Depth-wise modulation of T_2 relaxation time in articular cartilage degeneration

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INTRODUCTION

T_2 relaxation time measurements have been used in the assessment of articular cartilage properties and degenerative status [1-3]. The magic angle effect that significantly affects the T_2 relaxation time of articular cartilage due to the anisotropy of collagen fibrils, has also been studied [4]. Magic angle-related decrease in the T_2 relaxation rate results in a lamina of elevated T_2 values in the transitional zone, when the cartilage surface is perpendicular to B_0. Changes in the collagen fibril network accompanied by changes in the water content affect the depth-wise T_2 relaxation time. The aim of this study was to determine the depth-wise T_2 variation at various stages of cartilage degeneration, exploiting the knowledge on the relationship between collagen structure and depth-wise laminar appearance of cartilage T_2.

MATERIALS AND METHODS

Bovine patellar cartilage was used: intact samples (n = 11), samples with early, visually-detectable degeneration (n = 11) and samples exhibiting advanced degeneration (n = 10). The T_2 relaxation time was measured using a single-echo spin-echo sequence with six TEs (14, 24, 34, 44, 64 and 84 ms) and a TR of 2500 ms. A slice thickness of 1 mm was used and 1 mm depth-wise column was averaged for each sample, yielding relaxation time profiles with 39 µm depth-wise resolution. The profiles of the samples were further normalized to equal lengths, using two different approaches to both test the effect of and account for natural thickness variation: 1) linear interpolation to predetermined number of depth-wise pixels and 2) by first determining the boundaries for superficial, transitional and deep zones [5] and then interpolating each of these zones separately to predetermined number of pixels (zone-matched interpolation).

The degenerative status of the samples was determined by Mankin scoring[6]: 0 for intact, from greater than 0 to 3 for early and from greater than 3 to 10 points for advanced degeneration. Comparison between the degenerative groups was conducted in a point-wise manner at each depth, assessing the statistical difference between the groups using the non-parametric Mann-Whitney U -test. The analysis resulted in depth-wise probability (p) profiles indicating the magnitude and location for the statistical differences in depth-wise T_2 relaxation times between the degenerative groups.

RESULTS

Statistically significant differences between the degenerative groups were detected in different regions, depending on the groups compared and the selected depth normalization schema. Using linear interpolation, significant differences were systematically noted in the most superficial part of the tissue and less consistently throughout the remainder of the tissue (Fig 1, A-C). Using zone-matched interpolation, significant differences were also consistently seen in the most superficial tissue (Fig 1, D-F). Zone-matched interpolation also revealed significant differences in the transitional zone between intact and early degenerated samples and throughout the tissue depth except for the deepest part of the tissue between the samples with early and advanced degeneration (Fig 1, D, F).

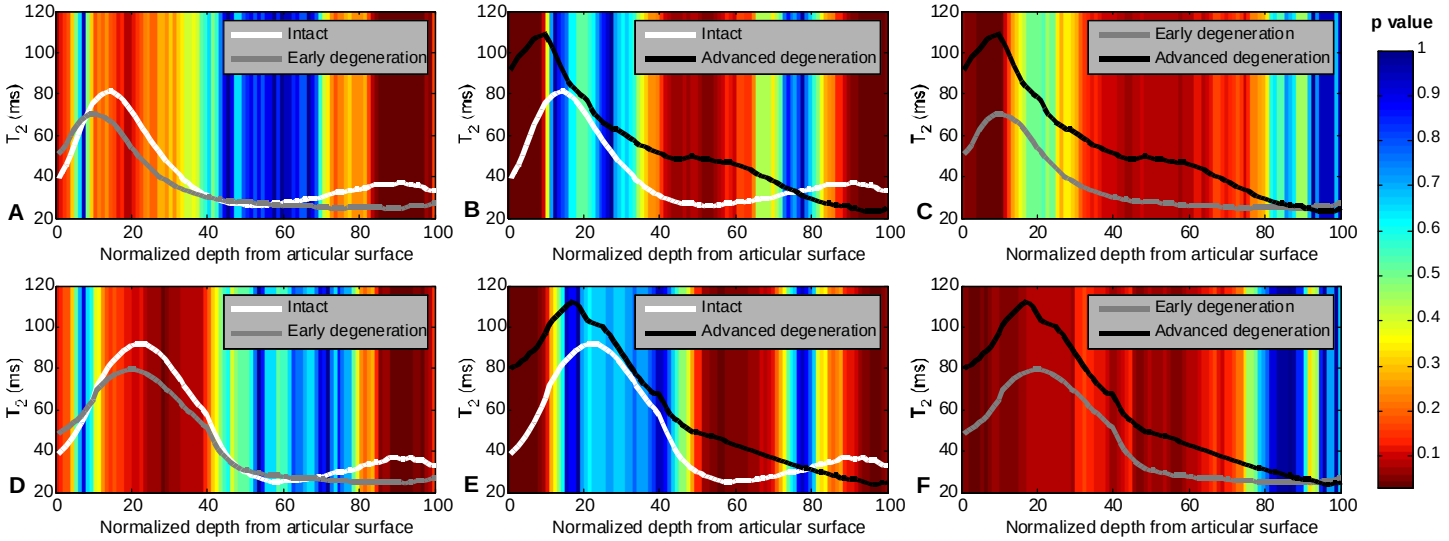

Figure 1. Group-average T_2 relaxation time profiles and color-coded statistical difference p-value maps for each comparison: A-C linear interpolation, D-F zone-matched inerpolation. Deep red color indicates significant differences between the groups and yellow to blue indicates no statistically significant differences (p values are given in the color bar).

DISCUSSION

Earliest degenerative changes of articular cartilage typically affect the superficial part of the tissue [7]. The present results also support this: differences between the degenerative groups were detected in the most superficial part of the tissue indicating that cartilage degeneration begins at the articular surface. Additionally, differences between intact samples and early or advanced degeneration were noted in the deepest part of the tissue. Linear interpolation process revealed the mismatch in the localization of the maxima of the T_2 curves (Fig 1), also resulting in spurious differences between the groups at different depths. The zone-matched interpolation matched the structural locations more precisely and depicted the tissue depths where differences could be seen between the groups. The present results indicated that the structure detectable by T_2 relaxation time measurements may vary with degeneration.

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