Variable fiber orientations of knee cartilages investigated by zonal T2* measurements with automatic segmentation

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Introduction

Osteoarthritis (OA) is a common disease in aged people, which results in degeneration of the articular cartilage and the meniscus [1]. Identification of the tiny changes of these cartilages is important to the early detection of OA and the monitoring of the disease progression. Recently, quantitative MR measurements, such as mapping of T1ρ, T2, and diffusion coefficient, have been used to evaluate the architecture of the knee cartilages [2]. However, in the thin layer of articular cartilage, manual selection of the regions-of-interest may become the major source of discrepancy for zonal analysis of the collagen fiber orientations with different extents of magic angle effect [3]. Therefore, the purpose of this study is to propose an efficient image segmentation method based on the 2D fussy C-means (FCM) algorithm [4] to facilitate MR T2* measurements, and to investigate the zonal difference of knee cartilages at variable fiber orientations.

Methods

Six normal volunteers were enrolled in this study. All were imaged in a supine position on a 3.0 T MR system (TIM TRIO, Siemens medical solutions, Erlangen, Germany). These images were acquired with an eight-channel knee coil using fast gradient echo sequence with TR = 732ms, TE = 2.67/8.04/14.1/20.16/26.22 ms, number of slice = 12, slice thickness = 3mm, matrix size = 768×768, in-plane resolution = 0.2×0.2 mm^2, total acquisition time = 3m30s. In order to obtain images with higher SNR, partial echo was used to decrease the minimal echo time. Fat suppression was also used for better contrast. The T2* maps were calculated on a pixel-by-pixel basis by fitting the echo times and the corresponding signal intensity to a single exponential model. After that, the signal intensity of the images and the corresponding T2* were chosen as the two features to be included in data clustering of 2D FCM. Spatial constraint was added by considering the relationship between each pixel with the neighbors to avoid erroneously sharp points as shown in the following equation.

$$J_{2DFCM} = \sum_{j=1}^{c}\sum_{i=1}^{n}\mu_{ij}^{z}\left\|x_i - m_j\right\|^2 + \alpha\sum_{j=1}^{c}\sum_{i=1}^{n}\mu_{ij}^{z}\left\|\hat{x_i} - m_j\right\|^2 + \beta\sum_{j=1}^{c}\sum_{i=1}^{n}\mu_{ij}^{z}\left\|t_i - v_j\right\|^2$$

where J_{2DECM} is the objective function, x_i and t_i represent the clustering data, and m_j and v_j are the corresponding centroids of different clusters in the feature spaces of image and T2* map, respectively. x_i^ is a mean of the neighbors around x_i, and μ_{ij} is the weighting matrix describing the memberships between data and every cluster, whose fussiness can be controlled by z. The parameters α and β adjust the percentages of spatial constraint and the second feature, respectively.

Results

A knee image acquired from the second echo is shown in Fig.1(a), and the target data involved in segmentation is magnified in Fig.1(b). Obvious difference between longer T2 component and shorter T2 component in the posterior horn of meniscus could be seen, but not in the anterior horn of meniscus and in the articular cartilage. Fig.2 displays the result of the 2D FCM-based segmentation. Compared to the anatomic image, we can clearly identify the three very thin zones of articular cartilage as well as the longer T2 component in the posterior horn of the meniscus in Fig.2. The corresponding T2* values are illustrated in Fig.3, showing statistically significant differences with $p < 0.001$.

Discussion

The present study indicated the feasibility of quantitative T2* measurements of knee cartilage facilitated by 2D FCM based segmentation, to reflect zonal differences of fiber orientations. In addition to the variable fiber orientations in articular cartilage, some investigations demonstrated that there are some radial "tie" fibers frequently shown in the outer portion of meniscus with higher signal intensity, which may result from the higher T2 distribution in the red zone of meniscus [2,5]. Our study is consistent with these previous reports. On the other hand, the statistical result of T2* measurements also revealed the increasing T2* values from the deep zone to the superficial zone of articular cartilage, which is believe to be related to the magic angle effect. Our preliminary finding suggests that T2* measurement with automatic segmentation is an effective and objective method to the investigation of the specific fiber orientations of the knee cartilages and has strong potential to eliminate manual ROI selection discrepancy in zonal T2* calculation.

Reference

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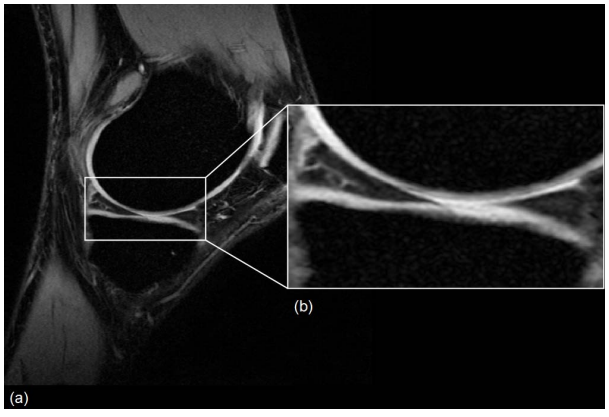

Figure 1 (a) the second echo image (b) the regional data involved in segmentation

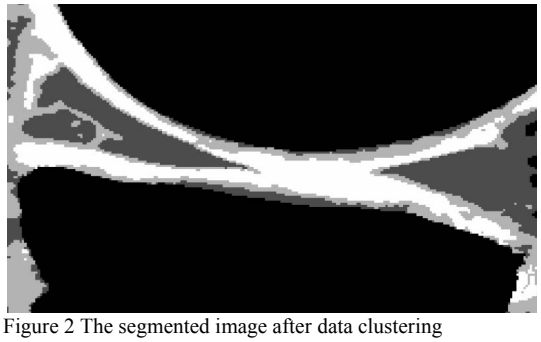

Figure 2 The segmented image after data clustering

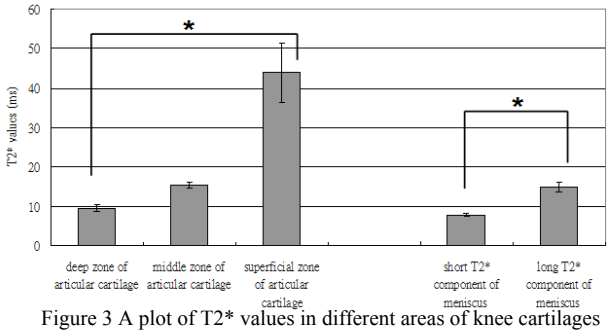

Figure 3 A plot of T2* values in different areas of knee cartilages