VALIDATION OF FOCAL CARTILAGE LESION QUANTIFICATION USING MAGNETIC RESONANCE IMAGING: A COMPARISON TO ARTHROSCOPY AND CONTROLLED LESIONS

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INTRODUCTION: Osteoarthritis (OA) is a debilitating joint disease affecting much of the world population, especially those with advanced age or risk factors such as joint injury, genetic predisposition and obesity. In the OA population, roughly 11% have focal lesions, the size of which has been shown to be an indicator of disease evolution. Currently, arthroscopy is considered the gold standard for arthritic lesion examination and cartilage lesion detection methods using noninvasive magnetic resonance imaging (MRI) have also been suggested [1][2]. These techniques, however, are subject to invasiveness, rough estimation of lesion dimensions or have not been validated rigorously. If an accurate, noninvasive evaluation technique is established, lesion quantification and lesion progress tracking can become clinically feasible for OA treatment and management. The goal of this study is to validate a Gradient Peak Method (GPM), an advanced computer-aided algorithm using MRI that quantifies lesion thickness, lesion area and eroded lesion volume. The references used in the study include in vivo arthroscopic exams of human knees and in vitro controlled lesions on fresh porcine knees.

METHODS: GPM identifies and quantifies focal cartilage lesions in sagittal MR images of knees, in which local minimum search is used in identification and the gradient and curvature on cartilage thickness maps are exploited in boundary detection for the identified lesions [1]. Since GPM is based on the gradient and curvature, not thickness, it is superior at quantifying lesions on undulating surfaces (an example is shown in Fig 1). Two sets of boundaries are sought: high boundary (HB) is defined as the points whose curvature is the most negative (red circles in Fig 1), and low boundary (LB) is defined as the points whose curvature is the most positive (blue diamonds in Fig 1). The 2mm strip outside HB is considered a normal reference area. Morphological properties of lesions are estimated that include (1) lesion diameter based on HB in the xy (in-plane) direction, (2) lesion diameter based on HB in the z (slice) direction, (3) lesion depth defined as the difference between the average thickness within LB and the average thickness of the 2mm normal strip (shading area in Fig 1), (4) lesion area based on HB and (5) eroded lesion volume defined as the volume between the true cartilage surface and the imaginary surface interpolated from the normal strip (dashed line in Fig 1).

Validation of GPM using MRI was accomplished by (1) comparing the measurement accuracy of GPM with manually measured dimensions of controlled lesions on the articular cartilage of fresh porcine knees and (2) comparing the morphological predictions of GPM with in vivo arthroscopic visualization and measurements in human subjects. First, two fresh porcine knees were obtained from a local market and submerged in phosphate buffered saline except during lesion creation and measurement. Second, three patients (age: 48–60 years) with existing lesions were recruited in the study. Video and still images were previously obtained by using an arthroscope (Stryker Endoscopy, San Jose, CA) and lesion morphology estimations were assessed by orthopaedists. Informed consent was obtained from all patients after the nature of the study had been fully explained. The study was approved by the local human research committee.

Controlled lesions were surgically created on two porcine knees using a 7-mm Dremel bit. Four cylindrical lesions of 1 mm in depth were made on Specimen 1 and three cylindrical lesions of 2 mm in depth were made on Specimen 2. The knees were mounted by placing the proximal region of the joint in a vice on the press with the bit perpendicular to the articular cartilage surface. A stopper was used on the drill press to set the drilling depth. The dimensions of the lesions were then measured using a caliper with resolution of 0.1 mm.

Table 1 Absolute Errors of GPM Measurements in Porcine Knees

Specimen1	Dia.(xy)	Dia.(z)	Depth	Area	Eroded Vol.
Average	1.18 mm	2.01 mm	0.04 mm	20.06mm^2	9.48 mm^3
SD	0.73 mm	1.11 mm	0.02 mm	7.83 mm^2	8.09 mm^3
Specimen2					
Average	0.32 mm	1.02 mm	0.32 mm	12.51mm^2	28.96 mm^3
SD	0.23 mm	1.63 mm	0.21 mm	7.83 mm^2	12.18 mm^3

Sagittal MR images were acquired with a SIGNA 1.5T scanner (GE Medical Systems, Waukesha, WI) and a dual phased-array coil (USA Instruments, Cleveland, OH), using a fat suppressed spoiled gradient echo sequence (30/3.1 ms, 30°, 1.2 cm FOV and 0.23/0.23/2 mm^3 voxel size). The porcine knees were operated and scanned on the same day while the human subjects underwent arthroscopic exams 1~2 months prior to the MR image acquisition.

