Evaluating Transverse Relaxation Trends in Cobalt-Chromium Particulate Deposits

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Introduction: MR techniques have recently been employed to assess soft tissues surrounding hip arthroplasties composed of metal-on-metal articulations. The complications from such replacements have been attributed to both high rates of wear (1) and hypersensitivity reactions without high wear rates (2). The ability to differentiate between and within these classes of local tissue response using MR means would be highly advantageous.

Some of the variation between metal-on-metal adverse tissue reactions involves the presence of microscopic particulate matter of high magnetic susceptibility. Therefore, a potential differentiating contrast may be gained from the transverse-plane relaxation rate, R2*. As an initial investigation into this possibility, here we present a phantom analysis measuring R2* rates as a function of cobalt-chromium (CoCr) alloy particulate concentration. .

Unfortunately, conventional R2* measurements are not feasible near most hip replacements, due to the substantial signal loss and distortions encountered in gradient echo images near metal implants. To address this problem, we postulate that some, if not a majority of the observed R2* effect is an irreversible R2-based mechanism. Under this guiding postulation, we demonstrate R2-based magnitude contrast using CPMG-based MAVRIC metal artifact suppression techniques. A more intricate means of quantifying particulate compositions using MAVRIC-based acquisitions is also proposed.

Methods: A phantom was constructed of 2% agarose, with 6 deposits of 44um CoCr alloy particles of varying volume densities. The volume densities utilized were [0.039 0.071 0.156 0.312 0.625 1.150]% (w/w). The CoCr deposits were placed on 3 vertically stacked plates, with 2 deposits per plate. Gradient-echo images were acquired on the assembly (256x192, 3mm slices, TR= 300ms) at echo times of 6ms, 7.5ms, and 9ms. Mean pixel values were determined from 0.36 cm^2 ROIs in each of the deposit regions. Exponential fits of the mean pixel values in the echo-time domain then provided R2* estimates for each sample CoCr concentration. Uncertainty estimates of the fits were determined as 50% confidence intervals using Matlab's *polyval()* function. R2* estimates were then plotted against CoCr concentration to assess a general trend of R2* as a function of CoCr particulate concentration. MAVRIC SL [3,4] images were also acquired on the CoCr agarose phantom to investigate possible contrast changes using a sequence that is feasible in the presence of metallic implants.

Results: Figure 1 presents calculated R2* rates from gradient-echo images acquired on the agarose phantom. The large confidence intervals render it difficult to identify an analytic trend of the R2* dependence with CoCr deposit concentration; however, it is clear that R2* has a strong dependence on the presence and [CoCr].

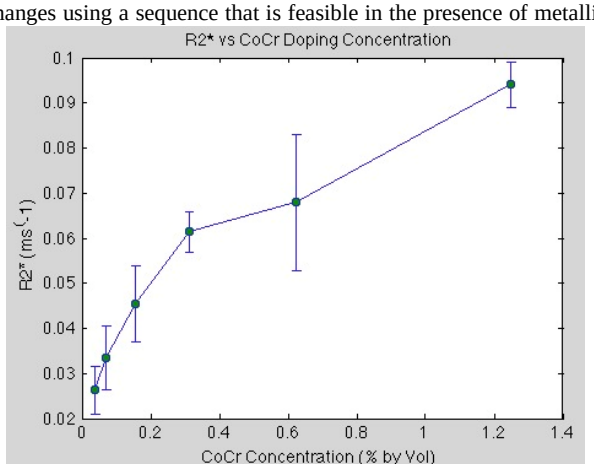

Figure 1: *R2* vs cobalt-chromium alloy particulate concentration*

Figure 2 presents a MAVRIC SL magnitude image of a sample with 0.625% and 1.150% CoCr deposits. The effective echo-time of the MAVRIC SL acquisition is roughly 8ms, with a TR of 4s – rendering the objective contrast to be proton-density in nature. However, even with this limited effective echo time (and negligible modification of the available imaging protons), we see a clear contrast differentiation between the two deposits, where the larger concentration has generated more signal loss in the 8ms echo time. This lends support to our postulation that the microscopic CoCr particulate debris is generating a substantial T2 component of relaxation, which will remain even in the presence of CPMG refocused acquisitions, such as MAVRIC SL.

Discussion: These results demonstrate clear transverse relaxation effects in the presence of CoCr deposits of modest concentration. This correlates with previous clinical observations that metallosis results in diminished T2-weighted signal characteristics [5]. A complication of the method is the measured non-linear relationship between R2* and [CrCr] which may require a poly-exponential analysis. The relaxation and signal dynamics near this type of debris has not been investigated to date. While these initial conclusions are encouraging, there are a variety of further developments and investigations that will need to be undertaken to demonstrate their clinical relevance.

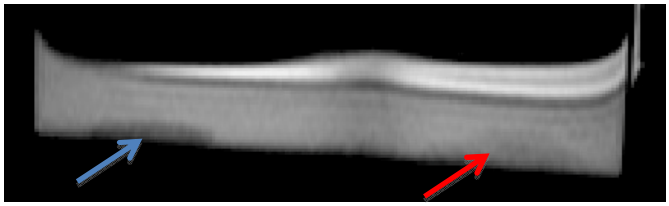

Figure 2: *MAVRIC SL* image demonstrating differing magnitude contrast for CoCr concentrations of 1.15% (blue arrow) and 0.625% (red arrow) with an effective echo time of 8ms

First, the size and distribution of particulate debris needs to be carefully correlated with clinically encountered in-vivo distributions and geometry. In this work, we have assumed and utilized roughly 50um particulate dimensions. Variations of the sizes and heterogeneity of particulate matter could impact the simple relaxation models that are assumed in this work.

Second, the exact mechanisms of the observed contrast need to be further studied. Experiments examining single spin-echo acquisitions with variable echo-time, as well as CPMG spin-echo acquisitions with variable echo-spacing need to be undertaken. This will help to clarify the R2 mechanisms that have crudely been observed in MAVRIC-SL images to date.

Finally, a means of using MAVRIC SL to quantify transverse relaxation in lesions near metal interfaces needs to be identified. A tempting line of investigation is in the "MAVRIC temporal domain", which has previously been presented and exploited to generate microscopic phase-contrast images near metallic devices [6]. It is hypothesized that information relevant transverse relaxation may be contained in magnitude data when viewed in the MAVRIC temporal domain.

[1] Amstutz et al, Orthop Clin. North Am, 42, 207-230, 2011 [2] Langton et al, J. Bone Joint Surg Br, 92, 164-171, 2011 [3] Koch, MRM 61:381-90 2009 [4] Koch, MRM 65:71-82 2011, [5] Toms et al, Brit. J. Rad, 82 (2009), e87–e91, [6] Koch, Proc ISMRM, 2012,