Quantification of Differences in Bone Texture from Plain Radiographs in Knees With and Without Osteoarthritis

Jukka Hirvasniemi1, Jérôme Thevenot1, Ville Immonen1, Tuomas Liikavainio2, Pasi Pulkkinen1, Timo Jämsä1, Jari Arokoski3, Simo Saarakkala1.

1University of Oulu, Oulu, Finland, 2Muonio Health Center, Muonio, Finland, 3Kuopio University Hospital and University of Eastern Finland, Kuopio, Finland.

Disclosures:

Introduction:
In addition to degeneration of articular cartilage, osteoarthritis (OA) causes abnormal changes in subchondral bone including thickening (sclerosis) as well as formation of osteophytes and subchondral bone cysts. Conventional knee radiography is the clinical gold standard imaging modality for detection of stage of OA. Therefore, quantitative detection of OA changes in subchondral bone from radiographs would be an advantage. Texture analysis of bone from radiographs is not as dependent of imaging conditions as direct evaluation of grayscale values. The potential of gradient- or Laplacian-based image processing algorithms that have already shown their effectiveness in hip fracture studies1,2, have not been studied in OA radiographs yet. Another potential method for the texture analysis of bone is a local binary pattern (LBP) method that has been widely used in machine vision field3. It is simple and quite insensitive to monotonic grayscale variations, e.g., in X-ray images to changes in radiation intensity. Hence, the aim of the current study was to investigate variable quantitative image analysis algorithms for detecting OA changes in subchondral bone from plain radiographs. We hypothesize that simple grayscale parameters estimating subchondral bone density and quantitative texture parameters related to bone structure would be different among OA patients than among age- and gender-matched controls.

Methods:
Standard anterior-posterior weight bearing radiographs (tube voltage = 60 kV, quantity of charge = 25 mAs; pixel resolution: 0.2 mm x 0.2 mm) from 203 knees (103 male subjects, age: 50-69 years) were analyzed using MATLAB software (MathWorks inc., USA) and graded according to the Kellgren-Lawrence (KL) grading scale4, in which 0 is normal and 4 is severe OA. KL grades were not known during image analyses. Joint space width (JSW) was measured from the center of medial and lateral condyles. Altogether four rectangle-shaped regions-of-interest (ROI) were extracted from the tibia and one circular-shaped ROI from the soft tissue beside the joint (Figure 1). To estimate bone density, mean grayscale value from the unprocessed ROI (= GV) and mean grayscale value of the soft tissue ROI subtracted from GV (= GVsoft tissue) were calculated. Local binary pattern (LBP) and second order partial derivatives (Laplacians) were calculated from the unprocessed ROIs to construct LBP- and Laplacian-based images. In the LBP method, the 8 neighbor pixels for each pixel in the ROI were examined and an 8-bit LBP-value was calculated. From the LBP- and Laplacian-based images, Homogeneity index (HI) and entropy (E) texture parameters were calculated to evaluate bone structure. HI was derived from gray-level co-occurrence matrix. Some ROIs had to be excluded due to distractions (e.g. bright edges) from a piece of the clothing or similar artifact. If one-way analysis of variance (ANOVA) was statistically significant, Fisher’s least significant difference post-hoc test was performed to find out which KL groups differed statistically significantly from each other. To evaluate intra-rater reproducibility of the analysis method, one investigator performed the analyses for a sub-population of 70 knees (38 controls, 32 OA) three times with two weeks interval. To evaluate inter-rater reproducibility, three investigators performed the analyses once for the same sub-population. Reproducibilities were evaluated using root-mean-square average coefficient of variation (CVRMS)4. SPSS 19 software (SPSS Inc., USA) was used for statistical analysis.

Results:
Distribution of KL grades was the following: KL0 = 110 knees, KL1 = 28, KL2 = 27, KL3 = 31, and KL4 = 7. The intra-rater and inter-rater reproducibilities of the texture parameters were better (Range of intra- and inter-rater CVRMS values: 0.23 - 2.48%) than the bone density-related parameters (1.45 - 22.19%). Particularly, ELBP, ELap, and HLBP were highly reproducible (0.23 - 1.59%). Medial JSW was significantly (ANOVA: p<0.05) higher in the control group (KL0) than in the KL2-4 groups. In the Figure 2, differences between KL groups using GV, ELBP, and ELap are shown. Furthermore, GVsoft tissue and HLBP were significantly (p<0.05) lower in the KL0 than in the KL2-4 groups in the medial subchondral bone plate. Similarly, HLBP was significantly (p<0.05) lower in the KL0 than in the KL1-4 groups in the medial and lateral trabecular bone whereas GVsoft tissue and HLap were significantly (p<0.05) lower in the KL0 than in the KL2-4 groups in the medial trabecular bone.

Discussion:
Our results indicate that the changes in bone texture in knee OA can be quantitatively evaluated from plain radiographs using...
advanced image analysis. Based on the results, increased bone density, due to subchondral bone sclerosis, can be directly estimated from the grayscale values, provided that the X-ray imaging conditions are constant between patients. However, structural analysis of bone was more reproducible than direct evaluation of grayscale values, and it is therefore better suited for quantitative analysis when X-ray imaging conditions are variable.

**Significance:**
Advanced image analysis may increase the diagnostic value of conventional knee radiography for detecting and monitoring changes in OA.

**Acknowledgments:**

**References:**
Figure 1. Regions-of-interest (ROIs) and illustrative presentation of unprocessed, Laplacian-based, and local binary pattern (LBP)-based ROIs. Black rectangles with continuous line = subchondral bone plate ROIs, black-colored rectangles with dotted line = trabecular bone ROIs, white circle = soft tissue ROI, and white line = joint space width.
Figure 2. Statistically significant differences between KL groups using mean grayscale (GV), entropy from Laplacian-based (E_{Lap}), and from local binary pattern images (E_{LBP}). Differences were studied separately from medial and lateral subchondral bone plate (SBP) and trabecular bone (TB). * = Studied KL group differs significantly from the indicated KL group.