Consistency of T1ρ Measurements: A Phantom Study

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Introduction:

Magnetic resonance imaging (MRI) remains the primary standard for visualization of cartilage defects and overall assessment of cartilage morphology. As the initial stages of osteoarthritis (OA) arise from biochemical changes at the tissue level such as proteoglycan (PG) loss, the standard contrast mechanisms acquired as part of routine clinical MRI protocols are not typically sensitive to hallmarks of early OA. A number of MRI-based methods have been developed and studied for their potential to serve as imaging biomarkers for these early changes. Examples include T2 mapping to evaluate collagen matrix integrity[1], and dGEMRIC [2] and T1ρ [3-4] imaging to assess proteoglycan depletion.

Among these methods, T1ρ imaging has held particular interest as it has demonstrated sensitivity to PG content (the primary target of dGEMRIC) while being straightforward to apply without the need for an exogenous contrast agent (like T2 mapping). T1ρ relaxation times are reflective of the low-frequency interactions between water and macromolecules, such as PG. These interactions are probed by preparing the magnetization with low power but relatively lengthy RF pulses prior to a repetition of a standard MR pulse sequence (typically a spin-echo or gradient-echo-based acquisition).

Ideally, T1ρ relaxation times should not depend on the scanner or coil hardware used to acquire the images. However, variations in the main (B0) field as well as the RF pulses (B1) over the volume of the coil may affect the quantification of T1ρ maps acquired on different hardware. These variations may complicate T1ρ assessment of cartilage degradation in populations or series acquired on a variety of hardware. The purpose of this study was to assess the consistency of T1ρ measurements across multiple acquisition platforms in a controlled phantom study.

Methods:

A purpose-built phantom was designed and constructed to assess pulse sequence and artifact conditions across MR imaging sequences and platforms specifically for imaging protocols in the knee (Figure 1). The phantom consisted of concentric Plexiglas rings separating compartments filled with a mixture of carrageenan and agarose gel and doped with gadolinium trichloride (GdCl₃). As described in Figure 1, the concentrations of agarose and GdCl₂ were varied to generate gels having T1ρ relaxation times over a range similar to that for cartilage. The central core was filled with lipid material (lard). The dimensions of the phantom were designed to fit inside and fully load typical extremity coils used for joint imaging.

Identical T1ρ imaging protocols were acquired on each of two 3T Siemens TIM Trio scanners, utilizing each of two transmit-receive extremity coils (one single-channel CP coil, one 15 channel coil) for a total of four complete imaging sessions. For all sessions, the pulse sequence consisted of a T1ρ preparation block applied to a fast spin echo pulse sequence with TR/TE=3000/12 ms, echo train length of 7, and 256 x 128 matrix over 3 slices. The T1ρ block consisted of a 90° square tip-down pulse, 400 Hz spin lock pulse of four different durations (10, 20, 40, and 60 ms, implemented as in [5] to minimize B1 inhomogeneity effects), a -90° tip-up pulse, and a final crusher gradient. The acquisition plane was oriented sagittally with a field of view of 160 x 160 mm² and slice thickness of 4 mm, equivalent to a typical in vivo protocol.

For each session, tuning with a 3D shim procedure was followed by the four spin-lock time acquisitions. To further assess the effects of B0 changes, the central acquisition frequency was adjusted over a range of ± 4% from the center of the coil at the outermost ring.

Results:

Figure 2 shows the mean and standard deviation of all T1ρ measurements (two regions in each of three slices) made in the five gels for each scanner and coil combination. The largest difference in mean T1ρ among scanner/coil combinations was 1.9 ms, seen in the 3% gel (on different scanners with the same coil), while the variation in the 5% gel was less than 0.7 ms. Some spatial variation in measured T1ρ was seen in the outer ring in one coil (anterior and posterior measurement differing by 8 ms in one slice), potentially due to coil B1 variations. T1ρ measurements changed by less than 1 ms over the ±25 Hz frequency range for the 3%, 4%, and 5% central gels, while the standard deviation of the measurements typically increased by a factor of 2 for the largest frequency perturbation.

Discussion:

The results from this multiplatform investigation validate that consistent T1ρ measurements can be made on multiple scanner and coil platforms, an important requirement for the widespread use and comparison of T1ρ imaging. Furthermore, the developed phantom may serve as a useful calibration and quality control tool for translating T1ρ pulse sequences to additional platforms.

References:


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Figure 1: Phantom consisting of (from outside to center) five layers of 1% carrageenan doped with 1-5% agarose and 100-200 μM gadolinium trichloride surrounding a central core of lipid material. The image at right depicts a sagittal MRI slice through the center of the phantom.

Figure 2: Mean ± standard deviation of calculated T1ρ relaxation times for each gel, scanner, and coil combination, showing consistency of results across environments. Variability in the 1% gel may reflect B1 inhomogeneities at the edges of the coil at the outermost ring.