ATLAS BASED METHOD FOR THE AUTOMATED SEGMENTATION AND QUANTIFICATION OF KNEE FEATURES: DATA FROM THE OSTEOARTHRITIS INITIATIVE

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Abstract: This work presents a fully unsupervised segmentation method for the segmentation of 3D DESS MRI images of the human knee. Five MRI knees manually segmented by human experts are used as reference atlases to automatically segment subsequent MRI images. The five segmentations are averaged to create the knee segmentation. The methodology was tested on the pilot Osteoarthritis Initiative (OAI) image set of MRI DESS sequences. The data includes longitudinal images from healthy normals and subjects with osteoarthritis (OA) scanned twice at baseline and at the 24 month follow-up. The segmentation methodology was able to create precise cartilage segmentations of the knees that were used to extract volume, thickness and subchondral bone plate curvature information of the knee. The quantitative thickness showed precisions ranging from 0.025mm to 0.051mm. The longitudinal reproducibility of the cartilage thickness measurement methodology showed intra-class correlations coefficients (ICC) ranging from 0.39 to 0.79.

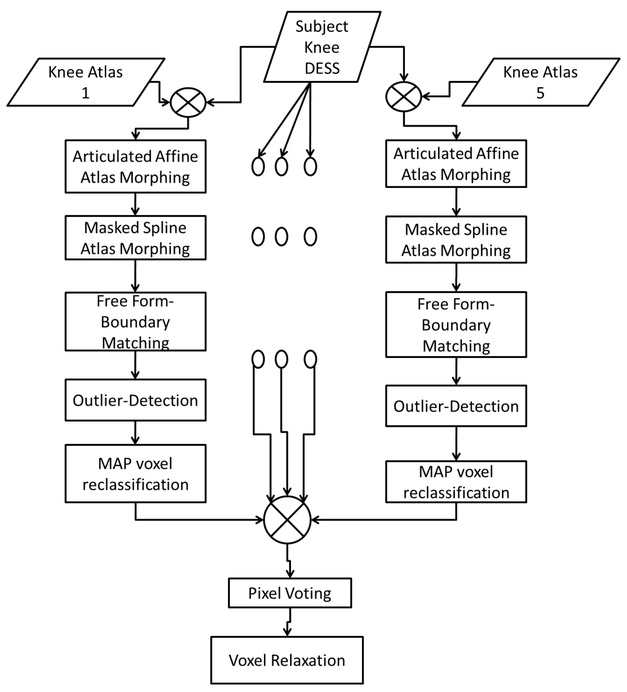

Fig. 1. Five MRI DESS atlases are used to create a single segmentation of the baseline and the 2 year follow-up of the OAI Pilot data set. Registration, relaxation, outlier detection, and pixel voting are used to create the segmentation.

