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7T cross-vendor repeatability study of cartilage T_2 values using DOSMA on qDESS images

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Synopsis

Keywords: Quantitative Imaging, Data Processing, Repeatability, cartilage, knee

Cartilage T_2 relaxation times (T_2), used to detect early knee osteoarthritis, lack standardization in acquiring and processing data, making comparisons between studies difficult. Standardizing image post-processing could possibly control for biases. Here, we assess qDESS cartilage T_2 repeatability across two different sites and 7T scanner vendors with identical automatic segmentation and T_2 mapping software. Within-site repeatability was good (ICC$\geq$ 0.75) for most cartilage regions, while cross-vendor repeatability was good for the tibial and femoral posterior cartilage. This preliminary study shows standardizing acquisition and post-processing can lead to repeatable T_2 values across different vendors.

Introduction

T_2 relaxation time, a surrogate measure of collagen microstructure and hydration levels of articular cartilage, has been used to study early osteoarthritis (OA) changes. Increased T_2 has been linked to OA progression[1]. To date, most T_2 measurement protocols have been developed, collected, and validated at 1.5 or 3T[2]. Limited work has assessed T_2 at ultra-high field strengths (7T). Benefits of using an increased field strength include improved the signal-to-noise ratio (SNR), which offers the potential for faster acquisitions and/or higher resolutions. A challenge of using 7T systems is the increase in field inhomogeneities, which may affect quantitative measurements and compromise the reliability of the data. Previous work has shown that repeatability of T_2 relaxation measurements collected at 7T and 3T are similar[3]. However, previous studies at 3T have shown that acquiring T_2 relaxation times using different scanners with different vendors produces systematically different T_2 values[4]. Furthermore, it has been shown that inter-rater, or even inter-algorithm segmentation variability produces biases in cartilage segmentation, which may affect calculated T_2 values[5]. This adds additional variability for comparing T_2 between sites or vendors. The purpose of our study was to evaluate the repeatability of cartilage T_2 relaxation time measurements at 7T from two sites with different scanner vendors, while standardizing for scanning sequence, coil, segmentation, and reconstruction, cartilage segmentation, and T_2 computation algorithms.

Methods

Five healthy adults (3 males, age range: 20-50 years) without history of lower limb joint trauma were enrolled in this Institutional Review Board-approved study with appropriate informed consent in place. Their right knees were imaged using the following whole-body 7T scanners: a GE950 7T (GE Healthcare, Waukesha, WI, USA) and a 7T MAGNETOM Terra (Siemens Healthineers, Erlangen, Germany). Both scanners used a 28 Channel Transmit/Receive Knee Coil (Quality Electrodynamics, Cleveland, OH USA). qDESS images were acquired to calculate the knee cartilage T_2 relaxation times[6]; sequence parameters and subject scanning conditions were standardized across vendors where possible (Table 1).

At each scanner, subjects were scanned twice. Between scans, the subjects were removed from the scanner and repositioned. Cartilage segmentation was performed using a publicly available deep-learning model provided by DOSMA, an open-source Python framework for musculoskeletal analysis[7,8]. All segmentations were manually checked, and no corrections were made. Voxelwise cartilage T_2 values were determined using a previously validated method based on extended phase graph modeling[6]. Mean T_2 was calculated across the full thickness of the cartilage of six tibial and femoral regions (anterior, central, and posterior regions of the medial and lateral compartments[9,10]) (Figure 1).

Reliability between-scans (same vendor and scanner) and between-vendors (different scanner) was assessed using generalizability theory[11]. Generalizability theory is a measurement theory framework that improves robustness of reliability estimates by allowing the calculation of specific reliability coefficients (between-scan or between-vendor) while simultaneously using all available data. Generalizability theory was used to compute relative reliability (intraclass correlation coefficient; ICC) and absolute reliability (standard error of measurement; SEM) for measurements between scans and between vendors. The computed SEM was then used to calculate a minimum detectable change at 90% confidence (MDC90) using the equation: *MDC = SEM * sqrt(2) * z-score* with a z-score of 1.645 used to calculate the MDC90. ICCs and SEMs were calculated separately for each anatomic region of interest. ICCs ≥ 0.75 were considered to have good to excellent reliability[12].

