Conclusions: This paper proposes an automated method of constructing subject-specific anatomy coordinate systems for the distal femur and proximal tibia from their 3-D bone geometries in CT images. The proposed method is able to locate the landmarks and to extract the anatomy axis automatically, and then constructs the ACS's for the femur and the tibia. Its performance is evaluated using real data sets, and the experimental results demonstrate the effectiveness and accuracy. For future works, the authors will focus on estimation of several threshold values in feature segmentation, and carry out ample tests with more CT image data sets.

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T1RHO MAPPING OF ENTIRE FEMORAL CARTILAGE USING NOVEL DEPTH AND ANGLE DEPENDENT ANALYSIS

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Purpose: T1rho-weighted MR imaging has recently been proposed as an attractive biomarker to existing conventional morphological MRI methods, and has been shown to be more sensitive to biochemical change in cartilage than T2 mapping. It enables us to detect early cartilage degeneration in early osteoarthritis (OA) patients before appearing morphological change. However for the methodology of segmentation, the number of slices measured is only one or several slices, not all slices from the knee in most of reports. There is also no previous publication about normal entire femoral T1rho map profiles for analyzing regional or cartilage layer variations. These unresolved problems and limitations make diagnosis of early OA with T1rho mapping difficult clinically. The objective of this study was to create normalized T1rho profiles of healthy entire femoral cartilage with 3 dimensional (3D) angular and depth dependent analysis, and evaluate their usefulness.

Methods: 20 healthy volunteers (mean: 28.9 y.o., range: 19-38) were enrolled in this study. The study was approved by IRB, and written informed consent was obtained from each subject. Sagittal T1rho images of the knee were acquired with spoiled gradient echo (SPGR) sequence. All MR studies were performed on a 3.0-T unit (Achieva, Philips Healthcare, Netherland) utilizing an 8-channel knee receive-only RF-coil. The acquisition parameters were as follows. SPGR: mode = 3D, fat-saturation method = PROSET, TR/TE = 6.4/3.4msec, Band width = 475Hz, ETL = 64, NEX = 1, FOV = 140*140mm, Slice thickness/gap = 3/0mm, Flip angle = 10 degree, Image-matrix = 512*512mm, number of slices = 31, Time of spin-lock (TSL) = 20/40/60/80msec, acquisition time = 4min09sec *4. Entire knee cartilage segmentation was performed by two raters independently slice by slice with Matlab. T1rho depth/angle-dependent profile was investigated by partitioning cartilage into two layers (deep; 51-100% and superficial; 0-50%) and angular segmentations in step of 4-degree over the length of segmented cartilage (the angle 0 defined along B0) (Fig.1). After manual segmentation, we normalized the entire femoral cartilage with 23 new slices of all subjects. We calculated the average T1rho values of every layer in representative angles of -54,-30, 0, +34, +54 degrees to evaluate angular dependent changes including magic angle effects. We also compare T1rho values between weight bearing and non-weight bearing portion. Finally we created 3D-graph by thin-plate spline method.

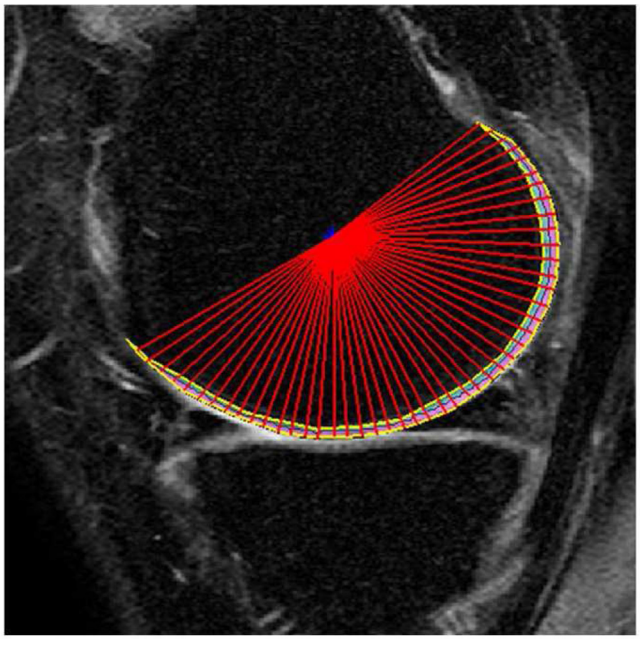

Fig.1. Sagittal SPGR images from T1rho sequence of knee MRI after manual segmentation with post-processing. Two observers segmented the entire femoral cartilage of the both images slice by slice independently. After manual segmentation, angular analysis in step of 4-degree and depth analysis with superficial and deep layers was performed automatically.

