Wave Behavior in Phantoms at 11.1 Tesla

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Introduction

B1 field inhomogeneities at high magnetic field strengths may be due to wave behavior in the sample itself. As the sample size and static magnetic field strength increase, the wave effects become more significant. In addition, electrical properties of the sample, i.e. the conductivity and permittivity, effect the wave behavior within the sample and the resultant B1 field. Severe B1 inhomogeneities, or large signal voids, on large water and saline samples have been demonstrated at high frequencies[1], but it is widely accepted that such inhomogeneities should not occur in *in vivo* tissue. However, large signal voids have been demonstrated on *ex vivo* brains and a large fresh piece of beef at 11.1T[2]. This study looks at B1 field inhomogeneities in cylindrical phantoms of varying size and electrical properties at 11.1T (470MHz). Specifically, the bottles range in size from 60mL to 2L, and are filled with distilled water, saline, or a solution equivalent to average brain tissue at 470 MHz.

Methods

Three series of bottles were imaged in an 11.1 Tesla, 40 cm Magnex clear bore magnet with a Bruker Biospec console. Each series consisted of 60 mL, 125 mL, 250 mL, 500 mL, 1 L, and 2 L plastic bottles. One series was filled with distilled water (conductivity (σ) = 0.05 S/m, permittivity (ε_r) = 78.7), a second with 50 mM saline (σ = 0.67 S/m, ε_r = 78.7), and a third with a solution (62.5% Acetone, 36.7% D2O, 0.76% KCl) equivalent to average brain tissue[3] at 470 MHz (σ = 0.61 S/m, ε_r = 48.8). The electrical properties of the solutions were measured with an HP85070C dielectric probe. Three different sized ReCav[4] coils were used to keep the filling factor between 45-55% for each bottle setup. Axial and sagittal spin echo images were acquired with the bandwidth per pixel kept constant (400 Hz/pixel). This allowed the use of small field of views (FOV) for the smaller bottles and large FOVs for the larger bottles. The spin echo parameters were; 512 x 512 matrix, TR 300 ms, TE 37 ms, rf pulse width 4000 µs, slice thickness 5 mm, and 1 average. The coils were tuned and matched using an HP4396B network analyzer before each imaging session. For the smaller bottles, 90° pulse widths were chosen by optimizing the digitizer filling. Exact power settings for larger coils were difficult to determine because of severe B1 inhomogeneities, but low power settings were investigated to be sure that the inhomogeneities were not simply caused by over tipping.

Results

Figures 1, 2, and 3 show the imaging results for the three series of bottles. Figure 1 shows the images of the distilled water phantoms. Although B1 inhomogeneities are evident around the edges of the smaller bottles, they are severe (i.e. signal voids in a large part of the image) in the 250 mL, 500 mL, 1L, and 2 L bottles. Figure 2 shows the images of the 50 mM saline bottles, where the electrical conductivity was increased to 0.61 S/m. As expected, the attenuation of the wave because of the increased conductivity changes the B1 inhomogeneity pattern. There are severe inhomogeneities in the larger bottles where diameters and heights are ≥ the electrical wavelength of the phantom. Figure 3 shows the images of the bottles containing the brain equivalent solution. The electrical wavelength is 9.1cm in this solution, longer than the 7.2 cm wavelength of the saline bottles and it appears as though the patterns in the 1 L and 2 L bottles are beginning to repeat the patterns in the 500 mL and 1 L saline bottles.

