Novel Quantitative Imaging for Early Detection of Joint Tissue Injury to Support Early Treatment Strategies

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Introduction

The Cartilage Restoration Center at the University of Pittsburgh conducts research using novel imaging technologies to detect early microstructural changes to articular joint tissues in degenerative and traumatic injury-induced articular cartilage and meniscus disease. Identification of early changes to joint tissues permits the identification of patients who could potentially benefit from therapeutic interventions. Quantitative strategies for the diagnosis and staging of joint tissue degeneration prior to the breakdown of the articular cartilage or meniscal surfaces remain a challenge. Our research has shown that the current clinical standard, arthroscopic visualization, and palpation of cartilage and menisci, may be insensitive to early subsurface alterations in these tissues, particularly in the deepest layers of articular cartilage [1–3]. Our work with quantitative Magnetic Resonance Imaging (MRI) and Optical Coherence Tomography (OCT) reveals a strong potential for these methods to provide information regarding early diagnosis and staging of subsurface tissue injury that are not readily available with current technologies [3–5].

Quantitative Imaging of Articular Cartilage

Our *in vivo* MRI T2 maps, UTE-T2* maps, and OCT measures of the subsurface cartilage matrix provide quantifiable measures of tissue integrity that are important to advancing the study of early cartilage degeneration (Fig. 1). OCT's nondestructive microscopic resolution cross-sectional images of articular cartilage and meniscus in near real-time provide histology-like images of the tissue matrix (Fig. 1b). Correlation between OCT image features and MRI T2 values support the continued exploration of OCT as a clinical research tool [1, 2, 6].

MRI ultra-short TE-enhanced T2* (UTE-T2*) mapping reflects the cartilage collagen matrix integrity as determined by polarized light microscopy and is sensitive to signal from the deepest layers of cartilage adjacent to bone [2, 3]. UTE-T2* mapping of articular cartilage and meniscus has the potential to visualize deep tissue characteristics better than standard T2 mapping due to its sensitivity to signal from short T2 tissues. We have shown that UTE-T2* mapping is feasible with good repeatability *in vivo* [2, 3], and we are currently investigating UTE-T2* mapping as a tool to detect early subsurface changes to cartilage and meniscus following traumatic injury and in degenerative disease (Fig. 2) [5–7].

MRI T2 mapping, UTE-T2* mapping, and OCT are also valuable tools in the evaluation of cartilage repair tissue (Fig. 3). T2 and UTE-T2* maps of chondral defects treated with different repair strategies (e.g., microfracture and implantation of bone marrow aspirates) are being used to augment the assessment of structural and biochemical integrity of the repair tissue in an equine model. OCT images of the repair tissue provide further insight into architectural differences between native and repair tissues.

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Fig. 1. Example *in vivo* MRI T2, OCT, and arthroscopic images of healthy articular cartilage. The (a) laminar MRI T2 map appearance, (b) birefringence from OCT, and (c) smooth and firm surface assessment by arthroscopy indicate healthy articular cartilage on the medial femoral condyle of this ACL-injured knee

Fig. 2. Example of an *in vivo* UTE-T2* map. A disrupted laminar pattern, indicative of collagen matrix disorganization in deep tissue of the central weight-bearing zone to the lateral condyle of this ACL-reconstructed knee, is clearly detected by UTE-T2* mapping

Fig. 3. Sample T2 maps of cartilage repair in an equine model. (a) T2 values are heterogeneous in the thin repair tissue at the center of the defect. (b) Laminar T2 pattern in healthy tissue remote to the defect indicates normal subsurface cartilage structure

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