Robust Image Registration for *In-vivo* Human Osteoarthritic Knees and Cartilage Specimens and Correlation Between *In-vivo* and *Ex-vivo* T1ρ

Wei-Ching Lo[1], Karupppasamy Subburaj[1], Lorenzo Nardo[1], Sharmila Majumdar[1], Michael Ries[2], and Xiaojuan Li[1]

[1]*Department of Radiology and Biomedical Imaging, University of California, San Francisco, San Francisco, California, United States,* [2]*Orthopaedic Surgery, University of California, San Francisco, San Francisco, California, United States*

Introduction: Along with the efforts of developing prevention strategies and new treatment methods for osteoarthritis (OA), there are increasing demands for early diagnosis and critical treatment monitoring of cartilage degeneration in OA. Quantitative MRI T1ρ relaxation times have been developed to detect early biochemical changes in cartilage matrix [1-2]. Previous studies correlated quantitative MRI T1ρ relaxation times with biochemical changes within cartilage matrix using specimens taken from total knee arthroplasty (TKA) [3-4], but no study has documented yet the relationship between *in vivo* and *ex vivo* T1ρ quantification in cartilage. The purposes of this study are to develop a robust registration algorithm between *in vivo* and *ex vivo* knee cartilage images and to evaluate the correlation between *in vivo* and *ex vivo* T1ρ relaxation time in human OA cartilages.

Methods: Eight patients (five women; mean age: 68±9 years) who were going to undergo TKA procedure due to severe OA were scanned before surgery. Eleven knee specimens from tibial-femoral joints were then resected and scanned with being positioned in the corresponding physiological orientation [2]. All scans were acquired using a 3T GE Signa MR Scanner with an 8-channel phased-array knee coil. The sagittal T2-w fat-saturated FSE images (TR/TE=4300/51 ms, FOV=14 cm for in vivo, 6-8cm for ex vivo, matrix=512×256, slice thickness=2.5 mm, gap=0.5 mm), 3D sagittal high-resolution fat-saturated SPGR images (TR/TE=15/6.7 ms, flip angle=12, FOV=14cm for in vivo, 6–8 cm for ex vivo, matrix=512 × 512, slice thickness=1 mm, bandwidth =31.25 kHz, NEX=1), and sagittal T1ρ relaxation time mapping images (MAPSS) (TR/TE=9.0/3.5 ms, FOV=14 cm for in vivo, 6-8 for ex vivo, matrix=256×128, slice thickness=4 mm for in vivo, 2mm for ex vivo, BW=62.5 kHz, VPS=64, recovery time=1.2 s, TSL=0, 10, 40, 80 ms, FSL=500 Hz) were acquired. The cartilage lesions were graded on in vivo MRI using modified Whole-Organ Magnetic Resonance Imaging Score (mWORMS) assessment [5]. T1ρ maps were reconstructed by fitting the T1ρ-weighted images voxel by voxel to the equation: $S(TSL) \propto \exp(-TSL/T1\rho)$. The 2D contours segmented in 3D SPGR images [6] were reconstructed into a 3D model and transferred to appropriate initial position. Surface points of the specimen model were registered to the *in vivo* cartilage by using an iterative closest point shape-matching algorithm [7] (Fig. 1). The specimen cartilage ROI was overlaid to the registered *in vivo* T1ρ maps. The *ex vivo* and *in vivo* T1ρ were then quantified in the exactly same regions of cartilage respectively.

Results: The registration errors were similar in all compartments (0.1±0.04 mm). The mean T1ρ values of the *ex-vivo* specimens were significantly higher than *in vivo* T1ρ in the same regions (71.1±3.6 ms vs. 41.9±3.8 ms, $p < 0.0001$). The *in vivo* T1ρ relaxation times showed a significant moderate positive correlation with *ex vivo* T1ρ values (R^2=.45, p<0.0001, Fig. 2). There was no correlation between *in vivo* mWORMS and the T1ρ differences of *ex vivo* and *in vivo*.

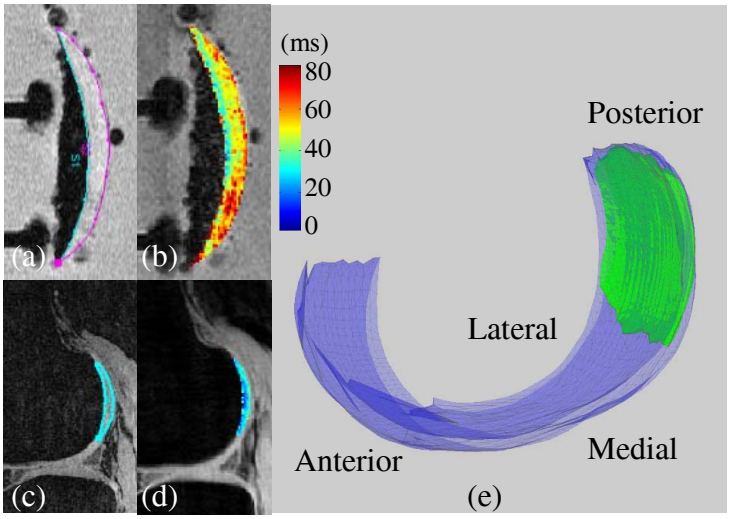

Figure1. Cartilage of specimens (a) and *in-vivo* knees (c) was registered (e) before T1ρ relaxation time quantification (b, d).

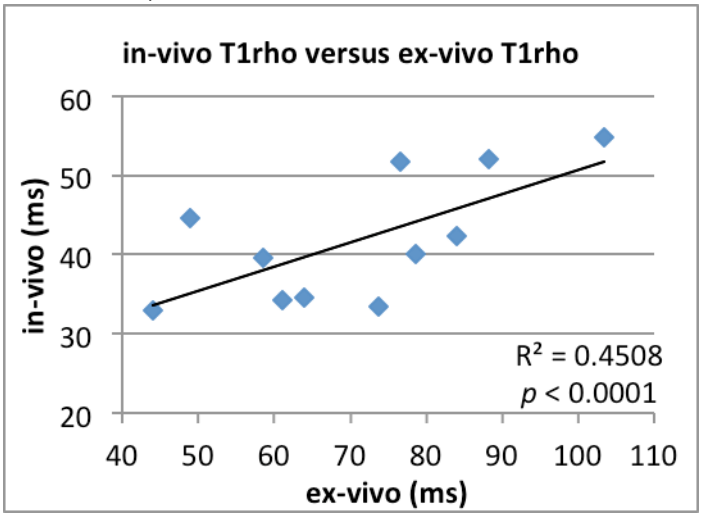

Figure2. Moderate correlation was found between *in-vivo* and *ex-vivo* human osteoarthritic cartilage.

Discussion: The registration error was comparable to the image resolution, showing good registration between in vivo and ex vivo images. The significant elevation of T1ρ in specimens may be explained by potential damages during surgery, and/or hydration and biochemical exchanges and further degeneration during specimen preparation. No correlation between mWORMS and T1ρ differences indicated that the different of the in vivo and ex vivo T1ρ was not dependent on the degeneration status of the cartilage..

Conclusion: This study developed a robust registration algorithm for *in vivo* and *ex vivo* cartilage imaging. The *ex vivo* imaging of specimens are powerful tools to explore the link between imaging measures and biochemical analysis. As a non-invasive imaging technique, it would be critical to link the biochemical analysis with *in vivo* imaging measures.

Acknowledgments: The research was supported by NIH/HIAMS K25 AR053633, R01 AR46905, R21 AR056773.

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