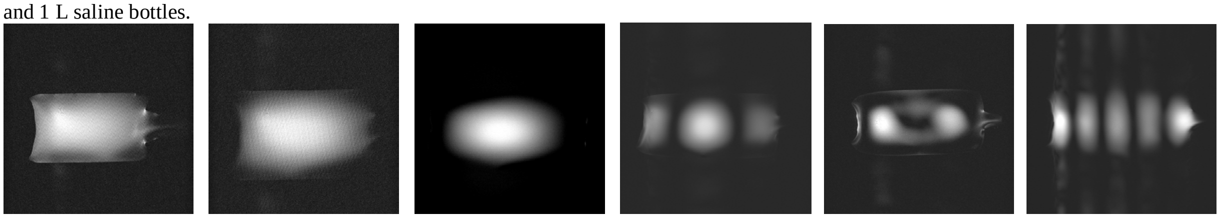

Fig 1 distilled water

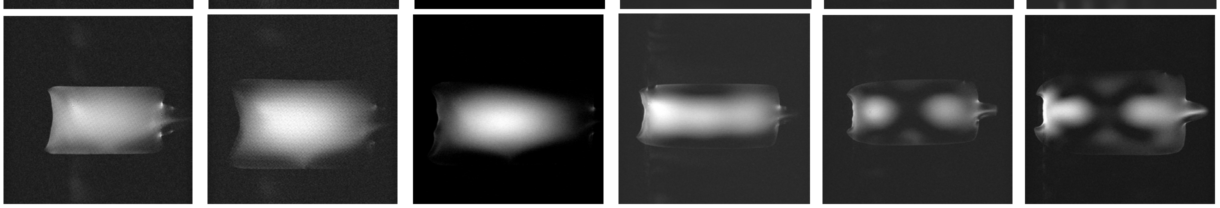

Fig. 2 50mM saline

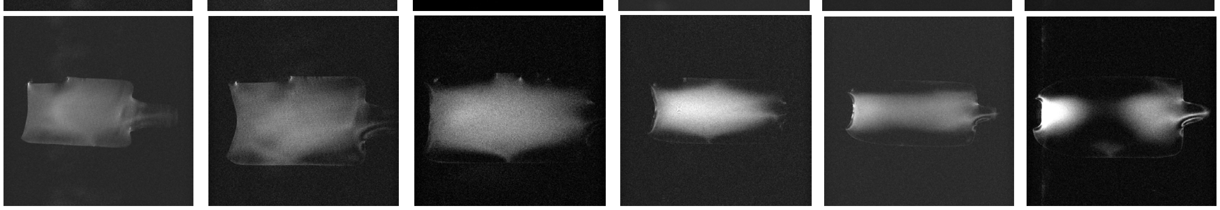

Fig. 3 Brain mixture

60mL, FOV 10 cm | 125mL, FOV 10 cm | 250mL, FOV 15 cm | 500mL, FOV 20 cm | 1L, FOV 25 cm | 2L, FOV 25 cm

Conclusions

The larger bottles are more prone to B1 inhomogeneities because the bottle dimensions are ≥ the electrical wavelength of the phantom and the resultant wave behavior. There are several mechanisms involved with wave behavior; i.e. reflections from boundaries, attenuation in conductive tissues, summation of multiple incident waves, and field focusing, to name a few. The distilled water phantoms likely have multiple reflections from the phantom boundaries as the cause of their B1 inhomogeneities. The known attenuation and strikingly different pattern in the conducting phantoms suggests a different mechanism, perhaps constructive and destructive interference of the multiple incident waves from the multileg coil. The tissue equivalent phantoms have a longer electrical wavelength than the saline phantoms, but patterns in the larger bottles seem to be replicating the patterns of slightly smaller saline bottles, suggesting that large homogeneous in vivo structures at high frequencies may suffer similar B1inhomogeneities. The 'twisting' pattern seen in the 1L / 2L saline and 2L brain mixture bottles has also been observed in a large piece of fresh beef [2].

References

1. Kangarlu et.al. J. Comput. Assist. Tomogr. Vol. 23, No. 6, 821-831 (1999).
2. Beck et. al., 11th ISMRM, Toronto, Ontario, #716 (2003).
3. Beck et. al., 10th ISMRM, Honolulu, HI, #765 (2002).
4. Gabriel, et.al. *Phys Med Biol*, 41:2231-2249 (1996).

Acknowledgements

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