The focus of the clinical research applications for UTE MR Imaging will focus on 3 major areas: deep radial and calcified cartilage, tendon and entheses and TMJ.

**Deep radial and calcified cartilage**
Articular cartilage is a highly ordered tissue with an organized, layered structure that can be functionally and structurally divided into four zones: the superficial (or tangential), the middle (or transitional), the deep (or radial) and the zone of calcified cartilage.

**Arthroscopic Diagnosis of Osteoarthritis**
The gold standard for the diagnosis of cartilage lesions has been arthroscopy which is both expensive and invasive. It is best suited to recognition of morphological defects (surface irregularity as well as partial- and full thickness loss of cartilage). The emphasis on superficial lesions is reflected in the commonly used arthroscopic grading systems for cartilage lesions. These include the Outerbridge and Noyes systems, both of which are four level classifications in which Grade 1 and 2 lesions involve softening or fissuring of the superficial articular cartilage not extending to the underlying bone. Grade 3 and 4 lesions have more significant cartilage loss extending to, or exposing, subchondral bone [1, 2].

*Problem 1: The current gold standard for cartilage evaluation is based on superficial loss of cartilage and is suboptimal for detection of intrasubstance lesions including lesions involving the deep radial and calcified layers of cartilage when they are not associated with loss of surface cartilage.*

**Current Imaging Evaluation of Articular Cartilage**
Many imaging methods are available to assess articular cartilage. Though computed tomography in conjunction with arthrography (CTA) and ultrasonography offer higher spatial resolution, these methods do not offer the soft tissue contrast provided by MR imaging, relegating their evaluation of cartilage to tissue loss with CTA, and superficial layer assessment with US. MR is generally regarded as the best currently available method for evaluating cartilage injury and repair [3-6], however, imaging of cartilage with this technique is challenging because of the zonal changes in structure and biochemical composition. These changes occur over a distance of a few millimeters and are associated with a marked reduction in mean T2 values from superficial to deep [7,8]. T2 values of the deep radial and calcified layers of cartilage are about an order of a magnitude less than those of the superficial layers, making their routine detection of the deeper layers of cartilage difficult or impossible with clinical sequences [9]. In contrast, UTE acquisitions routinely show both the calcified zone and the deep radial zone of cartilage and subchondral compact bone.

In terms of lesion detection, standard clinical imaging sequences have proven effective in the evaluation of chondral lesions which produce surface irregularity and/or loss of
cartilage thickness. Fat saturated three-dimensional spoiled gradient imaging, as well as fast spin echo (SE) imaging have reported sensitivities of 93-94% for the detection of such lesions [10-13]. A greater challenge has been detecting changes that occur in cartilage with a normal contour and thickness. This information may be crucial in understanding how OA is initiated and how it progresses. Extensive research has been devoted to developing novel imaging sequences and exploring the use of technological advances such as higher static field imaging and improved coils [14]. Initial experience in the knee suggests that the higher signal to noise ratio (SNR) available at 3T provides the potential for greater accuracy in the diagnosis of articular cartilage injury [16-18]. In spite of these advances, the deeper layers of articular cartilage and adjacent subchondral compact bone are virtually unexplored, due to the inability of clinical pulse sequences to acquire data in the short T2 range. UTE sequences provide access to these layers in the clinical setting for the first time [19-21].

Problem 2: To date, there has been no non-invasive way of evaluating the deep radial and calcified layers of cartilage in the clinical setting. This problem can be solved with UTE sequences.

Literature Cited
Tendon and entheses

Entheses are regions where tendons, ligaments or joint capsules are connected to bone. They are transition zones between flexible and rigid tissue and stress concentrates at the junction between the two types of tissue which have different mechanical properties. The structure of entheses can be understood in terms of the need to disperse this stress, and it is possible to relate this need to the gross anatomy, histology and biochemistry of the tissues of entheses including the presence of calcified and uncalcified fibrocartilage in the junctional region (1-6).

Entheses are very commonly involved in disease. This includes overuse injuries in sports (6) and the early stages of osteoarthritis (7). They are also the primary target of disease in the seronegative spondyloarthropathies. (8-10). Conventional clinical magnetic resonance (MR) imaging has not been helpful in demonstrating the key tissues present in normal entheses. These tissues all have short transverse relaxation times (T2s), and all show little or no signal with typical clinical pulse sequences using conventional pulse sequences with echo.
times (TEs) of about 8-20 msec or longer, and so the component tissues cannot be separately identified.

