In Vivo High-Resolution $T1_\rho$ MRI of the Wrist at 3T: Usefulness of Realignment during Post-Processing

Hon J Yu[1], Dave Michael Hitt[2], and Hiroshi Yoshioka[3]

[1]*Tu & Yuen Center for Functional Onco-Imaging, University of California, Irvine, Irvine, CA, United States,* [2]*U.S. Clinical Science, Philips Healthcare, Cleveland, OH, United States,* [3]*Radiological Sciences, University of California, Irvine, Orange, CA, United States*

Target audience:

Clinicians/researchers in study of cartilage via MR-based mapping techniques for functional assessment.

Purpose:

$T1_\rho$-map via MRI has been previously demonstrated for quantification of proteoglycan-induced changes in cartilage[1] and thus, presents a potential means for quantitative in vivo functional assessment in detecting early osteoarthritic cartilage damage before the associated morphologic changes in cartilage or clinical symptoms and/or in following up on cartilage repair procedures. Due to the anatomical nature of cartilage being three-dimensionally thin curved structure, however, motion-correction/realignment prior to the pixel-by-pixel fitting necessary for $T1_\rho$-mapping may have a role in overall fitting quality and subsequent quantification. In this study, the value of a realignment based on rigid-body transformation was evaluated in $T1_\rho$-mapping of small joint cartilage using the wrist at 3T.

Methods:

Utilizing an 8-channel wrist coil on a 3T scanner (Philips Medical Systems, Best, Netherlands), $T1_\rho$ scans with varying spin-lock durations (TSL) were performed in coronal orientation with 18 slices using 3D balanced-FFE sequence for $T1_\rho$ mapping (TR/TE=5.9/2.9 ms; voxel-size=0.28x0.28x2-mm). Using a rotary echo based $T1_\rho$ preparatory pulses,[2] 4 different TSL values (10,20,40,60 ms) were employed. Each scan was 2.25 min long and the images were processed off-line using a custom processing tool prepared in Matlab (the Math Works, Inc., Natick, MA, USA). The realignment tool of SPM software package[3] was utilized in realignment of the images based on rigid-body transformation with respect to the first series (TSL=10) prior to a monoexponential fitting for $T1_\rho$ on a pixel-by-pixel basis. In order to assess the effect of motion correction in $T1_\rho$ values, region-of-interest (ROI) was manually drawn on the first $T1_\rho$ series and the ROI-averaged $T1_\rho$ value was obtained from the corresponding $T1_\rho$ map and compared to that without motion correction. R^2-map was also generated for assessing the overall fitting quality of $T1_\rho$ map with and without motion correction.

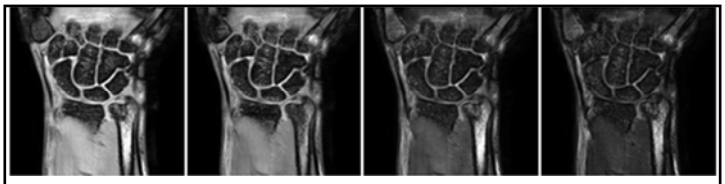
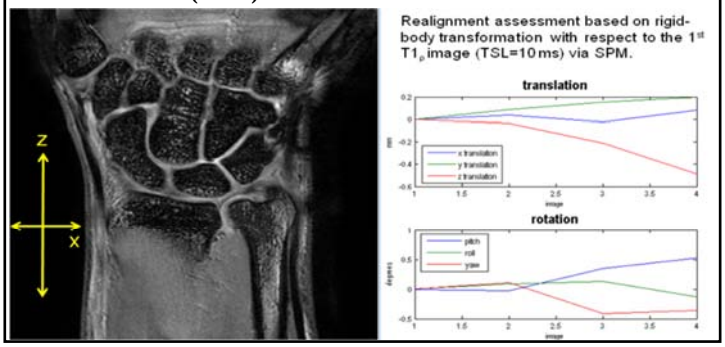


Fig. 1: $T1_\rho$ images with varying TSL: 10, 20, 40, & 60 ms, respectively (above). Realignment with respect to the 1st $T1_\rho$ image (TSL=10 ms) as assessed with SPM (below).



