A Head Mimicking Phantom for 7T, Matched for Tissue Parameters, B1+ Behavior, and Coil Loading Effects

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Overview: An agarose gel and saline solution phantom was developed to mimic properties of the human brain for imaging at 7T. Concentric annuli were nested within a cylindrical former, with grey matter/white matter contrast created via altering the agarose gel concentration to produce T2 differences, while T1 was modulated via doping with Gadolinium salts. Saline compartments mimicking the ventricles and peripheral cerebrospinal fluid (CSF) allow for proper loading and decoupling behaviour of RF coils tuned for the head. Additionally, the compartmentalized nature of the gel provides B1+ behaviour similar to that in the head. With these features, this phantom design is useful for evaluating sequence contrast, coil design, and B1 shimming at 7T.

Methods: The relaxivity of varying concentrations of Gadolinium and Agarose were measured in order to find tissue equivalents. A range of concentrations were prepared in 8-ml sample tubes and T1 and T2 values were determined via fitting of segmented inversion recovery and multi -echo spin echo imaging experiments.

Concentrations of GdCl3 and Agarose were chosen to provide T1 and T2 values that match average human grey matter and white matter values, as reported in the literature[1,2]. Chosen concentrations are detailed in Table 1 and are similar to values reported for imaging at lower fields[3]. A 15.2-cm diameter x 8cm length PVC pipe was used as a former and filled with the grey-matter-mimicking and white-matter-mimicking gels in concentric annuli, with a CSF-mimicking 50-mM NaCl solution in a central spherical compartment and in a thin annulus around the periphery. Phantom size was chosen to match the human brain by mass (~1.5 kg).

Coil loading was measured by tuning, matching, and decoupling a 6-channel transceive array for a human head and comparing the S11 and S12 parameters when loaded with the phantom.

B1+ effects were empirically determined via imaging experiments with multi-channel transmit arrays, noting the location of signal nulls in the phantom and in a human volunteer for two driving configurations: 1) single channel transmission and 2) 6-channel transmission phases set randomly to induce B1+ spatial cancellations.

Table 1: Agarose % and [Gd] chosen to match grey and white matter contrast.

Tissue	Target T1 (ms)	Target T2 (ms)	% agarose	[GdCl3] (uM)
Grey matter	2000	55	2.1%	8
White matter	1300	45	2.2%	22

Results: T1 and T2 contrasts matching grey and white matter were successfully created, as demonstrated in Figure 1.

The inclusion of the conductive CSF-mimicking 50-mM NaCl solution in the center and periphery of the phantom was found necessary to achieve coil-loading effects that matched the human head (as determined by S11 measurements). Coil coupling (S12) was worse than in the head by roughly 3dB per channel pair, due to the phantom coupling more to the coils. This increase in coupling, as compared to the head, is also visible in the amount of RF power required for excitation, which is nearly 5dB less in the phantom.

B1+ spatial behaviour is similar to that in the head, as demonstrated by the intensity patterns in Figure 2. Field maps (not shown) also show similar B1+ distributions to those found in the head.

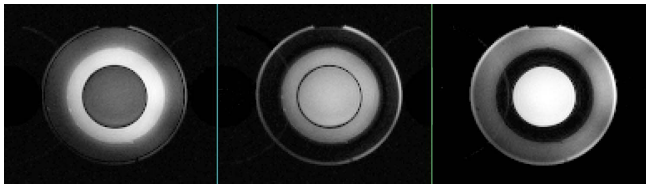

Figure 1: T1W MPRAGE images of the same slice of the phantom with different inversion times. Left: TI = 500ms, Mid: 1400ms to null GM, Right: 900ms to null WM.

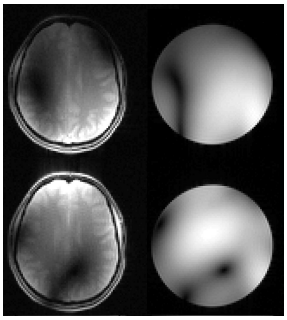

Figure 2: Comparison of RF interference patterns. Top row: Single element transmitting (located at back of head). Bottom row: All elements transmitting with random phases to produce interferences.

Discussion: Future work will focus on asymmetric phantoms to better mimic the coil loading properties of the human head, and methods to reduce the phantom-coil coupling to levels closer to that of tissue, providing a more realistic estimate of SAR limits during sequence development.

Phantoms for ultra high field imaging must mimic many different properties of tissue in order to be useful for many purposes. The design presented here provides an excellent reference for testing sequence contrast behaviour, B1+ inhomogeneaity effects, and for use in RF coil development.

References:

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2.Wright PJ et al. MAGMA 2008; 21:121-130
3.Yoshida A et al. Int J Hyperthermia 2004; 20:803-814