Results

T_2 relaxation showed better repeatability between scans than between vendors taken from different vendors (Table 2). T_2 relaxation times between scans had excellent repeatability (ICCs ≥ 0.75) in most regions (Table 2). Cross-vendors, the medial and lateral posterior cartilage of the tibia and femur had good to excellent repeatability (ICCs ≥ 0.75). The SEMs between repeated scans were relatively small at 1.4 to 2.6ms, yielding minimum detectable change values ranging from ~3-5ms. SEMs between vendors were larger, and thus required between 4-11ms of change to be detectable

Discussion

Between scan repeatability of cartilage T_2 values aligned with those previously reported for a single vendor[3]. Across sites/vendors, the posterior regions of the femoral and tibial cartilage were repeatable. Some limitations of this preliminary study include that subjects were not scanned at the same time of the day due to scanner availability and may not have been isocenter due to scanner bore and coil placement constraints. Suboptimal scanner stability may have contributed to some of the larger differences both at one of the sites and between sites. Despite the study's limitations, we found T_2 to be repeatable between 7T scans and vendors. To our knowledge, this is the first repeatability study across 7T vendors analyzing T_2 values in multiple compartments.

Conclusion

This preliminary work compared cartilage T_2 relaxation times calculated from scans acquired using the qDESS pulse sequences on 7T scanners from different vendors while standardizing the acquisition parameters, coil, automatic segmentation, and reconstruction algorithm across vendors. Results showed excellent between scan repeatability in most regions of tibial and femoral cartilage and good repeatability in the posterior cartilage of the tibia and femur between vendors. Having such repeatable quantitative measures tested on scanners from different vendors is promising for future cross-site T_2 comparative studies conducted at 7T.

Acknowledgements

This work was supported by the National Institutes of Health (R01EB002524, R01AR077604), GE Healthcare, the Wu Tsai Human Performance Alliance, and a CIHR Postdoctoral Fellowship.

References

1. Prasad AP, Nardo L, Schooler J, et al. T_{1r} and T_2 relaxation times predict progression of knee osteoarthritis. *Osteoarthr Cartil*. 2013; 21(1):69–76.
2. Chaudhari AS, Stevens KJ, Sveinsson B, et al. Combined 5-minute double-echo in steady-state with separated echoes and 2-minute proton-density-weighted 2D FSE sequence for comprehensive whole-joint knee MRI assessment. *Magn Reson Imaging*. 2019;49:e183-e194.
3. Asay JL, Gatti AA, Desai AD, et al. Repeatability of Cartilage T2 relaxation times measures at 3T and 7T using quantitative double-echo in steady-state. *Proc Intl Soc Mag Reson Med*. 2022; 2307.
4. Balamoody S, Williams TG, Wolstenholme C, et al. Magnetic resonance transverse relaxation time T2 of knee cartilage in osteoarthritis at 3-T: a cross-sectional multicentre, multivendor reproducibility study. *Skeletal Radiol*. 2013;42(4):511-520.
5. Schneider E, Nevitt M, McCulloch C, et al. Equivalence and precision of knee cartilage morphometry between different segmentation teams, cartilage regions, and MR acquisitions. *Osteoarthritis and Cartilage*. 2012;20(8):869-879.
6. Sveinsson B, Chaudhari AS, Gold GE, Hargreaves BA. A simple analytic method for estimating T2 in the knee from DESS. *Magn Reson Imaging*. 2017;38:63–70.
7. Desai AD, Barbieri M, Mazzoli V, et al. DOSMA: A deep-learning, open-source framework for musculoskeletal MRI analysis. *Proc Intl Soc Mag Reson Med*. 2019; 1106(27).
8. Desai AD, Schmidt AM, Rubin EB, et al. SKM-TEA: A Dataset for Accelerated MRI Reconstruction with Dense Image Labels for Quantitative Clinical Evaluation. arxiv :2203.06823 [**eess.IV**]. https://arxiv.org/pdf/2203.06823.pdf.
9. Monu UD, Jordan CD, Samuelson BL, Hargreaves BA, Gold GE, McWalter EJ. Cluster analysis of quantitative MRI T2 and T1ρ relaxation times of cartilage identifies differences between healthy and ACL-injured individuals at 3T. *Osteoarthritis and Cartilage* 2017;25(4):513-520.
10. Black MS, Young K, Chaudhari AS, Sveinsson B, Kogan F, Monu U, McWalter E, Levenston M, Gold GE, Hargreaves BA. T2-mapping of Femoral Cartilage 3-months Following ACL Reconstruction Surgery. 2018; Paris, France.
11. Brennan RL. Generalizability theory. New York: Springer; 2001. https://doi.org/10.1007/978-1-4757-3456-0.
12. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*. 2016;15(2):155-163.

