Modeling Magnetic Dipoles to Improve Accuracy of Passive Shimming

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ABSTRACT: To improve magnetic field uniformity, passive shimming has been employed to correct the high-order magnetic field perturbations generated by complex structures like the human head. Patches of high-susceptibility material modeled as point dipoles have been effective in improving magnetic field uniformity. However, to further improve field uniformity, dipoles must be more accurately modeled.

INTRODUCTION: Passive shimming has been effective in correcting small high-order magnetic field perturbations, such as those generated by tissue susceptibility patterns found in the human head. In previous work (1), patches of high-susceptibility copier toner were used for shimming. Each patch had dimensions of 38 × 31 mm and were modeled as point dipoles with the same spacing. To improve the corrections achieved with the passive shimming technique, the material in this patch is evenly divided into smaller amounts and placed closer together, so the physical situation better approximates the point dipole model. The cumulative effect of these smaller patches are calculated and plotted.

METHODS: Effects of a point dipole are modeled using the equation:

$$B_z = \frac{\mu}{4\pi\epsilon_0 c^2}\left(\frac{1}{R^3} - \frac{3z^2}{R^5}\right) \qquad (1)$$

which represents the z-component of the effects of the dipole on the main magnetic field. The material in a single patch is divided into $2 \times 2, 5 \times 5, 10 \times 10, 15 \times 15$ point dipoles and the effects modeled at voxel sizes of 6 mm, 3 mm and 2 mm (corresponding to matrix sizes of 32, 64 and 96 over a 192 mm field of view, respectively). The ideal point dipole and the dipole array into which the patch was subdivided were centered at (145 mm, 0°, 0 mm) in cylindrical coordinates, with respect to the center of the FOV. This value for r corresponded to the inner surface of a local head-gradient coil used for human brain imaging. Fig. 1 shows an axial image from the simulations and the line along which the profile of the dipole is taken.

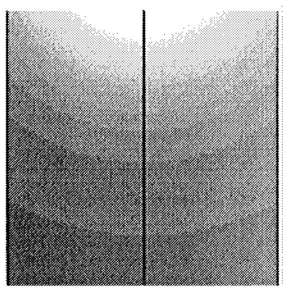

Figure 1: Axial image of dipole effect and line along which profile is measured.

RESULTS: At all voxel sizes, there was slight differences between the profiles of the single point dipole, the 2 × 2 and 5 × 5 arrays, but the deviation in the results disappeared if the dipole was further sub-divided.

DISCUSSION: A single point dipole requires approximately 3.5 MB of computer memory for its distribution over a $96 \times 96 \times 96$ spatial grid. Using 504 dipoles to shim a $32 \times 32 \times 32$ spatial grid requires approximately 30 minutes on a a 1 GHz AMD Athlon processor. Simulations indicate that the present technique, in which a 38 × 31 mm patch of high-susceptibility material was modeled as a point dipole, differs by approximately 0.5 ppm from the limiting cases, where the dipole distribution is more accurately modeled. By sub-dividing the patch into a 2×2, or a 5×5 grid, shimming accuracy can be improved, but in 2^2 or 5^2 times the computational time, respectively. These results indicate it is sufficient to perform the shim calculation over a coarse grid (6 mm voxels) and desired shimming accuracy can be traded with computational time.

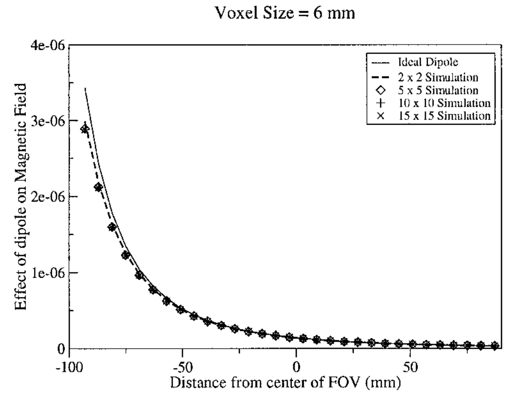

Figure 2: Dipole profile over a 32 × 32 × 32 grid.

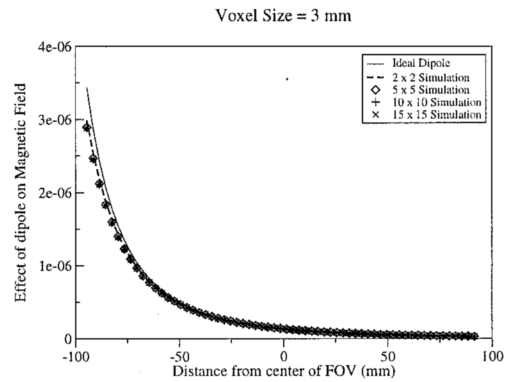

Figure 3: Dipole profile over a 64 × 64 × 64 grid.

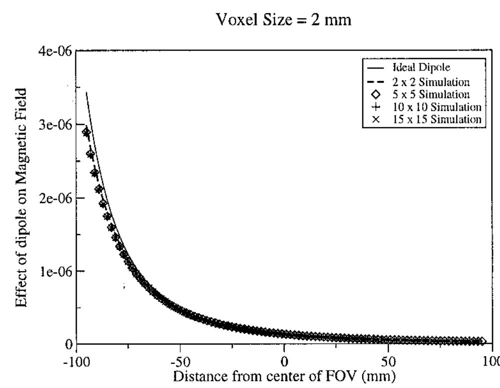

Figure 4: Dipole profile over a 96 × 96 × 96 grid.

REFERENCES:

1. Jesmanowicz, A. et al. *Proc. of the ISMRM, 9th Annual Meeting* (Glasgow), p. 617, 2001.