Multi-parametric MRI assessment of cartilage repair with correlation to histology

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INTRODUCTION

Several quantitative MRI techniques have been proposed for probing the macromolecular composition and structure of articular cartilage. The present study aimed to characterize the repair tissue following osteochondral defects and surgical osteochondral allograft transfer in minipigs using \( T_2 \), \( T_1 \), dGEMRIC and the diffusion coefficient (D) with reference to qualitative histology.

METHODS

The lateral trochlear facets in the knees of two immature Yucatan minipigs were operated to produce 5- or 6-mm osteochondral defects that were left empty. A third pig underwent osteochondral transfer surgery, in which an osteochondral plug was transplanted from the medial to the lateral facet and the donor site was left empty. The opposite non-operated knees served as controls. The animals were sacrificed approximately 2 months post-operatively, and both facets of the operated and control knees were removed for further MRI and histological analyses.

Samples were equilibrated in saline, followed by measurements of \( T_2 \) (multi-echo sequence with TR=3s and 11 TEs between 9-99ms) and \( T_1 \) relaxation times (saturation recovery sequence with TE=9ms and six TRs between 200-4500ms) at 8.45T and room temperature. This was followed by equilibration in 1mM Gd-DTPA\textsuperscript{2-} solution for a minimum of two hours, and consequent determinations of \( T_1 \) relaxation time i.e. dGEMRIC (TE=9ms, six TRs between 50-2000ms) and D (diffusion-weighted stimulated-echo sequence with TE/TR=15/1000ms, \( \Delta=14ms \), \( \delta=2ms \) and four B-values between 300-1200s/mm\textsuperscript{2}). The in-plane resolution was 100\( \mu \text{m} \) for \( T_2 \) and dGEMRIC measurements and 200\( \mu \text{m} \) for \( T_1 \) and ADC maps, with a 2-mm slice thickness.

Following the MRI measurements, both facets of the operated and control knees of two pigs (one with chondral lesion and one with osteochondral transfer) were processed for safranin-O-staining of glycosaminoglycans (GAGs), H&E-staining, immunostaining for type II collagen, and polarized light microscopy (PLM) of the collagen network.

RESULTS

The spontaneous repair tissue developed into the osteochondral lesion and the empty donor site of the osteochondral transfer showed (i) low GAG levels in histology, with a parallel low dGEMRIC index, and (ii) a non-hyaline-like fibrous appearance deficient in type II collagen, with a concomitant low \( T_2 \) relaxation time (Fig. 1). The cartilage of the osteochondral transfer appeared normal both in histology and quantitative MRI as compared to control tissue, however, qualitative MRI images (data not shown) demonstrated the cartilage-graft interface and histology revealed poor integration to adjacent cartilage. Spontaneous repair tissue in the osteochondral defects showed a trend toward lower \( T_2 \) and dGEMRIC values when compared to control, while the mean values of \( T_2 \) relaxation time and D were similar to control tissue (Fig. 2).

DISCUSSION

The preliminary results show the potential of quantitative MRI techniques to sensitively reveal the properties of repair tissue produced by different surgical procedures. dGEMRIC, developed for the indirect estimation of cartilage GAG concentration \[1\], reliably showed the differences in GAG between different tissues and was in agreement with histology of stained GAGs. \( T_2 \) relaxation time is sensitive to the collagen organization \[2\], concentration \[3\], and possibly also to the type of collagen or fibrous nature of the tissue. While dGEMRIC and \( T_2 \) relaxation time appeared as the most sensitive MRI parameters to identify cartilage repair and fibrous repair tissue, \( T_1 \) and D also showed potential utility in differentiation of the tissues.

ACKNOWLEDGEMENTS

Financial support from Cartilage Repair Center, Brigham Radiology Research & Education Foundation, National Institutes of Health, Sigrid Juselius Foundation, Finnish Technology Agency, Jyväskylä Central Hospital, Academy of Finland, Finnish Cultural Foundation, Instrumentarium Science Foundation and Paulo Foundation is gratefully acknowledged.

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