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### AUTOMATIC QUANTIFICATION OF CARTILAGE THICKNESS FROM MRI FOR MONITORING PROGRESSION OF OSTEOARTHRITIS - A LONGITUDINAL STUDY

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**Purpose:** During progression of knee osteoarthritis (OA) the cartilage breakdown causes gradual thinning of the articular cartilage sheets. The aim of this study was to investigate whether cartilage thickness measurements from an automatic, computerized framework for cartilage quantification from low-field MRI are suitable for use in clinical studies.

This was evaluated at baseline in terms of inter-scan precision and ability to separate healthy from knees with a degree of osteoarthritis. After 21 months, the longitudinal changes were compared to the precision and the ability to separate healthy from OA was evaluated.

**Methods:** A randomized population of both male and female subjects was prospectively selected such that there was an even distribution among male and female and across the ages from 21 to 80 (mean 56) with BMI from 20 to 38 (mean 27). Both left and right knees and both healthy and knees with varying degree of osteoarthritis (OA) as defined by the Kellgren and Lawrence score at baseline (KL) were used giving a total of 215 knees in the study.

MR scans were acquired using a sagittal Turbo 3D T1 sequence on a 0.18T Esaote C-Span scanner giving near-isotropic voxels with slice thickness of 0.8mm. Scans were acquired at baseline, after one week for a subgroup of 31 knees, and then again after 21 months for all knees.

The thickness of the medial tibial cartilage compartment was measured at baseline and after 21 months using a fully automatic framework for morphometric cartilage analysis based on supervised learning and a statistical cartilage sheet shape model. We measured the mean cartilage thickness across the entire area of the bone - including denuded regions which are measured with zero thickness. For baseline measurements, the cartilage thickness was normalized by the width of the medial tibial plateau.

**Results:** The precision of the thickness measurements was 0.08

mm (mean absolute difference) and 3.6% (relative difference) determined by comparing measurements on the 31 scan-rescan pairs at baseline.

At baseline, the healthy (KL 0) knees had significantly thicker cartilage than OA knees (KL > 0): 2.25 mm compared to 2.17 mm ( $p < 0.05$ ).

Furthermore, the longitudinal cartilage thinning over the 21 months was significantly higher for OA knees compared to healthy: 5.9% compared to 2.3% ( $p < 0.01$ ). The thickness loss is illustrated in figure 1 for the groups of healthy and OA, and then for each KL score (where KL 3 and KL 4 are pooled since there was only a single KL 4 knee).

**Conclusions:** The measurement precision of 0.08 mm or 3.6% was comparable to the difference between the groups of healthy and OA at baseline of 0.08 mm. Furthermore, the precision was comparable to the rate of cartilage thinning over the study period: 2.3% for knees healthy at baseline, and 5.9% for knees with OA at baseline. In addition, the quantification shows that the thinning was significantly higher for OA knees ( $p < 0.01$ ).

A nice detail is that when cartilage thinning is measured as the relative longitudinal change (in %), no normalization for knee size is necessary. Thereby, the thickness quantification seems suitable for monitoring the effects of potential disease modifying OA drugs.

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### ACCURACY OF MULTIMODALITY REGISTRATION OF ARTICULAR CARTILAGE AND UNDERLYING BONE IN THE HIP

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**Purpose:** There is a substantial need to integrate 3D quantitative bone and cartilage information gained from different imaging modalities to better understand the close relationship between cartilage and bone changes in osteoarthritis progression. It is not clear whether existing image registration algorithms can be used to integrate magnetic resonance (MR) and computed tomography (CT) based images of joints, how accurately these images can be matched, or which algorithm provides the best match. The purpose of this study was to assess the feasibility and accuracy of matching 3D MR-based representations of articular cartilage to corresponding 3D CT-based representations of the underlying bone in the hip.

