Reference aided imaging of rat tumor dielectric properties at 3.0T

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Target audience: Research personnel interested in dielectric properties of tumors, imaging dielectric properties, and improving specificity of MRI.

Purpose: Dielectric contrast (conductivity and permittivity) of tumors has received significant interest as potential means to improve specificity of cancer imaging (1-3). The dielectric properties can be estimated from MRI B_1^+ maps; the quality of B_1^+ maps and the reconstruction method may, however, lead to inaccurate results. Therefore, we propose a reference aided approach to validate data sets and fine tune reconstruction algorithms to improve the process of dielectric property imaging.

1. Acquire complex B1+
2. Calculate electrical properties of references
3. Compare with ground truth
4. If comparable, accept data set, otherwise discard
5. If accepted, optimize algorithm parameters
6. Use optimum algorithm on ROI

Figure 1: Improved process for electrical property imaging

Methods: Two reference solutions (2.2 g/L and 11g/L of NaCl in distilled water doped with 0.5g/L $CuS0_4$) were placed in 1.5cm and 1.7cm diameter, 16 cm long, sealed ampules. The conductivity and permittivity of the solutions were measured at 128MHz (85070E/E4991A probe kit, Agilent, CA). Following approval from institutional animal care and use committee, adenocarcinoma MAT BIII and MAT-Ly-Lu-B-2 strains were grown in female/male (Fischer 344 /Copenhagen) rat. The reference ampules and rat were placed in an animal imaging coil (63mm diameter coil, Doty Scientific Inc) and imaged in 3.0T scanner (MR750, GE Healthcare, Waukesha, WI). B_1^+ maps were acquired in an axial plane, using Bloch-Siegert B_1^+ mapping protocol (4)(TE/TR=22/950ms, 1.5mm thick slices, 13 slices, FOV 6cm x 12cm). Spin echo images of same slices were acquired (TE/TR=13/467ms). The rat and reference ampules were removed, a phantom filled with vegetable oil was placed and spin echo images were acquired with the same parameters. The phase of spin echo image was corrected with the phase of oil phantom image to remove system introduced phase variation. Complex B_1^+ was obtained from magnitude and corrected spin echo phase. The reference ampule regions in the images were selected (manual point selection followed by region growing algorithm) and the dielectric properties within these regions were calculated (kernel=3x3x3 voxels, 3 points for derivative estimate) (5) for the center slice (slice 7). The estimated values were compared with probe measured dielectric properties and the data set accepted if comparable, discarded otherwise. If accepted, the parameters of the algorithm (kernel size, number of points for derivative estimate) were increased to obtain estimates closer to measured values. Next the tumor region was selected freehand (Matlab, Mathworks, MA) and the dielectric properties were calculated using the parameters selected previously. The steps in the process are listed in Fig. 1.The freehand mask outlining the tumor was generated multiple times (N=10), and the calculated dielectric properties were averaged. An incision on skin was made, tumor exposed and using the dielectric probe, the conductivity and permittivity were directly measured. The measurements were carried out multiple times, retracting and placing the probe on tumor each time (N=5).

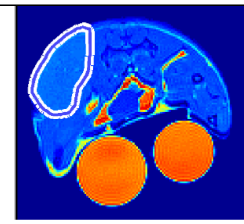

Figure 2: Axial image of the rat and reference solutions. Tumor is highlighted in white

Case	Solution	Conductivity (S/m)	Permittivity
F1	Ref1	1.9	72.8
	Ref2	0.6	76.6
C1	Ref1	2.7	82.2
	Ref2	0.7	87.2
F2	Ref1	2.1	77.3
	Ref2	0.3	77.3
C2	Ref1	1.9	86.9
	Ref2	-0.7	98.6

Table 1: MR measured values of reference solutions. The probe measured results were (conductivity/permittivity), Ref1=2.5/75.7, Ref2=0.6/74. Based on the results, data set 4 was discarded. (F=Fischer, C=Copenhagen rat)

Results: An image of the rat and reference solutions is shown in Fig. 2. The calculated dielectric properties for the reference solutions were comparable to probe measured values (+/- 20% conductivity, +/- 25% permittivity) and therefore, the first data set was accepted. The results were closer in the second iteration of calculations (kernel 5x5x5, 5 points for derivative) than the first (kernel 3x3x3, 3 points for derivative) and therefore, parameters in second iteration were used in further calculations. The results for reference solutions for 4 cases (2 Fischer rats, 2 Copenhagen rats) are shown in Table 1. Based on these results, the fourth data set was discarded. The results for tumors are shown in Table 2.

Case	Conductivity (S/m)		Permittivity	
	MR	Probe	MR	Probe
F1	0.7	0.7	59.5	73.4
C1	1.0	0.9	68.8	75.7
F2	0.7	0.7	72.3	73.7

Table 2: Tumor properties, MR and probe measured (F=Fisher, C=Copenhagen rat)

Discussion: As the initial estimate of dielectric properties of references showed values comparable to measured values, a level of confidence was established for the experiment (coil setup, imaging protocol, and imaging parameters). Increasing the number of points (kernel and derivative estimates) in the algorithm demonstrated better estimates and therefore these parameters were used in further calculations. Note that the computed values for tumors were sensitive to how tumor regions were selected. Heterogeneity within the tumor area was also observed.

The conductivity and permittivity values are comparable to single pole Debye fit curve of malignant breast tissue dielectric properties from three different studies(1) (approximately 0.7S/m and 55 at 128MHz). Our determined conductivity values are lower than results of (2), but closer to(3) .

Conclusion: The reference aided approach provides capability to validate data sets and optimize algorithms prior to estimating dielectric properties of region of interest, leading to an improved process for dielectric property imaging.

References:1.Fear EC et al Microwave Magazine, IEEE 2002;3(1):48-56. 2. Katscher U, et al, Proc ISMRM, Salt Lake City, UT; 2013. p 3372. 3. Shin J, et al, Proc ISMRM 2013;21:4180. 4. Sacolick LI et al, Magn Reson Med 2010;63(5):1315-1322. 4. Bulumulla S et al, Proc ISMRM 2013; Salt Lake City, Utah.

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