific SAR calculation in ultrahigh field MRI. Experimental studies should be performed in future investigation to validate this conclusion.

References [1] Zhang et al. ISMRM 2011, 126. [2] Van de Moortele et al. MRM 2005, 54:1503-1518. [3] Hoult. CMR 2000, 12: 173-187. [4] Zhang et al. IEEE Trans. Med. Imaging 2010, 29:474-481. [5] Gabriel et al. Phys. Med. Biol. 1996, 41: 2271–2293. [6] Yoo. Bioelectromagnetics 2004, 25:492-497. [7] Just et al. Radiology 1988, 169: 779-785. **Acknowledgment** NIH R01EB007920, R01EB006433, R21EB006070, Minnesota Supercomputing Institute of UMN. We are grateful to Dr. Van de Moortele for providing the head geometry and coil models.