Wave Independence Through Serial Excitation

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Introduction

Since the inception of MRI in the early 1970s, there has been a drive toward stronger magnets, with static magnetic field strengths increasing to 9.4 Tesla for state-of-the-art human research systems, and considerably higher for small animal systems. All promise higher signal to noise ratio, which in turn can be traded for faster imaging and/or improved spatial resolution. However, this promise has been compromised by field focusing and wave behavior within the sample when imaging large objects within traditional quadrature volume coils [1-4]. Severe signal voids have been demonstrated in ex vivo brains, fresh beef, and large cylindrical phantoms at 11.1Tesla [5], as shown in Fig. 1. The relatively short wavelengths make it virtually impossible to produce an external source of spin excitation that has sufficient uniformity to obtain a relatively uniform image of the biological sample. These results demand a new perspective be taken in volume coil imaging, which involves novel coil, pulse sequence, and processing algorithms. In this work, we have investigated making spatial and time dependent images to generate a uniform MR image. As a proof of concept, a CRC (counter rotating current) coil [6-7] was rotated radially around a large cylindrical phantom to acquire independent images. The images were then summed to produce a fairly homogeneous image, which had no significant signal voids.

Methods

A CRC coil was chosen over a single loop because of the improved B1 homogeneity at depth. The coil was placed on an acrylic cylinder of 15.3 cm (6") outer diameter. The outer loop had a diameter of 9 cm and the inner loop 6 cm. The inner loop was displaced vertically 0.5 cm. This geometry is shown in Fig. 2. The CRC was simulated with XFDTD, a finite difference time domain electromagnetic field simulator by Remcom. The Yee-cell was 1mm on a side, the simulation space 180x195x240 cells, and 20,000 time-steps of 1.93 ps were performed. The simulated load had the same electrical properties as the cylindrical phantom used for imaging; ε =48.6, σ =0.6 S/m @470 MHz. The simulated load (diameter 12.5 cm, height 14 cm) was slightly larger than the load used for imaging (2L bottle, diameter 12 cm, height 20 cm). Spin echo imaging was performed on an 11.1 Tesla, 40 cm Magnex clear bore magnet with a Bruker Biospec console. The spin echo parameters were; FOV 20 cm, matrix 256x256, TR 200 ms, TE 10 ms, 1 avg, 3 mm thick slice, sweep width 50 KHz. The CRC coil was first placed at the top of the cylinder, which was referenced as the 0º position. It was then rotated radially around the cylinder, in 45º increments, each time acquiring an image. This approach produces **W**ave **I**ndependence through **S**erial **E**xcitation (WISE™). Other researchers have considered the possibility of performing multiple acquisitions at different times [8].

Results

The FDTD simulation of the excitation field (load present but not shown) is in Fig. 2. The simulation indicates good penetration and fairly homogeneous B1 at depth. Figure 3 shows the axial images from the eight, 45° rotations of the CRC around the tissue equivalent phantom. Figure 4 is the sum of four rotations (0, 90, 180, 270) and Figure 5 the sum of all eight rotations. No significant signal voids are present, whereas, in Figure 5, standard spin echo images acquired with a multi-leg volume coil driven in quadrature, signal voids appear throughout major portions of the image.

Discussion

Large B_1 inhomogeneity can lead to non-uniform flip angles and power absorption throughout the sample, and/or actual signal voids in the image. Therefore, it is important to demonstrate that uniform MR images can be obtained at high frequencies. The summed images of the time and spatial dependent CRC rotations around the sample produce a much more homogeneous image than that acquired by the traditional quadrature volume coil. There are no significant signal voids. The sum of eight is more homogeneous than the sum of four, with the trend indicating that more elements will produce an even more homogeneous image. While it is understood that there are significant developments that need to occur to make this approach practical, we feel we have shown that the concept of spatial and time dependent imaging results in uniform MR images previously impossible.

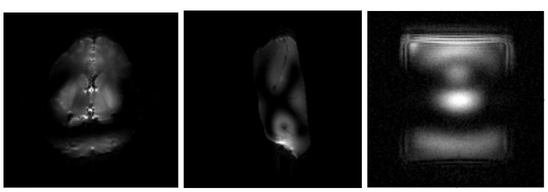

Figure 1 Images of excised brain (left), fresh beef (center), and tissue equivalent phantom (right) acquired with a traditional quadrature volume coil.

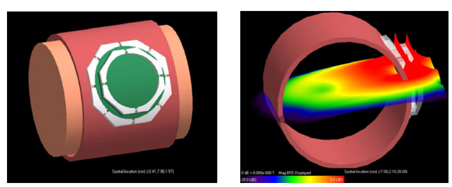

Figure 2 FDTD geometry setup (left), and excitation field (right).

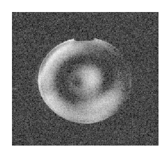

Figure 5 Image using traditional quadrature volume coil

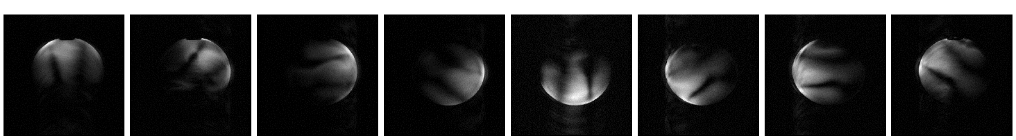

Figure 3 Axial images from eight, 45° rotations of the CRC around the tissue equivalent phantom

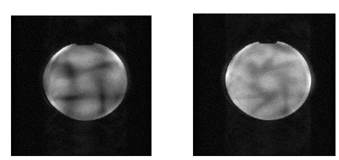

Figure 4 Sum of four rotations (left), and eight rotations (right).

References

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