Toward Understanding SAR patterns in the Human Head at High Field (200 to 400 MHz) MRI with Volume Coils

Z. Wang[1], C. M. Collins[1], M. B. Smith[1]

[1]Center for NMR Research, Penn State College of Medicine, Hershey, PA, United States

Introduction

Some recent numerical calculations have indicated a region of relatively high SAR near the center of the brain (1, 2). This can seem counter-intuitive from analytical theory, which predicts a low-SAR region near the center of a symmetric sample in a symmetric magnetic field (3). Here we compare SAR distributions in a homogeneous, symmetric sample (sphere) placed in the center of a volume coil with those for a heterogeneous human head with the majority of brain above the coil center. It is seen that in this case the overall pattern in the brain has some similarities to that in the upper half of the sphere, helping to explain the region of high SAR near the center of the brain.

Method

Cylindrical TEM coils were simulated at frequencies from 200 to 400 MHz and loaded with either a spherical sample of brain-equivalent material or an anatomically-accurate human head model. The coil had 16 copper elements, a 30-cm inner diameter, and a 16-cm length. Each rung was 1-cm wide. The diameter and length of the shield were 38 cm and 24 cm, respectively. Current sources were placed in each of four break points of each rung of the MRI coil and a 22.5-degree phase-shift was set between currents in adjacent rungs. All models had a resolution of 3mm in each direction. For the sphere model, the dielectric constant of 56.1, 51.9, 50.9, and 49.7, and conductivity of 0.51, 0.55, 0.57, and 0.59 S/m were used at 200 MHz (4.7T), 300 MHz (7T), 340 MHz (8T), and 400 MHz (9.4T), respectively. A Four-Cole-Cole extrapolation technique was used to determine values for the dielectric properties of the human head tissues at different frequencies. The tissue parameters and model geometry used in the computer simulation are available from the Brooks Air Force Laboratory database. Home-built 3D FDTD code was used in all simulations. All field values were normalized so that B_1^+ at the coil center had a magnitude of 1μT.

Results and Discussion

Figure 1 shows the SAR distributions on axial, sagittal, and coronal planes through the sphere and head models at 200 through 400 MHz. The SAR distributions are nearly symmetric in any one direction about the center of the spheres. For the spheres, the SAR decreases to a value of zero at the center and maxima are located above and below the center of the sphere, where eddy currents concentrated due to the geometry. These maxima exist throughout each cycle during quadrature excitation. At the lower frequencies, the maximum SAR is located at the edge of the sphere and SAR decreases with distance from the center. However, due to decreasing wavelengths the maximum SAR migrates toward the center of the spheres with increasing frequency, though SAR at the very center remains at a minimum. As the frequency increases, a standing-wave type SAR pattern rather complementary to the standing wave pattern in the magnetic fields exists inside the sphere. On the axial plane this standing-wave pattern gives the appearance of a circular band of enhanced SAR distribution inside the spheres. The diameter of the circular bands decreases with increasing frequency (i.e., is roughly proportional to the wavelength in the brain tissue). These results alone cannot be used to reconcile calculations showing a region of high SAR at the center of a spherical sample placed at the center of a volume coil (4).

Due to its highly heterogeneous and asymmetric nature, the maximum local SAR values in the head are much higher than those in the sphere model (5). As in the sphere, the maximum SAR in the head occurs at different locations with different frequencies. At lower frequency, SAR is nearly zero in the center of the head. With increasing RF frequency, the change in field pattern is not as simple as in the homogeneous and symmetric sphere, but some similarities can be seen. As in the spheres, a high-SAR region above the center migrates toward the center (visible most plainly on the coronal slice). Due to the asymmetric and heterogeneous nature of the head this also appears to drift in the anterior direction at high frequency. A high-SAR region below the coil center is not as evident in the head model because the electrical currents are not as constrained in the neck and shoulders as they are in the upper portion of the head and the spherical geometry.

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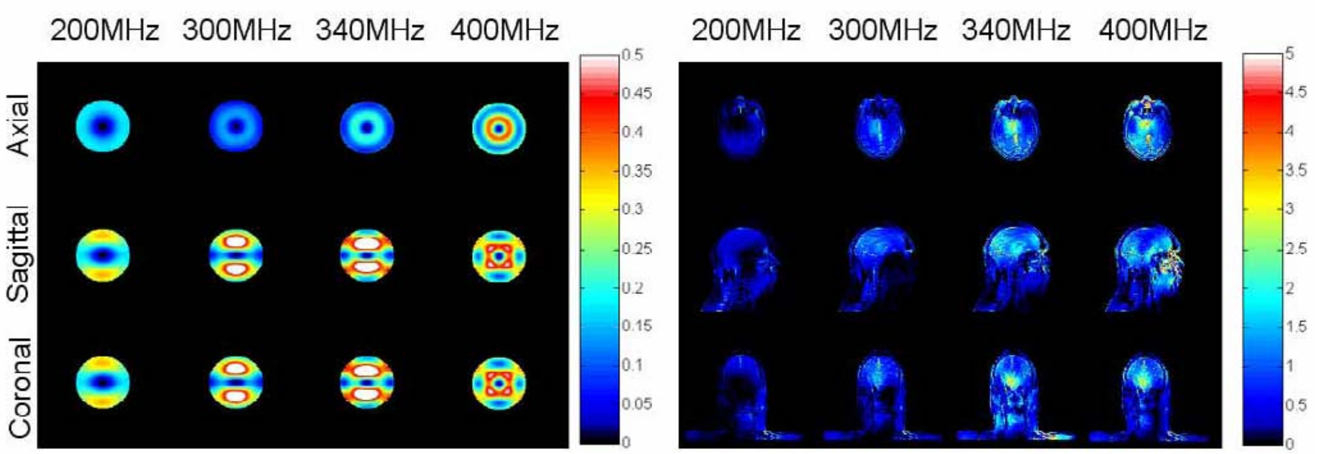

Figure 1. SAR distributions on axial, sagittal, and coronal planes through the sphere and head models at 200 through 400 MHz.