		Angle		T1rho value
Entire knee		(-180 ~ 180)	Whole	56.97 ± 2.82
			Superficial	58.94 ± 2.56
			Deep	55.68 ± 3.55
MC*	Non-weight bearing	(<-30, 30<)	Whole	57.50 ± 4.06
			Superficial	59.51 ± 4.07
			Deep	55.67 ± 5.42
	Weight-bearing	(-30 ~ 30)	Whole	54.91 ± 1.33
			Superficial	59.81 ± 1.85
			Deep	51.13 ± 2.11
LC**	Non-weight bearing	(<-30, 30<)	Whole	58.64 ± 2.47
			Superficial	60.92 ± 2.95
			Deep	56.96 ± 3.56
	Weight-bearing	(-30 ~ 30)	Whole	55.51 ± 3.34
			Superficial	62.11 ± 5.35
			Deep	52.46 ± 4.36

* MC: medial condyle **LC: lateral condyle

Fig.2. Average T1rho values in representative angles.

Results: Figure2 showed average T1rho values in representative angles. There was no influence of magic angle effect, although there was angular variation in each layer. Average T1rho values in the superficial layer of the femoral articular cartilage were higher than in the deep layer over the entire knee, medial condyle, and lateral condyle with significant difference ($p<0.05$) (Fig.3). T1rho values of the weight-bearing portion were lower than the non weight-bearing portion over the medial and lateral condyles in the deep layer with significant difference ($p<0.05$), while there was no significant difference in the superficial layer (Fig.4). The 3D-graph demonstrated cartilage T1rho values were not homogeneous over the entire knee (Fig.5).

Conclusions: T1rho values of the femoral cartilage demonstrate regional and depth variations with no significant magic angle effect. We can analyze the T1rho values across the entire femoral condyle 3 dimensionally by 3D-graphs using different displaying method from various points of view including angle, layer, slice, anatomic landmark,

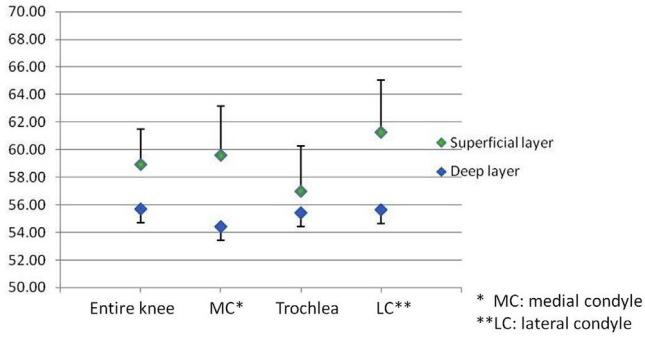

Fig.3 The difference of average T1rho values between the superficial and deep layers on each anatomical landmark. Average T1rho values in the superficial layer of femoral articular cartilage were higher than in the deep layer over the entire knee, medial condyle, and lateral condyle with significant difference ($p<0.05$)

and so on; improving on the previously reported 2 dimensional analysis. We should know normal T1rho profiles from entire knee cartilage to diagnose local or early T1rho abnormality and OA in clinical application.

		Angle		T1rho value
Entire knee		(-180 ~ 180)	Whole	56.97 ± 2.82
			Superficial	58.94 ± 2.56
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MC*	Non-weight bearing	(<-30, 30<)	Whole	57.50 ± 4.06
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			Superficial	62.11 ± 5.35
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* MC: medial condyle **LC: lateral condyle

Fig.4. Average T1rho values of weight-bearing and non weight-bearing portion in entire femoral cartilage, medial femoral condyle, and lateral femoral condyle.