**Methods:** A 3D solid model of the proximal femur was created from CT images using reconstruction software (Analyze 6.0), modeling software (RapidForm) and computer aided design (Unigraphics NX 2). A section of the surface of the femoral head was exported as a 3D point cloud representing the cartilage concave surface. The surface of the femoral head was exported as a 3D point cloud representing the convex underlying bone. The two point clouds were created with different neighboring point-to-point distances to minimize overlapping and simulate the disparity between different imaging modalities. The point clouds were input in an aligned position and the bone was translated and rotated by a known amount to bring the two models out of alignment. Three variations of the Iterative Closest Points (ICP) algorithm were used to match the cartilage and bone surfaces: (a) "classic" ICP which uses a point-to-point distance metric for calculating a transformation matrix, (b) random ICP which uses the same point-to-point distance metric with a random subset of points selected from the point clouds at each step of the iteration, and (c) normals ICP which uses a point-to-plane distance metric based upon surface normals to calculate a transformation matrix. The performance of each algorithm was assessed by the minimum average error and number of iterations until a minimum was reached.

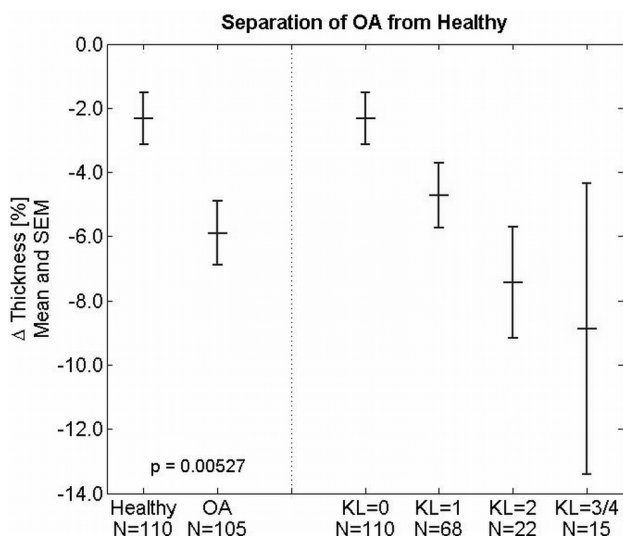


Fig. 1. The rate of cartilage change shown by mean (and SEM) for each group of knees with varying degree of OA at baseline. Left of dotted line: The groups of healthy (KL 0) and OA (KL > 0). Right: Each KL score.

P277 – Table 1. ICP Errors and Number of Iterations Until Minimum Error

Translation/Rotation	Classic		Random		Normals	
	Error (mm)	# Iterations	Error (mm)	# Iterations	Error (mm)	# Iterations
0.25mm/0.25deg	0.136	20	0.111	14	0.171	4
0.5mm/0.5deg	0.242	51	0.114	41	0.151	11
1.0mm/1.0deg	0.822	77	0.139	123	0.640	8
1.5mm/1.5deg	0.866	133	0.119	173	0.648	10
2.5mm/2.5deg	2.639	70	0.093	380	0.539	21
5.0mm/5.0deg	4.167	192	0.685	598	2.941	27

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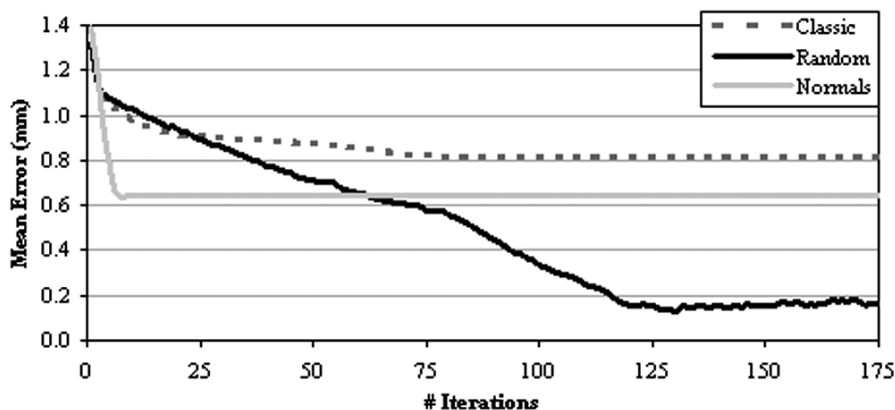


