Effects of Paramagnetic Structures with Simple Geometry on the Magnetic Field Distribution: A Combined Numerical and Experimental Study

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Synopsis

A different magnetic susceptibility of materials or tissue compartments is the reason for the occurrence of fast signal dephasing and artifacts in MRI. In numerical and experimental examinations, field effects due to different susceptibility of simple geometrical structures (plates) were investigated to estimate the influence of geometrical parameters and the interaction of those parameters.

Introduction

Different magnetic susceptibilities of materials generate microscopic field inhomogeneities. This effect is clearly visible in trabecular bone [1,2], resulting from the differences in susceptibility between marrow and bone. Field-sensitive measurements in MRI have shown a clear dependence of T2* values in spongy bone on bone mineral density [3]. Numerical simulations of simple geometrical models were performed to characterize the susceptibility effects more precisely and to elucidate the most determinant geometrical features on field inhomogeneities. Results of a numerical approach were compared with corresponding measurements of phantoms.

Methods

As models for numerical calculation and measurements of phantoms, parallel plates with different orientations to the static magnetic B_0 field were applied. The magnetic field distribution was calculated by superposition of elementary dipoles, which were ordered in a layer simulating a paramagnetic plate. To verify the numerical simulation, we performed corresponding MR measurements of the phantom on a 3T whole-body scanner (Magnetom TRIO, SIEMENS, Erlangen). The visualisation of the magnetic field inhomogeneities between the paramagnetic structures was obtained by using a field-sensitive MAGSUS technique [4]: Excitation with two pulses of 45° and -45° was applied with a delay of $\tau = 96$ ms to produce a pattern of isofrequency lines in the MR image. With an added field gradient, the formation of a pattern of lines nearly perpendicular to the gradient is provoked.

Results

The effects of geometric parameters of plates with materials of different magnetic susceptibility were measured (Fig. 1a) and simulated numerically (Fig. 1b, Fig. 2). Numerical solutions and measurements provided matching field distributions for all geometries tested. Dimension and thickness as well as the orientation of the plates in relation to the static magnetic field affect the field distribution. The field effects of plates are nearly doubled when the object is rotated from parallel to perpendicular position in the magnetic field. Inhomogeneity effects are most dominating at the edges of the plates. Fig. 2 shows dramatic effects on the resulting field distribution between the plates when the plates are shortened.

Conclusion

The chosen dipole model allows to calculate the magnetic field distribution of simple geometrical objects reliably, as quantitatively verified applying a field-sensitive MR technique. It was demonstrated that structural changes in simple geometrical structures might lead to marked changes in the magnetic field distribution. The results contribute to comprehension of the signal performance in field-sensitive MR measurements. The proposed numerical method applying the dipole model allows the calculation of the magnetic field distribution of more complex structures and even arbitrarily shaped geometrical structures in 3-dimensional grids of up to 200x200x200 elements using standard PCs.

References

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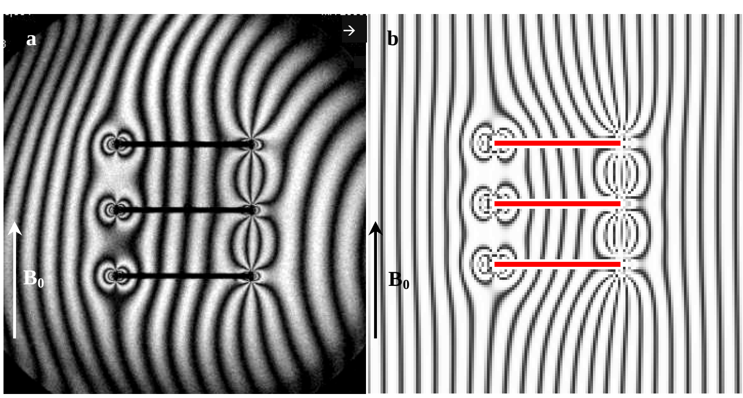

Figure 1: Comparison of a field-sensitive measurement with a calculated field distribution of a simple arrangement of plates.
(**a**) Field-sensitive MAGSUS image of three parallel synthetic plates (50x50x2 mm^3) with a difference in susceptibility to the sourrounding gadolinium-doped water.
Measurement parameters: TR = 600 ms, TE = 150 ms, $\tau = 96$ ms, and an added field gradient of 1 mT/m in phase-encoding direction.
(**b**) Depicted lines of the same field intensity of a calculated field distribution of three parallel layers of dipoles (50x50x2 dipoles) with an added field gradient.

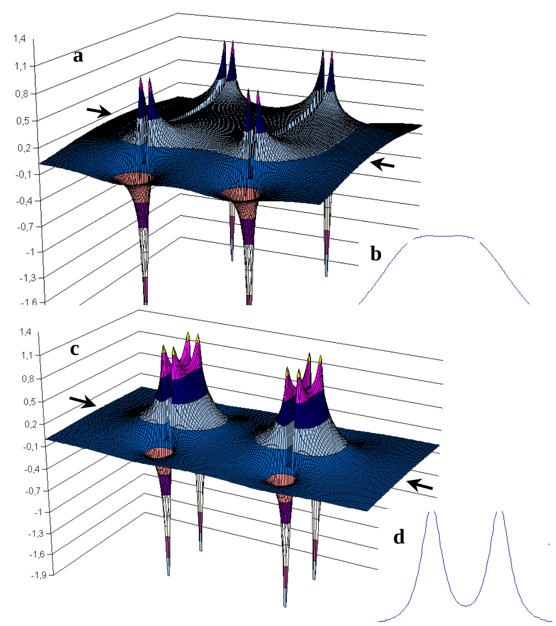

Figure 2: Calculated field distribution of two parallel plates with different dimensions of the plates.
(**a**) Three-dimensional field distribution of two plates with 100x100x2 dipoles with a relative distance of 60 between the plates.
(**b**) Cross-section between the triangles in picture (a).
(**c**) Three-dimensional field distribution of two plates with 25x25x2 dipoles with a relative distance of 60 between the plates.
(**d**) Cross-section between the triangles in picture (c).