Characterization of knee osteoarthritis using spatial distribution of T1p values: A longitudinal study

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Purpose: One of the most important biomarkers of knee osteoarthritis (OA) is the degeneration of cartilage. Clinical evaluation of cartilage is mainly based on radiographic evidence. X-rays only show changes in the bone, which occur later than the early cartilage biochemical and morphological changes like breakdown of the collagen-proteoglycan matrix. Morphological MRI provides excellent soft tissue contrast to look into the qualitative details. Quantitative MRI including T1p and T2 mapping have allowed to delve into the subtle early cartilage changes in knee OA as shown by increase in values in OA subjects[1]. However, spatial analysis of T1p and T2 relaxation times has been shown to improve identification of cartilage matrix abnormalities compared to global mean values[2,3]. The goal of this study is to longitudinally evaluate the changes in spatial distribution of T1p using texture analysis in unloaded osteoarthritic and healthy knee cartilage at baseline and one year mark.

Methods: 15 subjects, 6 females and 9 males (mean age 53.2±10.3 years and BMI 24.1±3.3 at baseline) who were a part of an ongoing study at our institution were analyzed. The study was approved by and performed in accordance with the rules and regulations of the Committee for Human Research at our institution. To be a part of the study, the OA patients had to be more than 35 years of age, showed frequent clinical symptoms and radiographic signs of OA. The controls were also older than 35 years and without any history of diagnosed OA, had no previous injuries, did not show any clinical OA symptoms or signs of OA on radiographs. In addition, exclusion criteria for all subjects included pain in any lower extremities except knees, a history of lower extremity or spine surgery, total joint replacement of any lower extremity joint, self reported inflammatory arthritis, any conditions limiting the ability to walk and contraindications to MR imaging. All subjects underwent MRI of the knee at baseline and the following year. MR data was acquired on a GE wide bore 3T scanner (MR750w) with an 8-channel phased array knee coil (Invivo Corp, Gainesville, FL). Morphological assessment was done using *modified* Whole Organ Magnetic Resonance Imaging Score (WORMS) classification. Cartilage lesions were assessed using WORMS for all six knee compartments with the highest grade recorded for each compartment. A WORMS score of 0 was considered healthy and considered separately from those with WORMS > 0 who were considered osteoarthritic. T1p images were acquired with the 3D MAPSS sequence previously developed for T1p imaging at 3T. The T1p sequences had the following parameters: FOV=14cm, 256x128 matrix, slice thickness=3mm, 30 slices, TSL=[0,2,4,8,12,20,40,60ms], spin lock frequency=500Hz, TE = [0 0,3.4,6.8,10.3,20.5,34.2,47.8,61.5ms], TR/TE=5.2/2.9ms. Composite tip-down and tip-up RF pulses were used to compensate for B_0 and B_1 inhomogeneities. Also, the 3T exam used 2x phase ARC acceleration. The articular cartilage was divided into six compartments namely, lateral femoral condyle (LFC), medial femoral condyle (MFC), patella, trochlea, lateral tibia (LT) and medial tibia (MT) during semi-automatic segmentation done using in house software in Matlab. T1p maps were reconstructed using in house software and the GLCM (gray level co-occurrence matrix, described by Haralick et al[4]) contrast, variance and entropy in the horizontal (0°/anterior-posterior axis) and vertical (90°/superior-inferior axis) directions were analyzed at one pixel offset. Contrast indicates the difference in adjacent pixel values; entropy is a measure of pixel orderliness and variance determines the variation in pixel values from the mean[1-5].

Results and discussion: At baseline, subjects with lesions had higher horizontal and vertical entropy for all compartments except the medial tibia compared to healthy subjects. Significant differences in entropy were seen between subjects with and without lesions in LFC (horizontal and vertical) and patella (vertical) directions (Fig 1a). Contrast values in OA subjects were higher in LFC, MFC and trochlea with significantly higher contrast observed in LFC (both directions), MFC (horizontal) and trochlea vertically. Higher variance was seen in LFC, MFC and trochlea in the both directions in subjects with lesions compared to healthy controls with significant differences seen in LFC in both directions. Variance values in trochlea were approaching significance (0.08 and 0.09) in both directions.

At year 1, higher entropy was seen in both directions in subjects with lesions in all compartments except medial tibia with the patella and LFC values significantly different between the two groups in both directions (Fig 1b). Higher contrast values were seen in subjects with OA in all compartments except patella in horizontal direction and vertical lateral tibia. Significant contrast differences were seen between the OA and non OA group in LFC (both directions) and patella (horizontal). Variance values were higher in OA group for all compartments except lateral tibia in both directions with significant differences seen between the groups in LFC in both directions and the medial tibia approaching significance (p=0.08) in horizontal direction.

Conclusion: Texture analysis is useful to evaluate the distribution of pixel values and quantify heterogeneity at the pixel level in an image. Parameters derived from GLCM method used in this study provide information on the variations in pixel values and distribution of signal in an image. Previous studies have looked at T_2 and T1p spatial distribution, but to our knowledge longitudinal changes in spatial distribution evaluation in T1p value for all six compartments has not been done.

To summarize, our preliminary results show higher entropy, contrast and variance values in subjects with lesions in MFC, LFC and trochlea longitudinally indicating increased heterogeneity in these compartments. Thus, these parameters along with T1p relaxation time can be used to differentiate OA and healthy subjects and may provide a more detailed longitudinal characterization of the OA cartilage[1-4]. Limitations of this pilot study include small sample size and uneven distribution of subjects in the lesion and non-lesion group. A study with larger patient cohort including analyzing cartilage sub compartments and other GLCM parameters like angular second moment (ASM) is ongoing.

References: [1] Blumenkrantz et al, [2] Carbadillo et al Med Phys 2009; 36(9):4059-67;[3] Li et al, MRM 2009; 61(6): 1310-1318; [4] Schooler et al, Osteoarthritis and Cartilage 2014; 22:51-62; [5] Boutsikou et al European J of Radiol 2013; 82:1266-1272

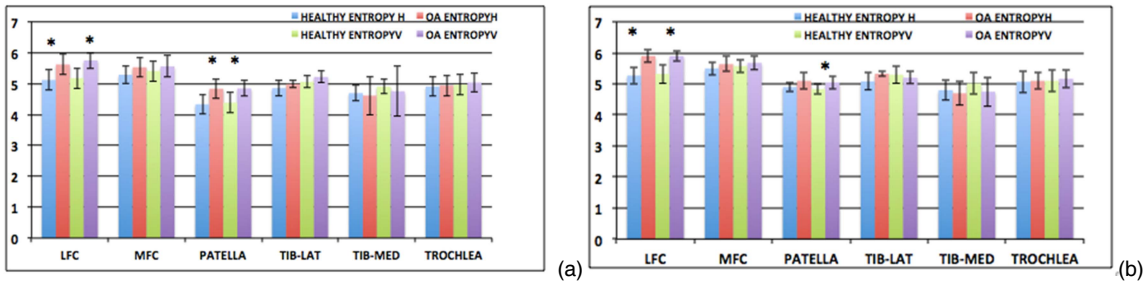

Figure 1: Bar graphs showing horizontal (0°/anterior-posterior axis) represented by "H" and vertical (90°/superior-inferior axis) represented by "V" entropy values for subjects without (healthy) and with (OA) lesions at baseline (a) and one year follow up (b)." *" represents significance ($p<0.05$)