Gradient switching induced artifacts near metal parts

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Synopsis

Gradient switching induces eddy currents in metallic implants or instruments if positioned off-center. For larger parts made of well conducting material eddy currents can become strong enough to produce significant temporary static-field inhomogeneity in their neighborhood. Spin-dephasing signal loss is observed even in spin-echo technique. Artifact patterns depend on slice selection, on excitation and read-out bandwidth, and on voxel size.

Introduction

Up to now, eddy currents induced in metallic parts (e.g., implants or instruments) due to gradient switching are assumed to have no influence on MR images. Camacho *et al* [1] also have come to this result investigating a copper (Cu) ring, but only at isocenter. The present paper shows that for sufficiently large metallic parts made of well conducting material significant signal-loss artifacts can occur if the part is located off-center. Even spin-echo (SE) imaging is affected.

Methods

In a 1.5 T MR-scanner (maximum gradient strength: 40 mT/m), a xy-plane orientated Cu ring (d_o=20mm, d_i=15mm, 2mm thick, cross-sectional area of 2.4 cm^2) was examined in a water phantom for two locations: at isocenter and at x=15cm, y=z=0, where only the x-gradient (G_x) could induce eddy currents (Fig.1). Applying 2D-SE technique, xy-, xz- and yz-slices were recorded for both possibilities to select encoding directions. G_x acted either as slice-selection, phase-encoding (PE), or read-out (RO) gradient. Excitation and read-out bandwidth was varied. The artifact behavior of an equivalent titanium (Ti) ring was investigated for comparison (Ti displays 32-times lower conductivity than copper and is a paramagnetic metal; Cu displays water equivalent magnetic susceptibility). Further experiments were performed on a hip prosthesis made of TiAl4V6 and on equivalent model prosthesis from Al. The specimens were arranged according to the application in a patient and examined with their center of mass at isocenter and at x=15cm, y=z=0. Voxel size was varied.

Results

At isocenter, the copper ring reproduced in all MR images according to its geometrical profile. For the Ti ring the typical susceptibility related artifacts due to disturbed gradient linearity became visible. At the off-center position, the Ti ring displayed the same artifact behavior as at isocenter, whereas for the Cu ring characteristic signal loss artifacts occurred. G_x acting as slice-selection gradient, they depended on excitation bandwidth. When G_x acted as RO gradient significant dependence on RO bandwidth was observed (Fig. 2a-c). In all cases where G_x acted as PE gradient, the Cu ring reproduced corresponding to its geometrical profiles (Fig 2d). Fig. 3 shows SE images obtained from the hip prostheses. For the TiAl6V4 specimen equivalent artifacts were observed at isocenter as off-center. The Al specimen showed reduced susceptibility artifacts. At the off-center position, strong eddy currents in the well conducting Al caused significant signal loss near the region where the specimen displayed large diameter. Voxel size enlargement increased artifact extension comparable to spin-dephasing artifacts in gradient-echo technique.

Discussion

Gradient switching induced eddy currents in metallic parts develop more intense in well conducting material. The eddy currents grow with the size of the part, since the induced voltage enlarges with the cross-section of the part; the electric resistance can be estimated proportional to the circumference. At off-center positions, the related magnetic field becomes strong enough, to superimpose significant inhomogeneity to the static field during and short after the gradient ramps. Switching-off a gradient causes an eddy current of opposite sign compared to the one induced by switching-on and rephasing compensates dephasing. This holds for gradients switched on and off between excitation and signal detection (e.g., the PE gradient). For switching-off of the slice selection gradient and switching-on of the RO gradient this compensation is missing. The representation of the artifacts strongly depends on the slice orientation and on the selection of the encoding directions. For complex shaped implants/instruments located at an arbitrary position in the scanner, eddy-current development seems to be quite difficult to predict: Not only the z-component but all components of the gradient-field produce electromagnetic induction. Additionally the eddy currents will experience Lorentz forces in the strong static field. Since the field inhomogeneities are superimposed temporarily, spin-dephasing signal loss also occurs for SE sequences. For the construction of fully MR-compatible implants or instruments low conductivity is as essential as low susceptibility.

