A Low-noise, Susceptibility-matched Solution for Endorectal Imaging of the Prostate

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Introduction: Endorectal coils are often used in prostate MRI. The small FOV offered by an endorectal coil provides high resolution and SNR. Inflatable coils, such as the Medrad MRInnervu, offer a well-tolerated, disposable, and high SNR method for endorectal imaging; however, the inflated coils can result in 10 ppm susceptibility artifacts at the air-tissue interface [1]. This presents a serious challenge for applications such as thermal ablation and spectroscopy that require 0.1-1.0 ppm homogeneity [2, 3]. Here we investigated whether an inflatable coil filled with manganese chloride solution could provide a susceptibility-matched, low-noise solution for endorectal imaging.

Methods: To minimize noise power contribution from the paramagnetic ion solution, a low-conductivity solution was desired. It was determined that Mn^{2+} offered the shortest T2 relaxation time at the lowest conductivity as compared to other paramagnetic ions such as Gd^{3+}, Cr^{3+}, Ni^{2+}, and Cu^{2+} [4]. In order to achieve rapid T2 decay, solutions of $MnCl_2{\cdot}4H_2O$ with concentrations between 2-9 mM were prepared. The DC conductivity of the solution was measured (Scientific Products, Evanston, IL). From the conductivity values, a relative noise power contribution of the $MnCl_2$ solution was calculated and compared to the expected noise power contribution from the body [5]. To verify the noise calculation, a Medrad MRInnervu endorectal coil was modified for unloaded and loaded Q measurements (HP 3589A Network Analyzer). A test setup consisting of 3.5mL vials of water, three concentrations of $MnCl_2$, and air was submerged in a water bath perpendicular to the main field in a GE 1.5T Signa scanner. An off-resonance frequency map was derived from the phase difference of two gradient recalled echo images (TE_1=15ms, TE_2=18ms).

Manganese Chloride Concentration (mM)	Mean DC Conductivity (S/m)	T2 Relaxation Time (ms)
9	0.15	1
4	0.07	3
2	0.04	5

Table 1. Mean DC conductivities and T2 relaxation times for three concentrations of $MnCl_2$.

Coil Condition	Unloaded Q	Loaded Q
Air-filled	61.8	28.0
$MnCl_2$-filled	50.9	28.1

Table 2. Q measurements for a Medrad MRInnervu coil filled with 60mL air vs. 60mL $MnCl_2$. The loading condition was a 900mL bath of saline doped to the conductivity of blood at 64 MHz [7].

Results: Table 1 summarizes the conductivity measurements and relaxation times determined for three concentrations of $MnCl_2$. For three samples of 9 mM $MnCl_2$, the mean conductivity was measured to be 0.15 S/m, less than a third of the conductivity of human tissue. Thus, it is expected that body and coil noise will dominate, and SNR should be degraded by less than 15% with the addition of $MnCl_2$ to the coil. Table 2 presents the Q measurements for the inflatable coil filled with air and with $MnCl_2$, both loaded and unloaded. When the $MnCl_2$-filled coil is loaded with a saline solution, the change in Q from the air-filled case is negligible. Figure 1 depicts the susceptibility artifact resulting from the air-filled vial in comparison to the $MnCl_2$ and water-filled vials.

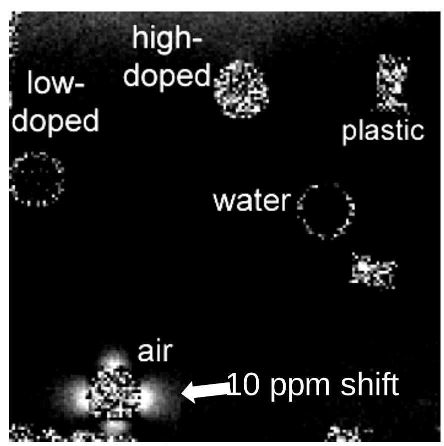

Figure 1. Magnitude of the off-resonance frequency. The air-water interface results in a characteristic dipole pattern outside the air vial. No dipole pattern exists outside of the three solutions. A lack of signal, such as from the plastic, manifests as phase noise. The doped solutions would be ideal for filling the inflatable coil because no artifact results.

Discussion: The off-resonant frequency map demonstrates that a vial filled with $MnCl_2$ solution will not cause a susceptibility artifact. In addition, the Q measurements indicate that the addition of $MnCl_2$ to an inflatable endorectal coil will not significantly degrade the SNR. The health hazard associated with using a $MnCl_2$-filled coil *in vivo* has not yet been fully examined. The required amount of 8.5mM $MnCl_2$ solution to fill a 60cc inflatable endorectal coil is 0.007% of the LD50, 1484mg/kg [6]. Thus, it is expected that the $MnCl_2$ would be safe for use in humans.

Conclusion: An inflatable coil filled with manganese chloride solution provides a low-noise method for effectively eliminating susceptibility artifacts during endorectal imaging. This approach is promising for demanding applications such as thermometry and spectroscopy, where achieving 0.1 ppm homogeneity can be critical.

References:

[1] Schenck JF. Med Phys 23(6): 815-850, 1996.
[2] Butts K, *et al.* JMRI 17(1): 131-135, 2001.
[3] Kurhanewicz J, *et al.* JMRI 16(4): 451-463, 2002.
[4] Morgan O, *et al.* J Chem Phys 31(2): 365-368, 1959.
[5] Suits BH, *et al.* JMR 135(2): 373-379, 1998.
[6] Material Safety Data Sheet $MnCl_2{\cdot}4H_2O$. Seton Resource Center. 1997.
[7] Gabriel C, *et al.* Phys Med Biol 41(11): 2231-2249, 1996.