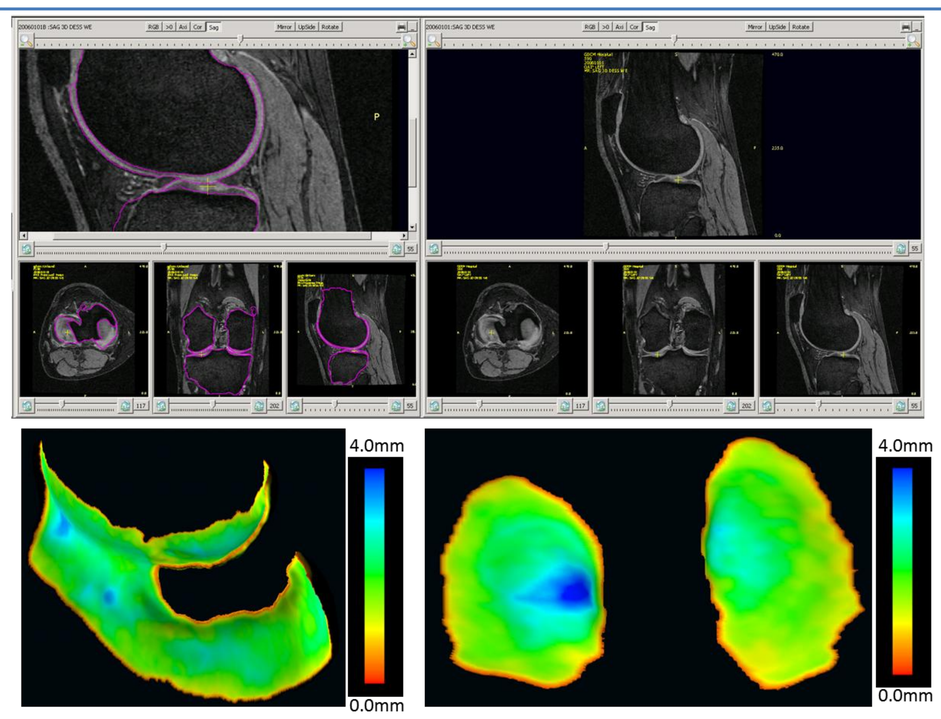

Fig. 2. Top left, segmented DESS MRI data. Top right, input DESS series. Bottom left, 3D reconstruction of the femoral cartilage. Bottom right, 3D reconstruction of the tibia cartilage.

TABLE I: Descriptive statistics of the test-retest data. The performance of the measurement is reported in absolute values as well as function of the measurement range (precision). The ICC is computed from the sample variances of the population and the error.

Quantitative Performance of Selected Knee Features (n=12, Scan-rescan, Baseline and 24 Month Follow-up)								
		Population Description				Performance (Test-Retest)		
		Average (μ)	Standard Deviation ($s^{\wedge}_d$)	Minimum (Min)	Maximum (Max)	Std of Error ($s^{\wedge}_e$)	Measurement Precision(CV) $\frac{s_e}{[max-min]}, (S_e/\mu)$	ICC $s^2_d/(s^2_d+s^2_e)$
Volume (mm^3)	Femur	9355.91	2522.25	6573.61	15530.74	223.02	2.5% (2.4%)	0.99
	Tibia	3054.41	736.38	2324.39	4937.74	170.13	6.5% (5.6%)	0.95
	Medial Tibia	1458.71	392.86	1038.05	2387.99	100.69	7.5% (6.9%)	0.93
	Lateral Tibia	1575.79	371.53	1169.80	2594.83	89.73	6.3% (5.7%)	0.94
	Central Medial Femur	1671.98	476.74	883.04	2566.64	45.27	2.7% (2.7%)	0.99
	Central Lateral Femur	1565.05	443.10	1134.08	2549.84	37.04	2.6% (2.4%)	0.99
Thickness (mm)	Femur	1.930	0.138	1.785	2.266	0.025	5.1% (1.3%)	0.97
	Tibia	1.709	0.162	1.511	2.111	0.037	6.2% (2.2%)	0.95
	Medial Tibia	1.609	0.202	1.209	2.029	0.051	6.2% (3.1%)	0.94
	Lateral Tibia	1.835	0.169	1.542	2.218	0.037	5.5% (2.0%)	0.95
	Central Medial Femur	1.801	0.230	1.247	2.182	0.041	4.4% (2.3%)	0.97
	Central Lateral Femur	1.827	0.133	1.623	2.111	0.034	7.0% (1.9%)	0.93
Curvature (mm^{-1})	Femur	0.0218	0.0052	0.0106	0.0288	0.0009	4.9%	0.97
	Tibia	-0.0130	0.0074	-0.0287	0.0005	0.0027	9.4%	0.86
	Medial Tibia	-0.0211	0.0054	-0.0285	-0.0084	0.0033	16.4%	0.63
	Lateral Tibia	-0.0036	0.0116	-0.0269	0.0246	0.0027	5.3%	0.94
	Central Medial Femur	0.0297	0.0075	0.0160	0.0407	0.0017	6.9%	0.95
	Central Lateral Femur	0.0281	0.0051	0.0154	0.0362	0.0011	5.1%	0.96

TABLE II: Reproducibility of the change. The change between the baseline and the follow-up was measured using four different changes. The agreement between changes is reported as the correlation between measurements using the Pearson correlation and the ICC.