References

[1] Camacho *et al*, J Magn Reson Imag 1995;5:75-88

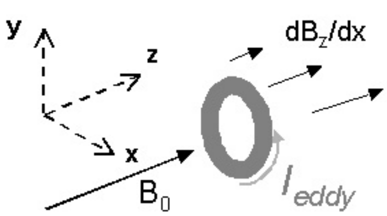

Figure 1: Coordinate system and arrangement of a ring sample to achieve sensitivity on gradient switching induced effects and to avoid RF coupling [1].

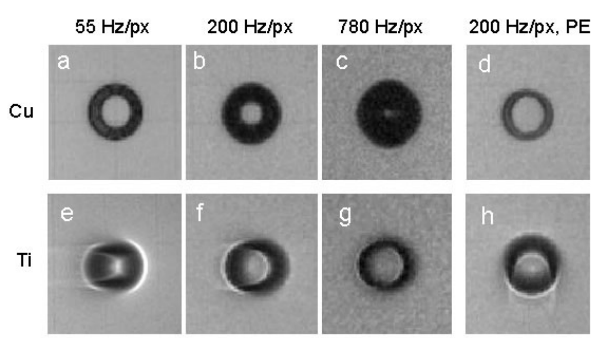

Figure 2: Transverse SE images obtained from the two rings positioned off-center at x = 15 cm, y = z = 0, G_x acting as RO gradient (a-c, e-g). An increase of RO bandwidth enlarges the conductivity-induced artifacts from the Cu ring and reduces susceptibility artifacts from the Ti specimen. For G_x acting as PE gradient (d, h), artifacts from Cu vanish completely.

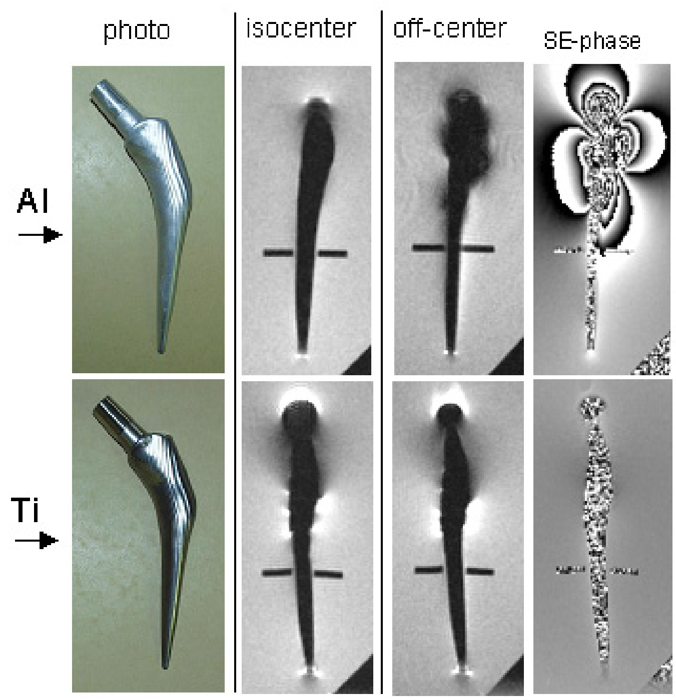

Figure 3: Photos and SE images of the hip prostheses (voxel size: 1 x 1 x 3 mm^3). At isocenter, the Al specimen reproduces almost according to its geometrical profile (near sagittal slice). Off-center, the eddy-current induced spin dephasing signal-loss becomes visible. The SE phase-image confirms this finding. For the Ti prosthesis susceptibility artifacts dominate and due to the bad conductivity of the material no effects from eddy-current induction are observable.