Automated cartilage morphometric and T2 mapping using 3D-FSE MRI at 3T

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PURPOSE: Quantitative MRI sequences such as T2 mapping are considered to be sensitive to the earliest biochemical changes that occur prior to gross cartilage tissue loss during Osteoarthritis (OA) [1]. Conducting this analyses, is time consuming as it typically relies on a trained expert to perform manual segmentation or manually correct semi-automatic segmentation approaches. Several schemes to automate the cartilage segmentation process for T2 images have been proposed [2]. In this paper, we present and validate the results of an automated segmentation scheme [3], to segment the cartilage from clinically 3D-Fast-Spin-Echo (3D-SPACE) MR images and extract biochemical information from co-registered T2 mapping images.

METHODS: A anonymized dataset of unilateral knee images from 25 asymptomatic volunteers (deemed asymptomatic through objective clinical examination and subjective score, no prior knee surgery, M:F=13:12, aged 23-34, mass 53-151kg) and 15 symptomatic patients (with varying knee pathology and OA progression ranging from ICRS grade I-IV, M:F=6:9, aged 23-32, mass 56-127kg) was acquired on a 3T MRI system (Magnetom Verio, Siemens Healthcare, Erlangen, Germany) for this study by the Steadman Philippon Research Institute (SPRI) with approval from the Vail Valley Medical Center Internal Review Board. The symptomatic knee for each patient was imaged using a 15-channel multi-element phased-array knee coil (Quality Electrodynamics, LLC, Mayfield Village, OH, USA) using standard clinical protocols, including single slab fat suppressed PDw 3D-SPACE (Tr/Te: 1200/45ms; Voxel-size (VS): 0.6×0.6×0.7mm; Field of view (FOV): 150mm; acquisition-time (AT): 4:46min) and T2 mapping sequences (Tr/Te: 2570/13.8-96.6 ms; VS: 0.5×0.5×2.0mm; FOV: 140mm; AT: 6:53min).

Manual segmentations of three cartilage plates (patellar, tibial and femoral) were performed on a slice-by-slice basis directly onto the T2 mapping scans, and a subset of eight 3D-SPACE scans. Manual segmentations were performed on the sagittal images (corresponding on average to x#, y#, z# slices for the patellar, tibial, and femoral cartilages respectively) with a stylus and touch screen monitor using Mimics software (Materialize, Plymouth, MI, USA) by a musculoskeletal radiologist. Manual cartilage segmentation masks were imported into custom Matlab programs (Mathworks, Natick, MA) for analyses. An automated scheme [3] was used to segment the cartilages from the 3D-SPACE images. The 3D-SPACE and T2 map images were co-registered for segmentation propagation. Statistical analysis was performed to quantitatively compare the automatic (A) and manual (M) segmentation (eg. Dice's Similarity Index (DSI): $DSI(A,M) = 2|A \cap M|/(|A| + |M|)$) of the extracted regional cartilage T2 signal (eg. T2.RD = 100 x | T2$_a$ – T2$_m$| / T2$_m$).

RESULTS: Example segmentation results are illustrated in Fig. 1, with group statistics in Table 1 and histogram of the DSI presented in Fig. 2. The average segmentation quantification for both 3D-SPACE and T2 map segmentation is promising (Table 1). A systemic bias in volumetry between manual segmentation on the 3D-SPACE and T2 map image, with variability in delineation towards the bone-cartilage interfaces (average Vol.RD = 6, 12, 11% for each plate). That said, for each of the patella, tibial and femoral cartilage plates there were strong correlations between the manual and automated T2 segmentations for volume measures (Table 1)

As the cartilages are quite thin, some of the reduced DSI is from mislabeling of boundary voxels from registration and partial voluming error. It can be observed that there is a small decrease in accuracy in the symptomatic subjects, this was primarily due to some additional mis-segmentation around cartilage defects.

There is a strong correlation (R > 0.75) and minimal relative absolute difference (RD < 6%) in the median "T2 average signal" (Table 2). These strong correlations are retained even when the (asymptomatic / symptomatic) groups are analyzed separately (Table 2).

