Reproducibility of Automatic Quantitative Analysis of the Articular Cartilages from MEDIC and weDESS Magnetic Resonance Images of the Knee at 1.5T

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Introduction: Osteoarthritis (OA) of the knee is characterized by degeneration of cartilage tissue. Magnetic Resonance (MR) imaging allows the monitoring of cartilage degeneration by analysing changes in the volume, thickness and surface area of these complex soft tissue structures. To perform this analysis requires the cartilages in the MR images to be accurately segmented. Unfortunately, due to imaging artefacts and low contrast in several regions of the knee joint, like the joint contact areas, tendons and ligaments, fully automated segmentation of the cartilage from MR images is difficult. This has made the clinical use of MR imaging for OA assessment impractical, with clinical studies performed using manual or semi-automatic methods [1]. Usually, high resolution sequences like T1 weighted water excitation FLASH (weFLASH) at 1.5 T have been used to image the cartilages which then appear fairly homogenous and bright compared to other tissue. Recently, the use of water excited Double Echo in the Steady State (weDESS) at 3T has been investigated with results validated against 3T weFLASH [2]. The T_2 and T_{2^*} weighting in weDESS obtains a rich variation in cartilage appearance that may be important clinically, however, it makes automated segmentation even more difficult. In our previous work [3,4] we developed a segmentation system for cartilages which was trained and tested using a database of fat suppressed SPGR images of healthy volunteers. In this paper we extended the approach to include a tissue estimate for synovial fluid and tested the reproducibility and test-retest error for our automatic segmentation algorithm by segmenting each individual cartilage in the knee from weDESS (Te=8.6, Tr=25, freq=63) and MEDIC (Te=22, Tr = 44, freq = 63) images acquired at 1.5 T.

Methodology: Using a 1.5 T Siemens MR scanner, four volunteers who were not known to have OA or knee pain underwent repeated examination using a weDESS and MEDIC sequence taken with various resolutions, positioning and time (over several months using a body coil). The aim of which is to ensure the results obtained using weDESS and MEDIC are similar while also considering the reproducibility and re-test error of the automatic segmentation algorithm. At 1.5T the resolution and signal to noise ratio of the weDESS and MEDIC images are reduced compared to the 3T weDESS used in [2], which limits the absolute precision and accuracy attainable and increases the partial volume effect. A summary of the sequences and resolutions used are presented in Table 1. The segmentation algorithm presented in [3,4] was repeated 3 times (different atlas initialisation) to extract each individual cartilage. The segmentations were resampled isotropic using shape based interpolation, after which quantitative analysis using volume and laplacian thickness [5] was calculated for each cartilage.

Results:

Table 1: Quantitative analysis obtained for each MR acquisition at various resolutions. Note: Each MR image was segmented 3 times.

Case	MR	Resolution	Median Volume (st. dev)			Median Thickness (st.dev)		
			Patella	Tibial	Femoral	Patella	Tibial	Femoral
A	weDESS (3)	0.46875x0.46875x1.5	4286 (196)	7060 (94)	14642 (252)	3.32 (0.075)	2.37 (0.049)	2.57 (0.006)
	weDESS (5)	0.46875x0.46875x1.0	4330 (103)	7071 (115)	14682 (202)	3.26 (0.047)	2.27 (0.025)	2.44 (0.029)
	weDESS (6)	0.41x0.41x1.5	4258 (45)	6817 (44)	13863 (223)	3.22 (0.092)	2.28 (0.009)	2.45 (0.042)
B	weDESS (11)	0.46875x0.46875x1.5	5026 (31)	5618 (503)	15006 (20)	3.61 (0.099)	2.29 (0.164)	2.60 (0.069)
	weDESS (16)	0.41x0.41x1.5	4552 (95)	4170 (113)	13422 (59)	3.45 (0.064)	1.89 (0.029)	2.42 (0.033)
	MEDIC (17)	0.41x0.41x1.5	4687 (29)	4818 (167)	13490 (85)	3.65 (0.042)	2.16 (0.045)	2.52 (0.031)
	weDESS (22)	0.41x0.41x1.5	4679 (53)	4897 (96)	13219 (290)	3.49 (0.030)	2.04 (0.047)	2.44 (0.049)
	MEDIC (23)	0.41x0.41x1.5	4923 (53)	5361 (254)	13452 (402)	3.66 (0.086)	2.05 (0.071)	2.40 (0.048)
C	weDESS (13)	0.41x0.41x1.5	4083 (78)	5804 (85)	13377 (591)	3.37 (0.076)	2.36 (0.086)	2.53 (0.038)
	weDESS iPAT (14)	0.41x0.41x1	4329 (63)	5902 (216)	13786 (649)	3.36 (0.084)	2.32 (0.035)	2.53 (0.025)
D	weDESS (19)	0.41x0.41x1.5	4183 (7)	6420 (70)	14929 (130)	3.45 (0.053)	2.43 (0.078)	2.61 (0.033)
	MEDIC (20)	0.41x0.41x1.5	4056 (54)	5966 (45)	13512 (124)	3.35 (0.034)	2.36 (0.039)	2.48 (0.018)
	weDESS (21)	0.41x0.41x1.5	2899 (108)	5763 (274)	12716 (264)	3.00 (0.105)	2.30 (0.074)	2.46 (0.048)

