3D Bio-Anatomical Imaging with High Isotropic Resolution for Musculoskeletal Applications

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Introduction: Anatomical intermediate T2-weighted and PD-weighted FSE images are commonly used in clinical MRI for detection of joint abnormalities (1-3). There is increasing interest in using T2 and T1rho of articular cartilage as biomarkers for earlier and improved diagnosis of osteoarthritis and related diseases (4-7). T2 or T1rho relaxometry is typically performed in 2D or 3D with inferior spatial resolution compared to anatomical imaging due to scan time limitations. In this work, we demonstrated reconstructing T2-weighted, intermediate-weighted anatomical images, and relaxometry maps with 3D isotropic resolution of 0.6mm from a single scan in clinically feasible scan time. Both relaxometry maps and anatomical images can be subsequently reformatted to arbitrary planes for post-analysis and diagnosis.

Methods: We applied a magnetization prepared 3D pseudo steady state fast spin echo pulse sequence, which was reported recently for 3D relaxometry (8). The high SNR efficiency of this pulse sequence makes it feasible to acquire 3D data with high isotropic resolution. After data acquisition, we reformatted data into standard planes and then averaged images along through-plane direction for a final through plane-resolution similar to clinical 2D FSE. The in vivo data sets were collected from a Discovery MR750 3T scanner (GE Healthcare, Waukesha, WI) using a trans-receive 8-channel knee coil (Invivo Inc., Gainesville, FL). The imaging parameters include: sagittal scan, fat sat, NEX 0.5, BW±62.5kHz, FOV 16x12.8cm, matrix 256x192, 192 slices, slice thickness 0.6mm, echo train length 60, data driven parallel imaging ARC(GE Healthcare) with 2X acceleration along phase encoding. For T2, we collected 3 data sets with TE 8, 16, 32ms, respectively, with total scan time 9:49min. For T1rho, we collected 4 data sets with TSL 1, 10, 35, 50ms, respectively, spin lock 500Hz, an additional 2X of ARC along slice direction with total scan time 7:05min.

For analysis of the T1rho and T2 relaxation times, we performed complex averaging of the signal. The sum of square of noise contaminated signal follows a non-central chi distribution, which causes significant bias to the mean of magnitude images when SNR is low. In contrast, according to central limit theorem, the averaging of complex signal results in an unbiased mean with markedly reduced variance. Relaxometry maps were calculated based on weighted least squares fit after data averaging. The same weighted least squares fit with Tikhonov regularization was used to reconstruct intermediate-weighted images which has much reduced T2 weighting. The T2-weighted images were formed from linear combinations of the T2 or T1rho-weighted source images. Scatter and Q-Q plots were used to study whether different images/maps provide complementary information. Data points with large fitting residual were discarded prior to data analysis. Since PD images estimated from T1rho and T2 data were assumed to be comparable, data points which violated this assumption were discarded as well.

Results and Discussion: Figure 1 compares complex and magnitude averaging in T2 quantification on a uniform phantom. Note complex averaging provides much improved quantification accuracy when SNR is low (Figure 1C). Figure 2 shows reconstructed anatomical images, T2, and T1rho maps in sagittal, reformatted axial and coronal planes. Pixels with T1rho/T2 larger than 100ms was interpreted as fluid and displayed with a single color for better dynamic range of T1rho/T2 maps of the articular cartilage. Focal cartilage thinning in the medial femoral condyle is observed on the anatomical images (white arrow) with observed elevation of T2 and T1rho (white arrow) at the corresponding regions. Scatter plots between T1rho and T2 in cartilage (Fig 3) showed good correlation for the sagittal and axial reformats, but less correlation for coronal reformat, suggesting the spatial distribution of T1rho and T2 may provide complementary information in that orientation. The Q-Q plot of T1rho and T2 in coronal plane suggested T1rho and T2 may have similar histogram distribution of their measured value, even though the spatial distribution is not significantly correlated. Correlation between T1rho and T2 decreased at large T1rho or T2 values. One possible cause might be the increased uncertainty of quantification at large T1rho or T2 due to the TE/TSL used in the experiments.

Conclusion: We demonstrated the feasibility of 3D isotropic high resolution bio-anatomical imaging to obtain reconstructed anatomical images and relaxometry maps in one scan in clinical feasible scan times. Post-hoc analysis can be used to guide how to utilize these images for complementary diagnosis. This bio-anatomical imaging approach may make it feasible to use 3D relaxometry in routine clinical practice as a byproduct of conventional anatomical imaging.