DISCUSSION AND CONCLUSION: We present the validation of a promising automated quantitative T2 mapping analysis scheme for the knee cartilage plates using clinically relevant 3D-FSE structural imaging. Although these are only preliminary results, it indicates that accurate automated quantitative T2 assessment using structural 3D-FSE sequences is feasible.
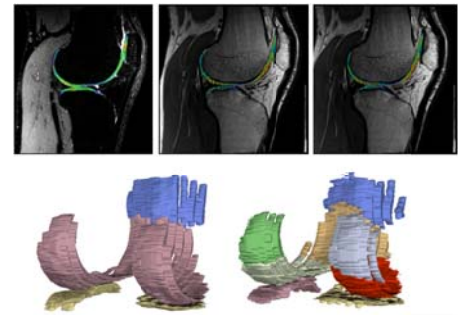

Fig 1: Example segmentation results (auto, manual) for a symptomatic knee (DSI_space=0.77, 0.81, 0.79, DSI_t2=0.7, 0.75, 0.77). (left to right) (a) Sagittal 3D-SPACE slice with automatic thickness map overlaid, (b and c) Sagittal T2w (echo2) with T2 map overlaid using (b) manual segmentation (c) automated segmentation after co-registration (d-e) 3D surface rendering of voxelized (d) manual segmentation and (e) automated segmentation.

Table1: Summary statistics for segmentation quality and volumetric calculations for asymptomatic and symptomatic group.

| Cartilage		N	DSI	Vol.Man	Vol.Auto	Vol.RD (%)	R
Patellar	Asymptomatic (SPACESeg)	3	77.45±2.82	4.35±0.82	3.64±0.33	15.3±8.85	1.00
	Symptomatic (SPACESeg)	5	78.91±2.78	4.51±0.81	4.15±0.71	8.17±6.45	0.89
	Asymptomatic (T2Seg)	25	73.9±3.96	3.49±1.28	3.12±0.96	12.76±8.54	0.95
	Symptomatic (T2Seg)	15	72.61±8.31	4.14±1.58	3.74±1.21	15.29±13.7	0.91
Tibial	Asymptomatic (SPACESeg)	3	78.64±1.88	6.19±0.16	5.66±0.05	8.63±1.61	0.94
	Symptomatic (SPACESeg)	5	79.03±5.41	5.47±1.66	5.52±1.29	5.81±6.87	1.00
	Asymptomatic (T2Seg)	25	69.69±5.27	4.19±1.81	4.65±1.47	16.25±11.84	0.96
	Symptomatic (T2Seg)	15	67.03±6.4	4.26±1.68	5.15±1.72	24.02±15.7	0.91
Femoral	Asymptomatic (SPACESeg)	3	80.13±2.34	14.75±1.56	13.24±1.86	10.44±5.17	0.94
	Symptomatic (SPACESeg)	5	77.78±3.03	14.04±2.69	13.88±3.76	10.95±4.96	0.91
	Asymptomatic (T2Seg)	25	70.29±5.52	9.98±4.2	10.8±3.74	12.16±10.2	0.95
	Symptomatic (T2Seg)	15	70.01±6.68	12.44±5.22	13.62±4.46	15.87±16.93	0.94
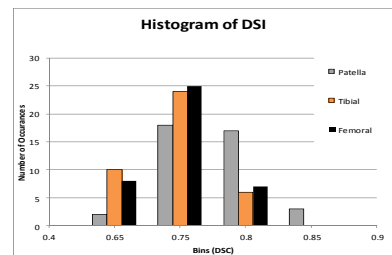
Histogram of DSI

Fig 2 (left): Histogram of DSI for each cartilage plate.

Table2: Summary statistics for T2 signal for asymptomatic and symptomatic group.

Cartilage		N	T2.Man	T2.Auto	T2.RD (%)	R
Patellar	Asymptomatic (T2Seg)	25	46.29±4.92	47.62±4.79	3.64±4.17	0.89
	Symptomatic (T2Seg)	15	47.85±7.2	50.46±10.06	5.65±8.58	0.89
Tibial	Asymptomatic (T2Seg)	25	45.2±5.4	43.48±5.05	5±4.34	0.87
	Symptomatic (T2Seg)	15	45.77±5.83	44.86±5	4.08±3.77	0.89
Femoral	Asymptomatic (T2Seg)	25	49.41±3.24	50.66±3.43	2.94±3.22	0.87
	Symptomatic (T2Seg)	15	52.67±4.54	55.4±4.66	5.89±3.7	0.75

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