Results:

Fig. 1 shows $T1_\rho$ images of wrist cartilage with the 4 different TSL values along with the assessed realignment via rigid body transformation with 6 degrees of freedom in respect to the first series of $T1_\rho$. Although still relatively small, the case shown demonstrates a progressively larger translation along the z-axis in $T1_\rho$ series up to about 0.5 mm. The $T1_\rho$ maps of the corresponding slice with and without the realignment are color-coded and shown in Fig. 2. The three manually drawn ROIs and the correpsonding ROI-averaged $T1_\rho$ values from the $T1_\rho$ maps with and without realignment are also shown in Fig. 2 along with the ROI-averaged R^2 values. Despite a small degree of realignment required (< 1˚ in rotation and < 0.5 mm in translation), a measurable difference ranging from 9 to 22% in mean of ROI-averaged $T1_\rho$ value was observed between with and without realignment. Due to the thin structural nature of cartilage and a larger translation in z-axis, the two ROIs (green and red) oriented more horizontally (x-axis) exhibited a larger difference in $T1_\rho$ value (12 and 22%) in comparison to that (9%) of the 3rd ROI (yellow) that is more vertically oriented (z-axis). The mean of ROI-averaged R^2 value was also substantially higher (0.94-0.96) with realignment in comparison to that without (0.72-0.80).

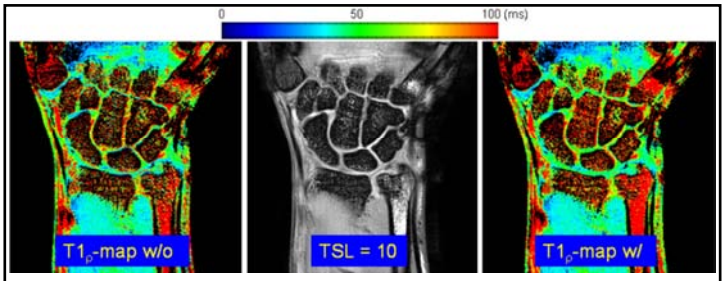


Fig. 2: Color-coded $T1_\rho$ maps w/o and w/ realignment (above). ROIs and ROI-averaged $T1_\rho$ values from $T1_\rho$ maps w/o and w/ realignment (below).

w/ w/o	$T1_\rho$ (ms) (ave±std)	R^2 (ave±std)
ROI (red)*	42±10.1 37±20.6	0.94±0.18 0.80±0.34
ROI (yellow)	68±13.8 62±28.5	0.96±0.08 0.74±0.47
ROI (green)*	51±13.9 40±27.2	0.94±0.13 0.72±0.39

*: The larger discrepancy in $T1_\rho$ between w/ and w/o correction for these 2 ROIs can be attributed to the relatively large displacement along z-axis as assessed during realignment.

Discussion:

The results demonstrate that large deviations in $T1_\rho$ value of cartilage can occur despite of relatively small mis-alignment between $T1_\rho$ series with varying TSL primarily due to its unique anatomical nature. In light of a subtle change in $T1_\rho$ value expected in early osteoarthritic cartilage damage, such deviations can be critical in accurate functional assessment of cartilage based on $T1_\rho$ mapping. In clinical setting where large mis-alignment between $T1_\rho$ series is more likely, a motion-correction/realignment is therefore necessary prior to generation of the $T1_\rho$ map for accurate assessment of cartilage based on such mapping technique. Use of only 3 different TSL values (10/20/60 or 10/40/60 ms) for $T1_\rho$ mapping yielded $T1_\rho$ values that differ less than 1% from those using all 4 TSL values based on the same ROIs when motion corrected (results not shown) and hence, implementation of less than 7 min. long $T1_\rho$ mapping protocol is certainly possible for a high-resolution imaging of cartilage. Although no MR-vendor is currently offering $T1_\rho$ mapping as a post-processing package *per se* to this author's knowledge, the processing techniques utilized in this study, such as a monoexponential based fitting and image realignment, are currently being used in MR-console for generation of T2 and ADC (apparent diffusion coefficient) map by various vendors and thus should easily be applicable for $T1_\rho$ mapping in clinical MR-scanner once it is classified as a clinical MR-protocol.

Conclusion:

Motion correction is a necessary step prior to $T1_\rho$ mapping for accurate assessment of a thin anatomical structure such as cartilage.

References:

[1] Regatte R, Akella S, Borthakur A, et al. Proton spin-lock ratio imaging for quantification of glycosaminoglycans in articular cartilage. J Magn Reson Imaging 2003;17(1):114-121. [2] Charagundla S, Borthakur A, Leigh J, et al. Artifacts in $T1_\rho$-weighted imaging: correction with a self-compensating spin-locking pulse. J Magn Reson 2003;162(1):113-121. [3] http://www.fil.ion.ucl.ac.uk/spm/software/.