Sensitivity of T1ρ MRI to Cartilage Injury After Acute ACL Rupture

+1Klocke, N F; 2Thedens, D R; 1Amendola, A; 1Martin, J A; 1Pedersen, D R

+1Department of Orthopaedics & Rehabilitation, University of Iowa, Iowa City, IA; 2Department of Radiology, University of Iowa, Iowa City, IA
doug-pedersen@uiowa.edu

INTRODUCTION:
Osteoarthritis (OA) is one of the most common diseases of articular cartilage, affecting approximately 14% of the adult population [1]. A severe mechanical injury, such as acute rupture of the anterior cruciate ligament (ACL), may progress quickly to post-traumatic OA (PTOA) [2]. Early signs of OA such as proteoglycan loss and collagen disruption within the cartilage matrix are not seen on morphological magnetic resonance images (MRI). However, early detection may now be possible with functional cartilage MRI sequences such as T1ρ, which probes free water proton interactions with proteoglycans [2]. Processing methods specific to the lateral femoral condyle objectively identify the bony ridge between the terminal sulcus and posterior condyle to accurately co-register patients’ T1ρ maps across imaging sessions. The condyle’s radius provides a knee-specific anthropometric scale for inter-subject comparisons to develop a baseline normal series of T1ρ values across the full cartilage thickness [3]. A biofidelic knee phantom was designed to quantify B0 measurement error effects, yielding variations of ±2ms on clinical T1ρ image sequence relaxation times across platforms [4].

This study examines cartilage in a distribution of post-ACL injuries as evidenced by elevations in T1ρ relaxation times from baseline normal depth-dependent values within the lateral femoral condyle (LFC).

METHODS:
Nine acute ACL rupture patients were enrolled for T1ρ MRI scans on a 3T Siemens TIM Trio scanner. Images were acquired sagittally through the midline of the LFC with a T1ρ spin-lock magnetization preparation block prepended to a fast spin-echo pulse sequence using a single channel transmit-receive extremity coil. All sessions were approved by the Institutional Review Board.

T1ρ relaxation maps were generated from all of the acquired slices, and an objective, Canny-derived line profile registration method was applied to compare the images [3]. Relaxation times were co-registered in the posterior lateral femoral condyle by utilizing a condyle-specific radius, which normalized the data across subjects by sampling in single degree increments from the posterior ridge of the sulcus through a 90° arc along the bone-cartilage interface (BCI) and at 0.5 mm, 1.0 mm, and 1.5 mm layers outward from the BCI [3]. These layers represent the deep, radial, and transitional zones of cartilage.

RESULTS:
Table 1 records elevated cartilage relaxation times for ACL patients (above one standard deviation) compared to composite normal values. To isolate areas of much higher T1ρ times, “hot spots” (potential area where impact occurred during injury) were identified where any portion of the cartilage layer had a T1ρ time elevated by more than one standard deviation over the ACL patient’s individual layer’s relaxation time. Table 1 further identifies the prevalence of elevated relaxation times compared to the composite normal values by expressing above normal values as a percent of each curve which fell into these categories (Table 1). Figure 1 shows locations of highly elevated elevations along the posterior condyle. Isolated elevations (not contiguous with other “hot spots”) were excluded from potential impact sites.

DISCUSSION:
T1ρ values were elevated in the majority of the ACL femoral condyles compared to the composite normal values (%AN for all layers and subjects: 83.9%, std. dev. 15.1 %). Localized “hot spots” of high T1ρ values indicate an elevated water/proteoglycan ratio and focal cartilage trauma (%HS for all layers and subjects: 15.6%, std. dev. 5.5%). While some “hot spots” are found near the sulcus region, most are located 40°-60° along the weight-bearing region (Figure 1). This suggests that the mechanism of ACL rupture may center on blunt impact across the flexed knee with tibial subluxation to impact the sulcus being the extreme case.

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