Prepolarized MRI of Orthopedic Implants

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Introduction: Each year, over 300,000 total knee replacements are done in the U.S. Yet, there are no good post-operative imaging methods. CT suffers from beam hardening, and MR suffers severe susceptibility dropouts near the implants. Susceptibility-induced frequency shifts scale with frequency [1]. By imaging at lower frequency, we could reduce artifacts with concomitant SNR loss. In this work we image metal implants at a lower readout field (27mT) using a Prepolarized MRI scanner [2]—which uses a stronger polarizing magnet followed by low-field imaging—and show significantly reduced susceptibility-based artifacts versus those at 1.5T.

Theory: Susceptibility-based resonant frequency shifts in MRI come from local field distortion due to an object's material properties. The shift ($\Delta\omega$) is related to the object's shape, susceptibility (χ), applied field (B_0), and the gyromagnetic ratio (γ) as: $\Delta\omega = \gamma\ \chi\ B_0/2$ for a cylinder.

Table 1 compares Δf for different implant materials at 1.5T and 27mT using this equation. Most MR-safe materials have constant χ below 1.5T, so we expect frequency shift to scale with field. Thus, Δf should be a factor of 56 lower at 27mT.

Methods: We constructed two $CuSO_4$-doped agarose gel phantoms within 6cm x 10cm plastic jars. We placed plastic grids in each to act as reference standards, and in one jar we placed a tibial implant (Titanium alloy base, polyethylene insert). Figure 1 illustrates the orientation of the base plate and its two stabilizing posts with respect to the grid.

To test the difference between susceptibility artifacts at different readout field strengths, we imaged the phantoms with a GE Signa 1.5T scanner, and with our own Prepolarized MRI scanner (27mT). We used spin-echo sequences in both cases. At 1.5T we acquired with TE = 10ms, 31.25kHz BW, 256x128, 24cm FOV, and 3mm slice. At 27mT we acquired with TE = 6ms, 16kHz BW, 128x128, 12cm FOV, and 1cm slice.

Results: Figure 2 presents example images of comparable slices in both phantoms and at both field strengths. The phantoms without the implant (a,b) display characteristic artifacts for images taken with each system. Of note are the moderate distortions in the PMRI image due to main field and RF inhomogeneity, as well as the loss of signal at top and bottom due to the limited extent of our RF coil. These same distortions are present in the PMRI image with the implant (d), but only slight distortions can be seen around the metal implant posts. In contrast, the comparable slice at 1.5T (c) displays severe signal voids, distortions, and other artifacts.

Conclusion: As expected, the susceptibility artifacts in 27mT images are significantly reduced as compared to those in 1.5T images. Indeed, the susceptibility artifact from the Titanium implant at 27mT seems less severe even than air-tissue susceptibility artifacts at 1.5T. These results confirm the theoretical prediction that susceptibility artifacts would be greatly reduced with Prepolarized MRI due to the lower readout field strength, and encourage further development of low-field methods for imaging metallic implants.

References

[1] Schenck, JF, Med Phy 1996, 23(6):815-850
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Material	$\Delta\chi$ (ppm)	Δf at 1.5T (Hz)	Δf at 27mT (Hz)
Air	10	640	11.4
Titanium	182	11700	209
Chromium	320	20500	364

Table 1: Susceptibilities and frequency shifts for cylinders of different materials transverse to the main field at 1.5T and 27mT in water.

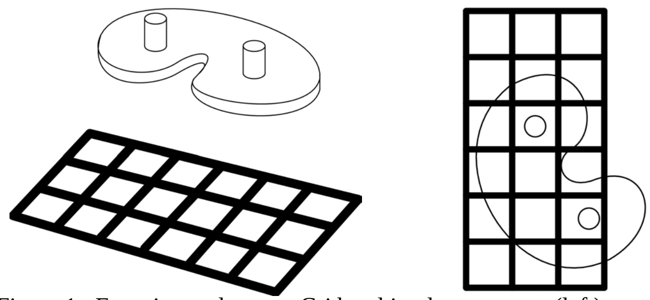

Figure 1: Experimental setup. Grid and implant separate (left). Implant posts within grid, as situated in the gel phantom (right).

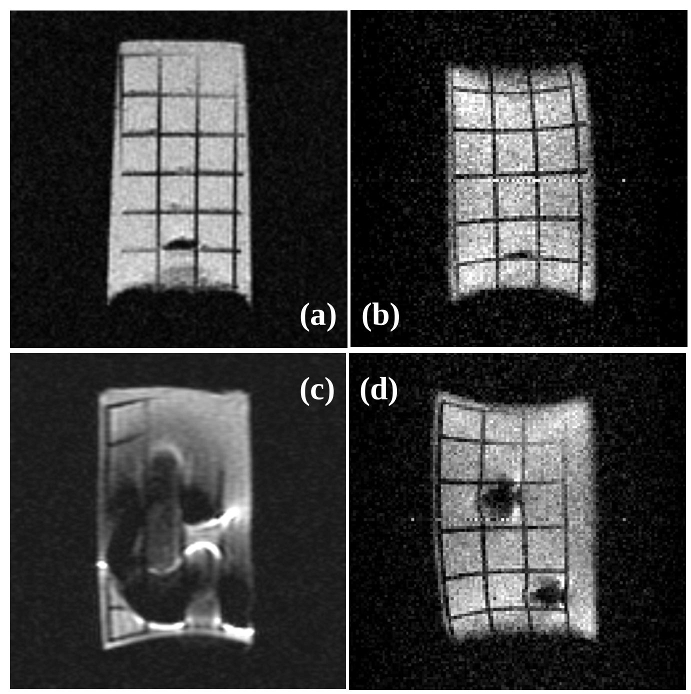

Figure 2: Spin-echo images acquired on 1.5T GE Signa scanner (left) and on 27mT PMRI scanner (right). (a,b) Agarose gel phantom with plastic grid. (c,d) Agarose gel phantom with grid and Titanium tibial plate implant. Note that two dark areas in (d) are the implant posts. PMRI images both show similar warping artifacts despite the presence of large amounts of metal in the second image.