Figures

Acquisition Parameter	$7T_{Siemens}$	$7T_{GE}$
Scan plane	Sagittal	Sagittal
TR/TE1/TE2 (ms)	19.4/6.2/32.6	19.4/6.2/32.6
Field of view (mm)	150	160
Acquisition matrix	416 x 416	416 x 416
Flip angle (°)	13	13
Slice thickness (mm)	1.5	1.5
Number of slices	104	104
Acceleration	GRAPPA: 2x1	ARC: 2x1
Acquisition time (min)	5:53	5:30

Table 1: Scan parameters used at each site. The qDESS sequences were programmed to ensure the scan parameters were as similar as possible across the Siemens and GE scanners.

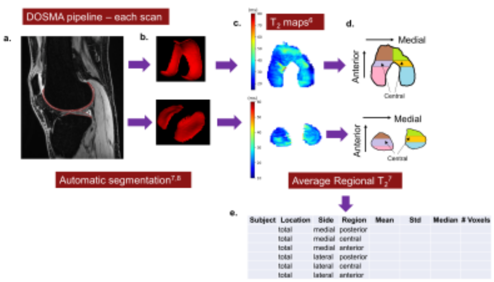

Figure 1: The processing pipeline for each image: a) the RMS of the qDESS echoes are automatically segmented using DOSMA[7,8]; b) The segmentations are reviewed, but no corrections were necessary; c) T_2 maps are created and visually inspected; d) Average regional T_2 values are calculated for the regions of the posterior, central, and anterior medial and lateral femoral or tibial cartilage; e) Data is extracted into a tabular format.

Cartilage	Region	ICC between scan	ICC between vendor	SEM between scan	SEM between vendor
Femur	Lateral Anterior	**0.85**	0.72	1.86	2.76
	Lateral Central	0.20	0.17	2.38	2.91
	Lateral Posterior	**0.80**	**0.81**	2.58	2.55
	Medial Anterior	**0.91**	0.57	1.39	3.59
	Medial Central	0.65	0.07	2.37	4.89
	Medial Posterior	**0.95**	**0.85**	1.88	3.40
Tibia	Lateral Anterior	0.17	0.17	1.97	1.97
	Lateral Central	0.54	0.66	2.43	1.74
	Lateral Posterior	**0.88**	**0.80**	2.38	3.21
	Medial Anterior	**0.77**	0.36	1.55	2.89
	Medial Central	**0.79**	0.61	1.68	2.32
	Medial Posterior	**0.91**	**0.79**	1.82	3.00

Table 2: Repeatability measures were calculated within and cross-vendor (ICC = intraclass correlation coefficient, SEM = standard error of the mean), **bold** = Good or excellent repeatability

Proc. Intl. Soc. Mag. Reson. Med. 31 (2023)
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