Off-resonance MRI for Detecting T_1 Changes around Metallic Implants

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Introduction: Detection of prosthetic joint infection is done with radionuclide labeled leukocyte imaging (1) and cannot be done with conventional MR imaging because of signal dephasing in the magnetic field of the metallic implant. Off-resonance excitation and refocusing has been used to image cells labeled with magnetic nanoparticles (2). We show that T_1 measurements can be made close to the implant using positive contrast MR imaging and thus has the potential to detect T_1 changes in tissue from prosthetic joint infection.

Materials and Methods: A 0.100 M copper(II) sulfate ($CuSO_4$) solution was prepared from copper(II) sulfate pentahydrate (C8027, Sigma-Aldrich Canada, Oakville, Canada) and heated to ~80ºC in an 80 mL plastic specimen cup. 2.70 g of agar (A7002, Sigma-Aldrich Canada, Oakville, Canada) was added to make a 5% w/w gel. Before the gel had sufficient time to solidify, a refrigerated cobalt chromium molybdenum alloy femoral implant with a 51-mm head diameter was dipped, tip first into the gel and removed slowly. After allowing the thin layer of gel to solidify, the tip of the implant was dipped into the gel again and removed slowly creating a layer of agar ~2 mm thick in total. A thin layer of liquid bandage (Nexcare, 3M Canada, London, Canada) was painted onto the hardened gel to decrease diffusion of $CuSO_4$. The implant was refrigerated for 10 min before this process was repeated with 0.075 M and 0.050 M $CuSO_4$ solutions and the appropriate mass of agar to make 5% w/w agar gels. After the last coat of liquid bandage was applied, the implant was refrigerated for 10 min and then completely submerged into 5% w/w agar gel in a 2 L rectangular pyrex dish. The agar was allowed to solidify overnight.

The T_1 of the $CuSO_4$-doped agar in the specimen cups were measured next to one containing undoped 5% w/w agar using spectrally-selective RF pulses (2) at the resonance frequency of water using a 1.5T MR scanner (GE Signa HD, GE Healthcare, Waukesha, WI) with TE = 14 ms, TR = inversion time + 500 ms, N_x = 128, N_y = 256, and FOV = 12 cm coronal projections. The inversion times used were 50 ms, 25 ms, 12.5 ms, 6.2 ms, and 5.9 ms. T_1 maps of the $CuSO_4$-doped agar on the implant, which was placed coaxially with the MR scanner bore, were made at the off-resonance frequencies 2000 Hz above and 1500 Hz below the resonance frequency of water in 500 Hz steps.

Results: The T_1 values of the 0.100 M, 0.075 M, 0.050 M $CuSO_4$-doped, and undoped agar were 14.7 ± 1.5 ms, 20.1 ± 1.6 ms, 29.8 ± 0.9 ms, and 1088 ± 391 ms, respectively. T_1 values measured in the $CuSO_4$-doped agar are shown in Table 1.

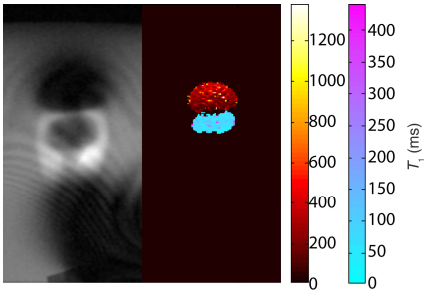

Fig. 1: Proton image (left) and T_1 map (right) of the tip of the hip implant imaged at 1 kHz above (red, larger cluster) and 1 kHz below (blue, smaller cluster) the water resonance frequency.

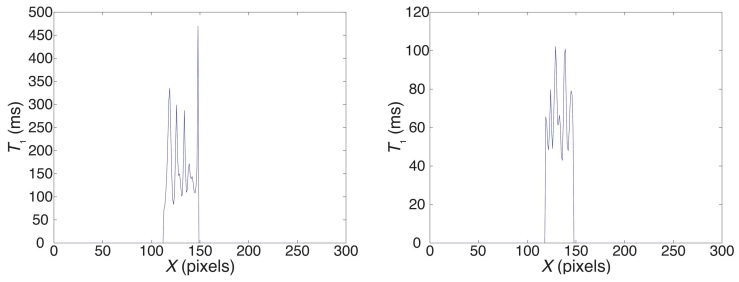

Fig. 2: Horizontal cross section of T_1 values in the $CuSO_4$-doped agar measured at 1 kHz above (left) and below (right) the water resonance frequency.

Frequency Offset from Water Resonance (Hz)	T_1 (ms)
+2000	135 ± 69
+1500	140 ± 36
+1000	168 ± 84
+500	208 ± 66
–500	90 ± 19
–1000	67 ± 16
–1500	52 ± 25

Table 1: Measured T_1 values in $CuSO_4$-doped agar

Discussion: Measuring at increasing frequency offsets from that of the water resonance are expected to counter the magnetic field inhomogeneities caused by the metallic implant. This is seen in the results presented in Table 1. Since the layers of agar were constructed to have decreasing T_1 values closer to the implant, the decreasing measured T_1 values indicate the ability to measure increasingly closer to the implant. The measured T_1 values in the vicinity of the implant are larger than expected presumably due to a combination of diffusion of $CuSO_4$ out of the individual layers into the surrounding undoped agar and a partial volume effect between the agar layers. The positive frequency offset region appears larger than the negative one possibly due to the magnetic field geometry near the implant. Though images were acquired in this experiment, off-resonance T_1 measurements are inherently localized and could be performed in 3 s per off-resonance frequency.

Conclusion: T_1 values of agar can be measured in the vicinity (on the order of millimeters) of metallic hip implants using a positive contrast spin echo technique. This can potentially enable the detection of prosthetic joint infection.

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References: 1. Palestro et al. Best Pract Res Clin Rheumatol 2006;20(6):1197–1218. 2. Cunningham et al. Magn Reson Med 2005;53:999–1005.