RESULTS AND DISCUSSION: The morphological data quantified by GPM were compared with the manual measurements of the controlled lesions and the average and standard deviation (SD) of the absolute errors were listed in Table 1. In each case, the depth estimates are accurate and the diameter estimates in in-plane direction are better than those in slice direction, due to finer in-plane imaging resolution. Moreover, the diameter estimates of Specimen 2 are more accurate than those of Specimen 1 as deeper lesions exhibit a clearer shape. One might notice that a 1-mm change in radius in a 4-mm-radius lesion translates to a 28-mm^2 change in area; therefore, the quantified areas and volumes by GPM are in line with the error from diameter estimates and represent reasonable estimates. Overall, the controlled lesion validation has shown that GPM provides fair precision on morphological properties of focal lesions and its accuracy is within the error from imaging resolution.

In arthroscopic validation, a large, irregular-shaped lesion was seen on the lateral trochlear of Patient#1 and GPM reproduced its morphology. In Patient#2, the lesion scoped by the orthopaedist was assessed as "a 12×25 mm^2 lesion on the weight bearing and meniscal bearing portion of the medial femoral condyle contacting the tibia between 30 and 70 degrees"; while GPM estimated an area of 501 mm^2 and a volume of 298 mm^3. A representative arthroscopic picture of Patient#2 is shown in Fig 2 and a cartilage thickness map is displayed in Fig 3 with the HB denoted by a red dashed line. In Patient#3, a 1-cm focal chondral lesion was reported in an arthroscopic exam and an area of 53 mm^2 and a volume of 84 mm^3 were given by GPM. Although arthroscopic quantitative measurements are prone to errors, arthroscopy does give true views of lesions and has shown the ability and accuracy of GPM in reproducing and quantifying lesion morphology.

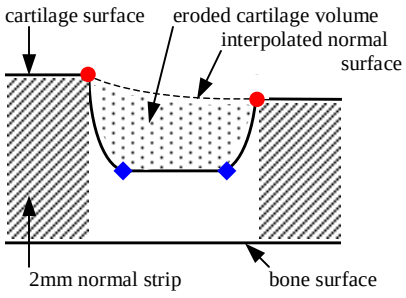

Fig 1 Illustration of a sample lesion

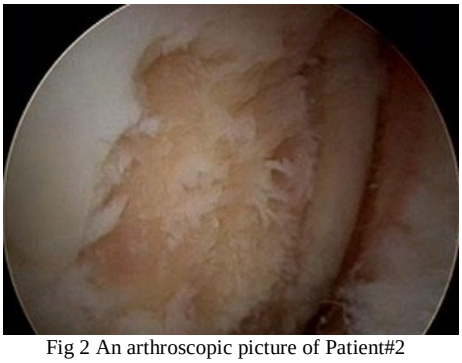

Fig 2 An arthroscopic picture of Patient#2

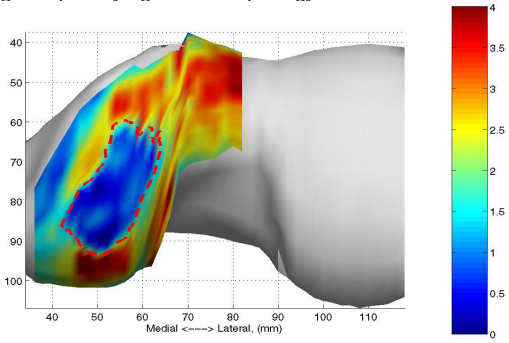

Fig 3 Cartilage Map of Patient#2

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