LOCAL TISSUE PROPERTIES OF HUMAN OSTEOARTHRITIC CARTILAGE CORRELATE WITH T1RHO AND T2 RELAXATION MAPPING MAGNETIC RESONANCE IMAGING

INTRODUCTION

Osteoarthritis (OA) is a debilitating disease associated with the degeneration of articular cartilage and results in pain and loss of mobility. OA initiates with alterations in the matrix composition and gradual losses of mechanical function of the cartilage matrix [1]. The ability to detect these changes at an early stage may provide diagnostic and therapeutic insights towards OA. Magnetic resonance imaging (MRI) of articular cartilage is a useful clinical tool to provide quantitative analyses of cartilage morphology. In addition, advances in MRI technology have allowed the non-invasive quantitative assessment of cartilage composition [2,3]. In turn, changes in matrix composition are known to correlate with alterations in the matrix mechanical behavior [4,5]. Yet direct relationships between MR imaging parameters and local tissue material properties are not well-established. Thus the objective of this study is to examine the relationship between the mechanical behavior of human osteoarthritic articular cartilage with high-resolution MRI using high-resolution T1ρ/T2 relaxation mapping and in situ dynamic indentation.

METHODS

Three human tibial plateau specimens with severe OA were obtained immediately post-surgery and frozen in accordance with CHR approved protocols. The samples were scanned on a GE 3T EXCITE MRI scanner using a quadrature transmit/receive wrist coil. The knee cartilage specimens were mounted on a plastic grid for location reference with Simethicone applied to the cartilage surface, and placed and glued into a plastic container and immersed in phosphate-buffered saline (PBS).

A sagittal 3D T1ρ-weighted imaging sequence was used with the following imaging parameters: TR/TE = 9.3/3.7 ms; FOV = 6.8 cm, matrix=256 x 128, slice thickness=2 mm, BW=31.25 kHz; VPS=64, TSL=1.5 s, TSL=0, 10, 40, 80 ms, FSL = 500 Hz. T2 mapping was performed immediately after the T1ρ sequence by adding a nonselective T2 imaging sequence with TR/TE=2000/4.1,14.5,25,45.9 ms.

T1ρ and T2 maps were quantified on a pixel-by-pixel basis. In plane resolution for both map sequences was 0.3 x 0.3 mm. Each region of interest extended 6 pixels wide and 2 pixels deep from the cartilage joint interface based on the size and depth of the indentations. Indentations were performed immediately after MR imaging. 4-5 sites were selected from each tibial plateau based on the grid system and each site was at least 0.5” apart to provide a greater sampling of tissue variability. Dynamic indentations were done in situ with the sample submerged in PBS at 20°C using a Tissue Diagnostic Instrument (Biodent 1000™ TDI, Active Life Tech, CA) [6]. Using a reference probe to determine the articular surface, a 1.47mm diameter cylindrical probe cyclically indented the tissue to 15µm at 2Hz and the force-displacement data was collected. At each site, five indentations were conducted and averaged. Evaluated parameters of cartilage viscoelastic behavior include peak indentation force (Fmax), energy dissipation (ED) - area enclosed by the force-displacement curve, peak dynamic modulus (PDM - slope determined from linear regression of the maximum 20% of the loading curve) [7], and tan δ (tangent of the phase shift “δ” between force and displacement peaks). Pearsons’ correlation analyses were used to determine the relationships between MR parameters (T1ρ and T2 relaxation times) and articular cartilage viscoelastic behavior (Fmax, ED, PDM, and tan δ).

Regression analyses were conducted from significant pair-wise MRI-mechanical relationships (p<0.05). Statistical analyses were conducted using Minitab (Minitab USA, PA).

RESULTS

T1ρ and T2 relaxation mapping revealed that heterogeneities across the cartilage surface exist within the same donor, (Fig 1,2). Likewise, mechanical testing shows that the cartilage surface has considerable inter-site variations in both its elastic (peak dynamic modulus) and viscous (tan δ) characteristics (Fig 2). T1ρ relaxation times are significantly correlated with increasing viscous behavior of articular cartilage (Fig 3) and the T2 relaxation time correlated with the elastic behavior of cartilage (not shown).

DISCUSSION

Arthritic articular cartilage is highly heterogeneous as confirmed by both MR maps and local mechanical properties, and measurements made at a single anatomic site may not be fully representative of the entire tissue. Despite these heterogeneities, we demonstrate significant associations between MR mapping and tissue mechanical properties at the local level using site-specific high-resolution imaging and mechanical testing modalities. The viscoelastic behavior of cartilage can be attributed to the triphasic interactions between the collagen, water, and proteoglycan components [5], and changes in one phase may alter its interactions with other matrix constituents. It is thus critical that the assessment of the mechanical behavior of cartilage tissue account for both the elastic and viscous components of the tissue. Previous studies have shown that MR T1ρ mapping of articular cartilage correlate with the amount of proteoglycans in the cartilage matrix [8], and the loss of proteoglycans alters the time-dependent mechanical behavior of cartilage [5]. Consistent with these observations, the results of this study suggest that MR T1ρ/T2 may be sensitive to changes in the mechanical behavior of articular cartilage. Our results show that the increase in T1ρ is coupled with the increased viscous behavior at the local tissue level. Similarly, the increases in T2, which are correlated with collagen hydration [3], are associated with matrix elasticity as measured by peak dynamic modulus. Taken together, the trends observed in the MR T1ρ/T2 maps and the changes in the cartilage mechanical behavior suggest that there may be a direct association between noninvasive imaging and local tissue mechanics. Further understanding of this relationship may provide valuable insights in the diagnosis and treatment of OA.

REFERENCES


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