Rapid multiparametric mapping near orthopedic implants at 3T using plug & play parallel transmission

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INTRODUCTION: Under some circumstances, the complex electrodynamic interactions between the subject and the incident RF field can distort RF excitation to such an extent that the diagnostic value of MRI is compromised [1]. Metal implants, in particular, are a well-known source of MR artifacts, resulting not only from distortion of the main magnetic field, but also from distortions of the excitation RF field [2]. In this work, we explore the potential of a generalized implementation of the recently proposed plug & play parallel transmission (PTX) framework (3), to enable rapid multiparamatric mapping (T1, T2, PD) in the presence of orthopedic implants.

THEORY AND METHODS: At 3 Tesla, large metal implants such as the titanium rod depicted in figure 1A can interact significantly with the incident RF field. Depending on the polarization of the applied RF field, different reactive fields are produced which in turn perturb the uniformity of the excitation. When one uses a single RF transmitter configuration, such as the circularly polarized mode of the birdcage coil, a signal void can appear in the image (**Fig. 1B**). However, each of the two linear modes, traditionally combined together to comprise the quadrature excitation, interact differently with the implant. By driving these modes independently, complementary field distributions can be formed to secure sufficient signal throughout the field of view.

To demonstrate this principle we designed a generalized PTX fingerprinting sequence (**Fig. 2**), which consists of 4 segments each containing 120 excitations 4.8ms apart. The first and third segments contain RF spoiled gradient echoes that predominantly encode B_1^+ and T1, whereas the other segments also add a T2 relaxation component (no RF spoiling). Collectively, these 480 snapshots capture a distinct signal evolution (the MR fingerprint) that simultaneously identifies the RF-field distributions and the tissue properties. To increase T1 accuracy and help decouple transmit phase interactions a strategically chosen delay was inserted between segments. Interleaving 6, or more, slices, each delay can be used to image a different slice, thus eliminating all dead time in the protocol. A golden angle radial sampling strategy was selected to promote incoherence between undersampling artifacts [3]. The reconstruction dictionary was pre-computed based on the extended phase graph formalism [4] and was permanently stored. The underlying tissue properties in each voxel were retrieved by identifying the dictionary element that best correlates with the compressed fingerprint. The matching algorithm was implemented in MatLab (The MathWorks, Inc., Natick, Massachusetts, United States) augmented with C++ code.

To validate the accuracy of the proposed approach, phantom measurements were performed. The phantom consisted of 7 test tubes (2.5cm diameter), filled with distilled water doped with different concentrations of Manganese Chloride. The matrix size was 160x160, with an in-plane resolution of 1.5x1.5 mm^2, TR/TE = 4.8/2.3 ms, 5.0 mm slice thickness. Single spin echo experiments were performed to obtain a gold standard T1 map (TI = {25, 50, 100, 200, 400, 800, 1600, 3200, 6400} ms) and T2 map (TE = {12, 24, 36, 48, 60, 72, 84, 96, 144, 192, 278, 384} ms). In both cases a repetition time of 6.5s was selected to minimize saturation effects. Fitting of the T1 and T2 was performed in Mathematica.

Bilateral leg images (same volunteer as shown in **Fig. 1**) were acquired using the lower extremity receive array in a clinical dual-transmit 3 Tesla system (Siemens, Erlangen, Germany). Sequence parameters were: 224x224 matrix, 2x2mm^2 in-plane resolution, TR/TE = 4.8/2.3 ms, 5mm slice. Each snapshot consisted of 22 radial spokes for a total scan time of ~5min (51s per slice). The study was approved by our institutional review board (IRB), and written informed consent was obtained prior to the examination.

RESULTS & DISCUSSION: Good accuracy and precision is maintained over a broad range of physiological T1 and T2 values (**Fig. 3**). At the far end of the spectrum, i.e. for T2>150ms, substantial deviations can be observed. Due to the relatedly short duration of the T2 encoding segments (~0.6s), the encoding of large T2 values is compromised. For most clinical applications this should not be a problem, but if desired longer segments could be used to increase the sensitivity to long T2.

The in-vivo measurements reveal the RF interactions with the implant (**Fig. 4**, top). Although highly non-uniform, the transmit sensitivities profiles remain complementary, allowing accurate artifact free quantitative maps to be reconstructed throughout the field of view.

The lack of adiabatic pulses or other power-intensive pulses in this multi-transmit fingerprinting sequence allows for low SAR in quantitative imaging (30% of the limit in this study). Moreover, an efficient "plug & play" workflow is maintained, free from patient specific calibrations or complicated procedures. Such an approach can easily be generalized to other parts of the body.

REFERENCES: [1] Bernstein JMRI 2006; 24:735–746. [2] Graf, et al., MRM, 2005;23:493-9. [3] Cloos et al., ISMRM 2014 p542. [3] Winkelmann, et al. IEEE-TMI, 2007;27:68-76. [4] Weigel JMRI, 2014; DOI: 10.1002/jmri.24619

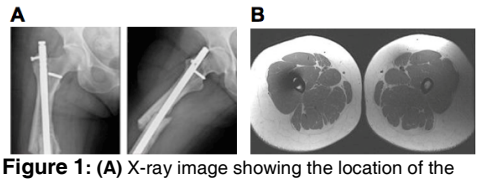

Figure 1: **(A)** X-ray image showing the location of the Orthopedic Implant (Titanium rod, approved for 3T MRI). **(B)** Axial turbo spin echo image with B_1^+ artifact near the implant due to interactions with the incident RF field (3T).

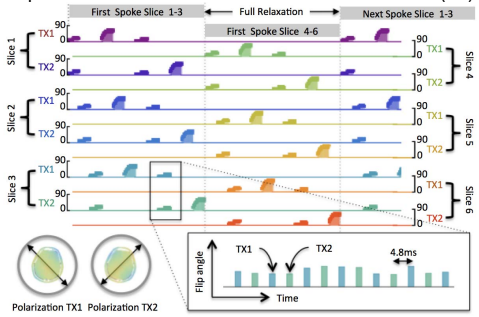

Figure 2: Sequence diagram, illustrating the plug & play parallel transmit sequence.

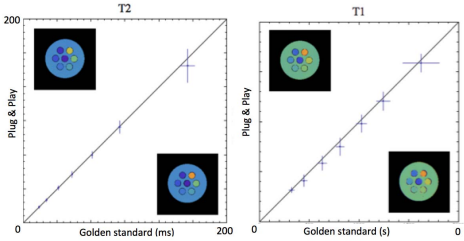

Figure 3: Validation against established gold standards of T2 (left) and T1 (right) values obtained with the proposed MR fingerprinting technique. Each datapoint shows average and standard deviation of T2 and T1 in a different phantom compartment.

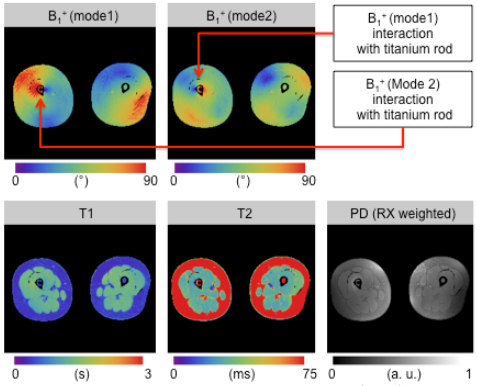

Figure 4: Quantitative parametric maps (B_1^+, B_1^+, T1, T2) obtained in-vivo at 3T (2x2 mm^2, 5mm slice, total scan time ~45s per slice).