

## **Design and Construction of a Tissue-Mimicking Phantom to Validate Electrical Properties Mapping Techniques based on Magnetic Resonance**

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Knowledge of the spatial distribution of electrical properties (EP) of human tissues, namely electric conductivity ( $\sigma$ ) and permittivity ( $\epsilon$ ), could be used to detect pathologic tissue (e.g., cancer), as well as to accurately estimate radiofrequency (RF) safety limits for ultra-high field (UHF) magnetic resonance (MR) imaging. Various techniques have been proposed for non-invasive mapping of tissue EP in the radiofrequency range based on MR measurements. The aim of this work is to design and build a two-compartment MR phantom for validation of EP mapping techniques. We chose 300 MHz as the target operating frequency because RF-based EP mapping techniques are more promising at UHF.

**METHODS:** We selected heart ( $\epsilon_r = 69.3$ ,  $\sigma = 0.90$  S/m at 300 MHz) and trachea ( $\epsilon_r = 45.3$ ,  $\sigma = 0.61$  S/m at 300 MHz) as two tissues with sufficiently distinct EP, based on published values. Following validated recipes, we mixed five ingredients to create materials mimicking the EP of the selected tissues: deionized water as solvent, NaCl (Sodium Chloride – anhydrous, free-flowing, Redi- DriTM, ACS reagent,  $\geq 99\%$ , Sigma-Aldrich®) to vary conductivity, sugar (Premium Pure Cane Granulated, Domino Food Inc) to vary permittivity, Benzoic Acid (99.5%, Acros Organics) as preservative and gelatin (Unflavored Gelatine, Knox®) as gelling agent. The EP of the two materials were measured with a dielectric probe (Agilent 85070E slim probe kit). The Open/Short/Load calibrations of the probe were performed using the manufacturer calibration kit and distilled water as the known load. For each material, 3 sets of 10 measurements, repeating the calibration before each set, were performed in the frequency range of 200-400 MHz (1,601 data points). The average values among all measurements of  $\epsilon$  and  $\sigma$  were extracted and compared against the expected EP of the corresponding tissues at 300 MHz. The outer shell of the phantom was composed by two 3D printed empty plastic semi cylinders with identical internal volume. The two halves were glued together, interleaving a 0.5 mm plastic layer in the middle to insulate the two compartments. The two tissue-mimicking materials were poured in separate compartments when still in a liquid state and the phantom was left to cool down at room temperature until the materials reached a gelatinous state. To eliminate air bubbles, the phantom was subsequently placed for two hours in hot water with the screw tops removed. We acquired gradient-echo MR images of the phantom on a 7 T full-body scanner (Magnetom, Siemens Medical Solution), using 256 x 256 matrix size, TE/TR = 4/1000 ms, 0.5 x 0.5 mm<sup>2</sup> in-plane spatial resolution and 3 mm slice thickness.

**RESULTS:** For the heart-like material there was a good agreement for both conductivity (0.95 vs. 0.90 S/m) and relative permittivity (70.6 vs. 69.3) at 300 MHz. For the trachea-like material  $\sigma$  and  $\epsilon$  were 0.51 vs. 0.61 S/m and 40.4 vs. 45.3, respectively. The acquired images show the absence of air bubbles, a clear separation between the two uniform materials and an almost invisible boundary for 0.5 x 0.5 mm<sup>2</sup> spatial resolution.

**CONCLUSION:** We built a two-compartment MRI phantom that mimics the EP of the human heart and the trachea. MR-based EP mapping techniques rely on the estimation of derivatives of measured data (e.g.,  $B_1^+$ ) with numerical methods that employ multivoxel kernels, which results in artifacts near EP boundaries. We designed our phantom to minimize this issue by separating the two compartments with a plastic layer thinner than the typical spatial resolution used in EP mapping (i.e.,  $\geq 1$  mm). Future work will include measuring the phantom's EP at 7 T (i.e., 300 MHz) non-invasively with Local Maxwell Tomography and the development of a four- compartment phantom.