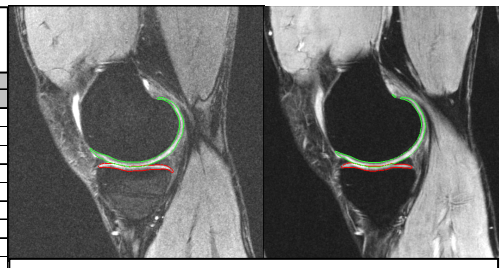

Figure 1: MR of similar slice from the same case with segmentation contour overlayed for *left* weDESS *right* MEDIC.

Table 2: Mean, standard deviation and coefficient of variation (CV) of volume and thickness for each case. Note: The results are from an arbitrarily selected segmentation run.

	Case (Volume mm3)				Case (Thickness mm)			
Patella	A	B	C	D	A	B	C	D
mean	4324.13	4791.82	4278.48	3663.03	3.19	3.49	3.25	3.17
stdev	76.29	209.59	140.10	804.94	0.10	0.07	0.05	0.28
CV	1.76	4.37	3.27	21.97	3.27	1.98	1.43	8.83
Tibia								
mean	7020.88	4647.38	5691.31	5930.76	2.27	2.01	2.25	2.31
stdev	123.98	367.69	159.74	457.48	0.02	0.10	0.05	0.11
CV	1.77	7.91	2.81	7.71	0.98	4.96	2.15	4.90
Femur								
mean	14549.85	13464.23	14516.13	13444.77	2.46	2.41	2.51	2.47
stdev	618.55	931.95	241.48	1244.92	0.09	0.08	0.03	0.09
CV	4.25	6.92	1.66	9.26	3.64	3.12	1.05	3.54

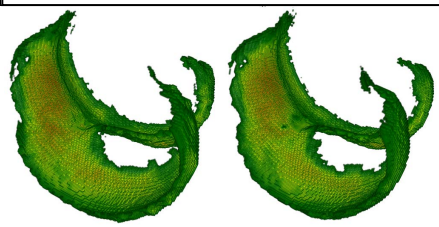

Figure 2: Laplacian thickness map of the tibial cartilage from *left* weDESS *right* MEDIC.

Discussion: The variability in segmentation obtained on the same scan was quite small, however as can be seen in Table 1 and 2 there can be quite a large difference in quantitative measures when using different resolutions, positions, sequences and over time. In general, the automatic segmentation algorithm obtained reproducible results for the quantitative measures. Only the patella in case (D) had a high CV, which was caused by a poor estimation of the tissue properties, resulting in significant under-segmentation. The lower resolution, higher noise and tissue inhomogeneity, in the weDESS compared to the MEDIC were the primary cause of the variability (and errors) between segmentation results. This was most obvious towards the ends of the cartilages in the slice direction, where partial volume effects resulted in inconsistent inclusion and exclusion of cartilage tissue. Other areas which caused segmentation errors were the cartilage interfaces, the ends of the femoral cartilage and between the tibial cartilages where ligament tissue was sometimes falsely segmented. Synovial fluid was inconsistently handled, although the results from weDESS images were generally better than MEDIC.

Conclusion: In this paper we have reported reproducibility experiments for our automatic segmentation algorithm used on weDESS and MEDIC MR images. The results obtained by both sequence were generally accurate and consistent, which is promising as the accuracy will be further improved at higher field strengths (higher resolution and improved SNR).

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