Identification and Quantification of Focal Cartilage Lesions of Osteoarthritic Knee Using Magnetic Resonance Imaging

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An algorithm to identify and quantify focal cartilage lesions was developed using MR images of knees with and without Osteoarthritis (OA). A total of eight subjects divided into three groups, normal, mild OA and severe OA, were examined. The results showed a good classification among the groups using the total volume of focal lesions. The volumes of lesions also correlated with the radiographical grade of cartilage defects as assessed by a radiologist.

Introduction
Osteoarthritis (OA) is a disease characterized by the progressive loss of articular cartilage and density and structure changes of the adjoining bone. Traditionally, OA is radiographically assessed, and cartilage lesion detection using noninvasive MRI has been suggested. In addition to cartilage volumes and thickness measurements, the quantification of focal cartilage lesions would be beneficial in the study and monitoring of OA. The goal of this study is to develop methodology for quantifying focal cartilage lesions in MR images of the knee three-dimensionally.

Method
An algorithm to identify and quantify focal cartilage lesions of the knee cartilage was developed using MR images of subjects with and without OA. The images were acquired at a 1.5 Tesla (GE Signa scanner). The sagittal images were obtained using a fat suppressed gradient echo sequence, at a resolution of 234 \( \mu \text{m} \) in plane and a slice thickness of 2 mm. The algorithm developed consists of five steps: segmentation, surface fitting, cartilage thickness calculation, local minima search and defect volume estimation. Eight subjects of an average age of 55 years (range: 22-74 years) were examined to illustrate the feasibility. Among the subjects, three were considered normal (OA0), three with a Kellgren-Lawrence (KL) score of 1 and 2 were classified as Mild OA (OA1), and two with a KL score of 3 and 4 were classified as Severe OA (OA2).

Cartilage segmentation was manually performed using an in-house, Java-based software. All analysis following the segmentation step was then executed using MatLAB. 3-D cartilage surfaces were fitted by a triangle-based cubic interpolation and cartilage thickness was defined as the distance between inner and outer surfaces along inner normal direction.

Figure 1 shows a femoral cartilage surface with thickness represented by color. To identify cartilage lesions, a local minima search on thickness map was implemented and a point on the map was classified as a focal defect if it had the thinnest cartilage within 8 mm spatial radius. Black dots in Fig 1 present the result of a minima search. Because of the edge effect, all focal defects found on the edge of the map were considered false and ignored unless a visible lesion or osteophyte was found on MR images. The largest closed curve on the contour map of cartilage thickness was selected as the criteria for defining the edge of a defect, once a minimum was identified. The volume of a defect defined by this edge was then calculated as the summation of the products of the area each contour line encloses multiplied by contour slice thickness. For example, the contour of 1.5 mm thickness was chosen as an edge with a local minimum of 1.15 mm in Fig 2.

Results and Discussion
Figure 3 shows the lesion volumes in the representative cases analyzed to test the algorithm. The proposed algorithm was able to provide a classification among three groups of OA0, OA1 and OA2 based on the total volume of defects. Even the total volume of the special case (central medial femoral condyle of Grade 3, otherwise healthy) in OA1 group was greater than the volume of any in OA0. The feasibility of the algorithm was also demonstrated in Fig 4, as the volumes of lesions were roughly proportional to the sum of six grades of (a) femur and (b) tibia.

Our quantification is based on the total volume of lesions, not the number of defects found. Therefore, choosing a smaller radius for local minima search may find more defects, but the total volume will not be largely affected. On the other hand, defect edge selection may have an effect on the outcome and should be implemented consistently. Currently, an investigation of different selection criteria is in progress.

Fig 1 A cartilage thickness map.

Fig 2 A contour plot of cartilage thickness.

Fig 3 Volume of lesions versus OA groups

Fig 4 Volume of lesions versus grade sum.