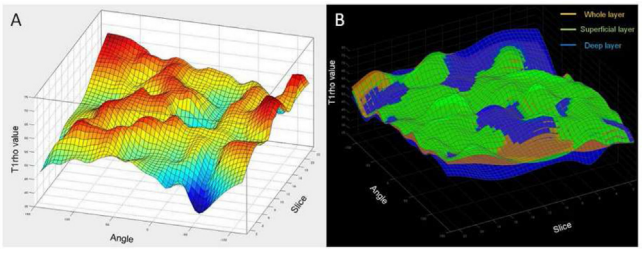

Fig.5. 3D-graph of T1rho mapping of femoral cartilage based on thin-plate spline. (A) 3D-graph of one layer colored on the basis of the difference of T1rho values (B) 3D-graph applied a single color tone per layer with simultaneous expression with superficial, deep, and whole layers.

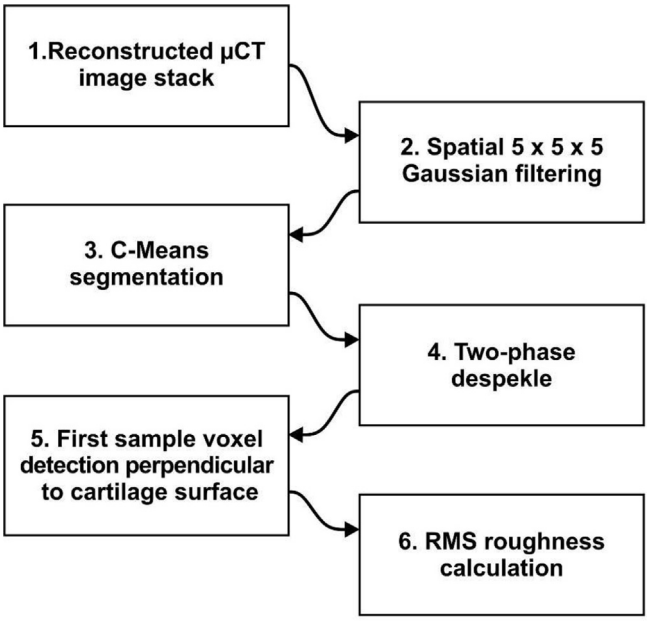

Figure 1. Segmentation was conducted by first applying 5×5×5 3D Gaussian filter (SD = 1.1 voxels) to the image stack to remove noise and then subjecting the stack to C-Means segmentation to separate sample from the background (sample probability: 0.67). Erroneously segmented volumes were removed with two phase despeckle operation. Sample AC Surface was detected as first sample voxel from the AC side of the sample when approaching from direction perpendicular to AC surface (ROI: approx. 1200 × 900 µm rectangular area). Steps were 2-5 were conducted using a custom-made C++ program and step 6 with a custom-made Matlab (version 2014) program.

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SURFACE CHARACTERIZATION OF DEGENERATED ARTICULAR CARTILAGE SURFACE BY CONTRAST-ENHANCED MICRO-COMPUTED TOMOGRAPHY

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Purpose: Histopathological grading (e.g. OARSI grading and Mankin score) is based on light microscopy assessment of articular cartilage (AC), with significant contribution from surface morphology, in thin (~5 µm) 2D tissue sections. However, this approach has major limitations: 1. the sections represent only a small tissue region; 2. sections are subjected to cutting artefacts; 3. visual evaluation is qualitative at best.
Our previous study showed that phosphotungstic acid (PTA) provides anatomical detail and good contrast in micro-computed tomography (µCT) imaging of AC. In this study, our goal was to develop an algorithm to quantify the 3D AC surface roughness and compare this with histology (OARSI grade).
Methods: Human osteochondral cylinders (n = 5, diameter = 4.6 mm) were prepared from tibia or femur of resections pieces, which were collected from three patients during total knee arthroplasty (ethics approval PSSHP 78/2013; consents obtained). Each sample was split into one half (for histology) and two quarters (one quarter used for this study) and subject to formalin fixation (5 d). The samples were then immersed for 36 h in 70% EtOH containing 1% w/v PTA. Following PTA staining, the sample was imaged with µCT (Nanotom 180NF, Phoenix X-ray Systems/GE; 80 kV, 100 µA, 1200 projections, 750 ms/frame, 7 frames/projection, isotropic 3.0-3.2 µm voxel size). Projections were reconstructed using datos|x (version 1.3.2.11, GE Measurement & Control Solutions/Phoenix X-ray, Fairfield, CT, USA).
The reconstructed image stack was subjected to the algorithm depicted in Fig 1. Surface trends were renormalized as follows: 1. A bicubic