INTRODUCTION: The homogeneity of the radio frequency magnetic field, B, has been shown to progressively decrease in large samples (e.g., human head) with increasing B, frequency. This is due largely to wavelength effects contributed to by the samples size, geometry, and complex permittivity, as well as the RF coil used. Although this behavior can be observed at frequencies as low as 100 MHz, it is seen more readily at high frequencies. In this work we present a comparison of MR images and numerical calculations of the signal intensity distribution in gradient-echo (GE) and spin-echo (SE) images at 300 MHz (7.0 Tesla) for the human head in a quadrature volume coil.

METHODS: All numerical studies were performed using the full set of Maxwell equations with the finite difference time domain (FDTD) method of calculation for electromagnetics (1) to solve for the B, field distribution. An anatomically-accurate multi-tissue model of the human head was created (2) from the digital photographic data of the NIH visible male project. The resolution of the model is 2mm in left-right and anterior-posterior dimensions, and 2.5 mm in the inferior-superior dimension.

An ideal quadrature band-pass head-sized (30cm diameter, 25cm length) birdcage was modeled using methods described previously (2), with one voltage source performing the function of each capacitor. The FDTD method was used to find the steady-state magnetic field at 300 MHz. All FDTD calculations were set up and performed with the aid of xfdtd software (Remcom; State College, PA). The magnitude of the pertinent transverse circularly-polarized component of the RF magnetic field (B,1) was then calculated (3). All fields were normalized so that the resulting field would produce a 90° flip at the coil center with a 3ms rectangular pulse.

Signal intensity at a voxel in a GE sequence was calculated as being proportional to water content of the tissue in the voxel, the sine of the flip angle in that voxel, and the magnitude for B,1 produced with unit driving voltage (proportional to coil sensitivity). Signal intensity at a voxel in a SE sequence was calculated as being proportional to water content of the tissue in the voxel, sin2 of the flip angle in that voxel, and the magnitude for B,1 unit driving voltage.

All imaging was performed using a 7.0 Tesla 90 cm diameter magnet (Magnex Scientific Lmt.) with a Varian Unity Inova console (Palo Alto CA) operating at 300 MHz for proton. A 16-element TEM coil (length: 21cm, inner diameter: 28.8cm, outer conductor diameter: 34.4cm) was used to obtain the images. GE images were acquired using a 1256 data matrix, 5 mm slice thickness, FOV=24x22cm2, and TR/TE=5000/5. SE images were acquired using a 1256x128 data matrix, 3.5 mm slice thickness, FOV=24x22cm2, and TR/TE=3000/40.

RESULTS: Calculated and experimental images are shown in Figure 1. A bright central region is present in all images indicating a stronger central B, magnetic field strength due to wavelength effects within the tissues of the brain. Gradient echo images show a more uniform distribution of intensity. Hyperintense regions around the brain periphery are seen frontally in the calculation and distally in the actual image. The differences in brain periphery is effected to a high degree similarity with a central bright region, bright frontal region, and clearly defined distal dark centers spaced symmetrically on the edges.

DISCUSSION AND CONCLUSIONS: This study shows good agreement between GE and SE images and images predicted by numerical evaluation of the Maxwell wave equations at 300MHz. The calculation predicts the region of higher B, strength at the brain's center. It further, particularly in SE images, demonstrates other wavelength effects seen as symmetrical dark minima about the central hyperintensity. Studies at other frequencies show the distance between these hypointense regions changing as expected as a function of frequency. Predictions to exactly calculate the signal intensity distribution seen in experiment would require exact models of the head and coil used in experiment. Additionally, accurate information for the frequency-dependent permittivity and conductivity of tissues would be required.

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