Reference: 1. Escobedo et al, AJR 1996, p1223 2. Schaefer et al, Eur J Radiol 2006, p 411 3. Sonin et al, AJR 2002, p1159 4. Duvvuri et al, MRM 1997, p863 5. Regatte et al, Acad Radiology 2004, p741 6. Kijowski et al, ISMRM 2012, p52 7. Li et al, Osteo. and Cartilage, 2007, p789. 8. Chen et al, ISMRM 2011, p231

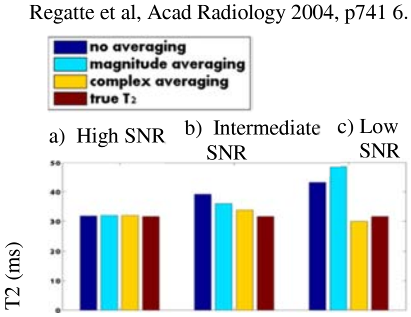

Figure 1: Measured T2 value from a uniform phantom with different level of SNR (left: high SNR; middle: intermediate SNR; right: low SNR). Note different methods have comparable measurement when SNR is high, but the complex averaging provide most accurate T2 measurement when SNR is low.

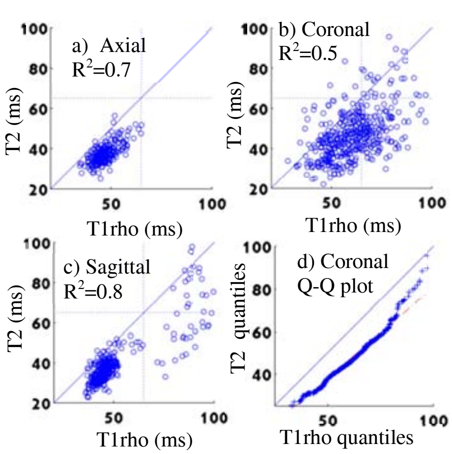

Figure 3: Scatter plots between T1rho and T2 in reformatted axial (a), reformatted coronal (b), and sagittal (c), and Q-Q plot of T1rho and T2 in coronal plane (d). Lower correlation in coronal plane suggested the spatial distribution of T1rho and T2 may provide complementary information in that orientation. A relative straight line in the Q-Q plot suggested T1rho and T2 may have similar histogram distribution in their respective measurements in coronal plane.

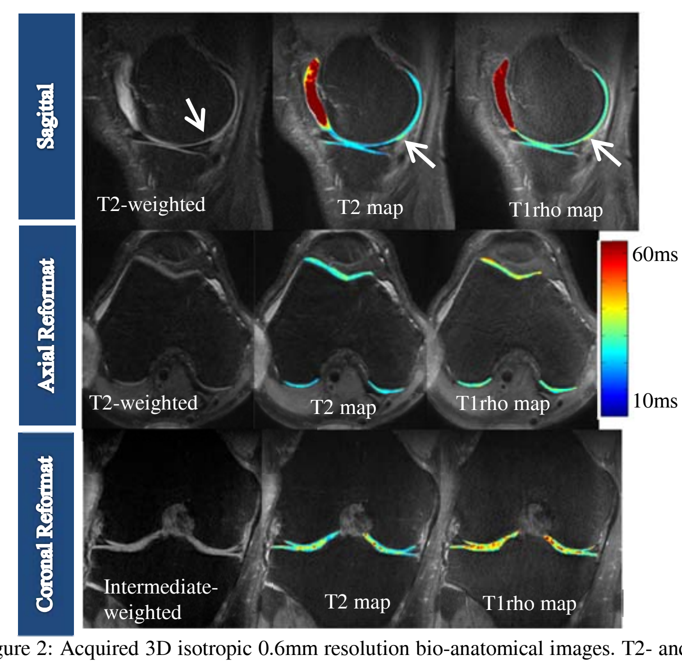

Figure 2: Acquired 3D isotropic 0.6mm resolution bio-anatomical images. T2- and intermediate–weighted images were acquired in sagittal plane, and reformatted to axial and coronal planes. The white arrows show an area where cartilage thinning manifests and the elevated T2 and T1rho value at the corresponding region.