Quantitative Change between Baseline and the 24 month visit of Selected Knee Features (n=12, scan-rescan)								
		Change Description				Performance (Test-Retest)		
		Average Change	Standard Deviation of Change	Minimum Change	Maximum Change	Standard deviation of Error	Correlation of Change	ICC of Change
Volume (mm^3)	Femur	-26.23	663.18	-1085.69	1090.20	223.02	0.84	0.80
	Tibia	52.67	264.49	-382.32	698.07	170.13	0.43	0.43
	Medial Tibia	20.76	139.94	-254.10	267.88	88.95	0.34	0.43
	Lateral Tibia	27.03	123.23	-127.42	332.50	89.73	0.31	0.33
	Central Medial Femur	28.46	105.19	-118.40	237.03	40.38	0.74	0.76
	Central Lateral Femur	-32.66	73.95	-175.85	71.69	37.04	0.62	0.65
Thickness (mm)	Femur	0.003	0.071	-0.119	0.142	0.025	0.85	0.79
	Tibia	0.033	0.068	-0.043	0.204	0.034	0.57	0.67
	Medial Tibia	0.034	0.075	-0.075	0.205	0.046	0.37	0.53
	Lateral Tibia	0.027	0.091	-0.113	0.226	0.037	0.75	0.73
	Central Medial Femur	0.028	0.056	-0.067	0.114	0.041	0.47	0.39
	Central Lateral Femur	-0.017	0.065	-0.130	0.091	0.034	0.58	0.59
Curvature (mm^{-1})	Femur	-0.0005	0.0009	-0.0017	0.0007	0.0008	0.15	0.25
	Tibia	-0.0006	0.0026	-0.0043	0.0055	0.0024	0.03	0.11
	Medial Tibia	0.0000	0.0076	-0.0093	0.0197	0.0033	0.76	0.68
	Lateral Tibia	-0.0005	0.0051	-0.0133	0.0084	0.0027	0.57	0.56
	Central Medial Femur	-0.0009	0.0011	-0.0031	0.0004	0.0015	(0.40)	-
	Central Lateral Femur	-0.0011	0.0016	-0.0045	0.0010	0.0009	0.41	0.61

Results

Figure 2 shows a sample of the output segmentation created by the multi-atlas segmentation algorithm. The cartilage tissue of the segmented results are 3D reconstructed and quantitated for volume, thickness, and surface curvature. Table 1 shows the performance of the method on the OAI pilot data set. Coefficients of variation of 1.3% were achieved for the average cartilage thickens. The reproducibility to observe changes in cartilage topography are shows in table 2. Good ICC were observed in the estimations of change for the femoral cartilage volume and thickness (ICC>0.75). Changes in curvature were not as significant and as changes in cartilage volume

Conclusion

This work shows that it is possible to get precise quantitative data automatically from OAI data sets. The measured degree of precision enabled detection of reproducible changes in a two year period using only 12 subjects from the pilot OAI data. The main limitation of the system is that it may introduce some atlas bias to the measurement. The system mitigated this defect by the introduction of five different atlases, but those atlases are still based on normal knee anatomy. Therefore this system may not be applicable to advanced OA subjects that have large focal cartilage lesions. As next steps, we will evaluate the performance of the system in large OAI data sets and corroborate the observed changes by other OAI investigators

ACKNOWLEDGEMENTS

The OAI is a public-private partnership comprised of five contracts (N01-AR-2-2258; N01-AR-2-2259; N01-AR-2-2260; N01-AR-2-2261; N01-AR-2-2262) funded by the National Institutes of Health, a branch of the Department of Health and Human Services, and conducted by the OAI Study Investigators. Private funding partners include Merck Research Laboratories; Novartis Pharmaceuticals Corporation, GlaxoSmithKline; and Pfizer, Inc. Private sector funding for the OAI is managed by the Foundation for the National Institutes of Health. This manuscript was prepared using an OAI public use data set and does not necessarily reflect the opinions or views of the OAI investigators, the NIH, or the private funding partners