Fig. 1

**Results:** The classic and normals ICP algorithms were prone to incorrect alignments resulting in errors exceeding 1mm (Table 1). The random ICP had the lowest reproducible error, but the highest number of iterations. The noisiness of the random algorithm resulted in the error metric fluctuating about a local minimum without converging (Fig 1). While prone to inaccuracy, the normals ICP algorithm was the fastest technique and generally offered a moderate error metric. The classic ICP demonstrated the largest error of all the ICP variants except when closely aligned.

**Conclusions:** It is feasible to match CT and MR-based data together (Table 1) but the choice of algorithm radically affects the accuracy of the match and computation time. The subtle differences between the larger convex bone and smaller concave cartilage make registration difficult, computationally expensive and prone to error, thus the two meshes must be manually aligned as close as possible prior to performing the registration. The random ICP should be employed for registering geometrical point clouds of cartilage and underlying bone as it produced a low, reproducible error in all test cases. The normals ICP algorithm should be employed if speed is required and a moderate error is acceptable. The resulting shape-matched images have the potential to show and quantify the changes in both bone density and cartilage morphology that characterize progression of osteoarthritis.

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### EVALUATION OF SUBCHONDRAL TRABECULAR BONE USING 3 TESLA (3T) MAGNETIC RESONANCE IMAGING

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**Purpose:** Changes in the subchondral bone are central to osteoarthritis (OA) pathophysiology but measurement of this region is challenging. Trabecular bone has been assessed using high

resolution MR with axial 3D acquisitions at 1.5T but regional artifacts in the subchondral bone limit their utility. 3D acquisitions in the coronal plane may be feasible at 3T providing more pertinent visualization of subchondral bone as 3T MR systems allow higher spatial resolution and high contrast-to-noise (CNR). Our objective was to determine the optimal trabecular bone MRI parameters for coronally acquired images and to assess their interpretability.

**Methods:** We sought volunteers  $\geq 40$  years old without inflammatory arthritis, arthroplasty or MRI contraindication. We used a Siemens Trio 3T MRI with a USA Instruments quadrature transmit/receive knee coil. Starting with previously published 1.5T parameters we optimized the sequences at 3T to maintain spatial resolution and minimize scan time. We systematically varied the flip angle between 10 and 70 degrees using a TR of 20 msec and a 3D gradient echo sequence.

Each participant had one scan of each knee. Each set of 3T MR images acquired using the optimized parameters was evaluated qualitatively and quantitatively using Analyze<sup>®</sup> software. We placed an anatomically-standardized medial tibial region of interest (ROI) box systematically on all coronal slices that imaged subchondral bone. The ROI on each slice was assessed for mean and maximal marrow signal. The "bone signal" was calculated for each ROI as 1-(mean marrow signal/maximal marrow signal). Bone signal topography (BeST) reflecting "bone signal" on each coronal slice was performed on each knee.

**Results:** The optimized parameters were 1mm slice thickness, in-plane spatial resolution of 0.2 mm x 0.2 mm, with a 12 cm imaging field-of-view, 512 x 512 matrix, 72 slice coverage with TE 4.92 msec (fat-water in-phase), TR 20 msec, flip angle 50°, phase right/left, interpolation to 1024 x 1024, and no partial Fourier. A typical acquisition required 12-14 minutes.

We enrolled 5 participants; one had radiographic OA (ROA) with occasional symptoms (46 F), two had symptoms without documented ROA (51 F and 51 F), and two had no documented ROA or symptoms (47 M and 48 F).

The asymptomatic knees exhibited prominent horizontal trabeculae in the tibial subchondral bone, while the OA knee had an appearance of disorganized subchondral bone and absent horizontal trabeculae. Quantitative evaluation of the medial tib-