FULLY AUTOMATED RADIOGRAPHIC KNEE SHAPE ANALYSIS OF THE OAI DATASET: IS KNEE SHAPE ASYMMETRY AN EARLY INDICATOR OF UNILATERAL KNEE OA?

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INTRODUCTION: Symmetry between the knees of an individual is required for the knee joint to function without causing any discomfort. Knee shape asymmetry may develop as a sign and/or consequence of disease. The analysis of radiographic bone shape in large scale datasets provides the opportunity to examine predictors and biomarkers for OA such as knee shape. However, manually outlining the shape of interest in every image is tedious, time-consuming and prone to inconsistencies.

OBJECTIVE: To develop a fully automated shape analysis (FASA) system to study radiographic knee shape, and to apply the system to radiographs from the OAI dataset to explore the role of knee shape asymmetry (KSA) in unilateral radiographic knee OA (urKOA, defined by KLG $\geq$ 2 and JSN $\geq$ 1).

METHODS: All analyses were based on bilateral PA knee radiographs from the OAI dataset where all right knees were mirrored to appear as left knees. For the development of the FASA system (following [DOI: 10.1007/978-3-642-40763-5_23]), we used 508 subjects randomly selected to include cases and controls (254 without rKOA, 254 with rKOA); none of these subjects was included in the KSA analysis. We designed the system to automatically locate 74 points along the contour of each knee, and evaluated its performance using 2-fold cross-validation experiments. We report the point-to-curve error averaged over all points per knee (P2C), comparing the fully automatic search results with manual annotations. For the analysis of KSA, we included 894 controls without any urKOA at both baseline and 96 months, and 293 cases with urKOA at 96 months of which 60 subjects (caKL01) had no urKOA at baseline, 172 subjects (caKL2) had urKOA with KLG=2 at baseline, and 61 subjects (caKL3) had urKOA with KLG=3 at baseline. We applied the FASA system to automatically locate all 74 points on each control/case knee, aligned the landmark positions of both knees per subject into a normalised reference frame, and calculated the signed x-/y-displacements between both knees to estimate KSA. We used the displacement values as features to train a Random Forest (RF) for classifying control and case subjects. This was done in both asymmetry directions (i.e. left minus right knees, and right minus left knees) for training and testing, using the maximum case response as classification result. For each experiment, we randomly sampled 80% for training and used the remaining 20% for testing the RF, and repeated this 50 times. We summarise the classification performance using the area under the receiver operator curve (AUC) averaged over all 50 iterations with a 95% confidence interval.

RESULTS: The FASA system (available from www.bone-finder.com) searched a single knee in on average 12 seconds, and achieved a cross-validated P2C error of less than 0.7mm for 99% and within 1.0mm for 100% of all 508 images; the mean P2C error over all knees was 0.3mm. Table 1 gives the results of the classification experiments, and Figure 1 visualises the KSA in cases.

Table 1: Results of subject classification based on KSA as given by standardised x-/y-displacements.

	controls vs caKL01	**controls vs caKL2**	**controls vs caKL3**	**controls vs caKL0123**
AUC [95% CI]	0.615 [0.598-0.632]	0.620 [0.608-0.632]	0.860 [0.845-0.875]	0.874 [0.866-0.882]

CONCLUSION: The FASA system fully automatically outlines the shape of the knee with high accuracy and robustness. Utilising the latter to analyse radiographic KSA has the potential to automatically identify subjects with urKOA, even at an early stage. The caKL01 classification performance suggests that KSA is an indicator of disease before characteristics of urKOA can be identified.

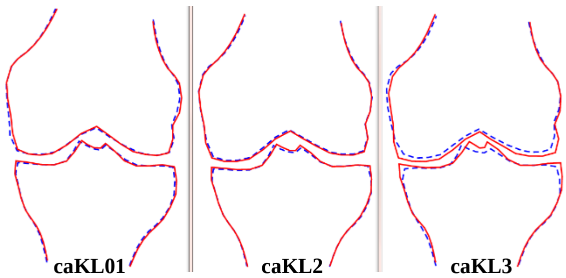

Figure 1: Visualisation of shape asymmetry between means of affected (red) and unaffected (blue) knees at baseline (exaggerated by factor 5 to aid visualisation). Left/right knee differences not taken into account.

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