Ultrashort TE (UTE) pulse sequences with TEs 100-1000 times shorter than those available on conventional clinical MR systems can detect signals from the different short T2 tissues of entheses before these have decayed to very low levels and allow the different tissues to be distinguished (11-17). The UTE sequences provide quite new options for examining enthesis and it is our intention to study the relationship between the newly visible tissues and their mechanical functions and to exploit these new options to study enthesis involvement in osteoarthritis and psoriatic arthropathy. Our central hypothesis is that the ability to directly image the components of entheses will provide new and important options for correlating their structure with their mechanical function, and provide a valuable means of recognizing involvement in disease.

Literature Cited

**TMJ**

MR imaging, due to its excellent soft tissue contrast and multi-planar imaging capabilities, served to revolutionize the understanding of temporomandibular joint pain and dysfunction. Prior to the advent of MR imaging, TMJ symptoms were relegated to a syndrome diagnosis. With MR imaging, the radiologist was allowed a window through which to assess the structures of the TMJ, moving to a specific anatomic diagnosis.

The basic MR evaluation of the TMJ has focused primarily on the disc, characterizing its morphology, its position with an open- and closed-mouth, and to a lesser degree its intrinsic signal intensity. With regard to disc morphology and position, standard clinical MR sequences at 1.5T appeared to be effective in accurate characterization [1-7]. This has been somewhat debated with a recent study questioning the level of evidence in past literature for the efficacy of MR in the diagnosis of disc position and configuration among other things and emphasizing the need for high-quality studies on the diagnostic efficacy of MR in TMJ disease [8]. Similarly, debate exists over the signal intensity of the TMJ disc. It has been reported that the normal TMJ disc has low signal intensity throughout, and as the TMJ disc degenerates, it becomes high in signal intensity [9, 10]. Other reports describe the normal TMJ with intermediate to high signal intensity on T1-weighted MR images, and with degeneration signal decrease [11]. Most recently, increased signal intensity on proton density-weighted fat-suppressed and T1-weighted sequences within the posterior band of the TMJ disc has been described in the setting of tissue degeneration [12].

There has been little in the way of novel MR imaging introduced in the realm of TMJ evaluation. Initial exploration of parameters of diffusion weighted MR imaging has been introduced in the literature for the ultimate characterization of the stages of inflammation [13]. In addition, a single article has addressed the use of 3T MR imaging for TMJ evaluation. It stressed the advantages of investing the higher SNR at 3 T to improve spatial resolution in this articulation.

Though MR imaging provided the initial steps toward non-invasive evaluation of the structural components of the TMJ, its intrinsic tissue characteristics have thwarted more specific advances. The fibrocartilaginous nature of the articular surfaces and disc
suggest that these tissues have a relatively short intrinsic T2 (MR imaging characteristic intrinsic and specific to all tissues), making them incompletely detected by standard clinical sequences, and unable to be accurately quantified with standard T2 measurement techniques.

Ultrashort echo time (UTE) pulse sequences allow signals from short T2 tissues to be detected and have the ability to provide quantitative assessment for tissues with predominantly short T2 tissue components in the clinical setting for the first time. The gradient echo techniques (2D FSPGR (2 Dimensional Fast Spoiled Gradient Recalled Echo) and 3D FSPGR (3 Dimensional Fast Spoiled Gradient Recalled Echo)) have the ability to measure T2 values in the 1 to 2 ms range, though they do so at the expense of resolution, requiring large field of view (FOV), increased slice thickness and bandwidth. This compromise is unacceptable for tissues such as the TMJ condylar articular surface and disc as they require high resolution to localize tissue for the purposes of sampling. In addition, the lowest TE’s that can be achieved on a clinical scanner are in the 2 msec range, resulting in suboptimal curve fitting. In the ideal situation, curves are generated from data points sampled on both sides of the intrinsic T1 or T2 of the tissue in question. The UTE sequences were originally implemented by Bergin et al. in 1991[14]. Since their first introduction the minimum TE has progressively decreased from 150 µs to 80 µs and now to 8 µs though the precise definition of TE for short T2 tissue components is still a matter of debate[14-18]. Though the T2 values of TMJ condylar fibrocartilage and disc are unknown, this range of TE’s is more than sufficient to afford ample data points around the shortest T2 values. Once the T2 values are established, the performance of the spectrum of MR sequences that have the ability to emphasize short T2 values can be explored: UTE techniques crucial for very short T2 tissues (1 ms range), gradient techniques possible for a longer T2 tissue range (greater than 2.5 ms). The tissue characteristics desired to be emphasized (better contrast versus better signal intensity for morphologic evaluation) may require a different range of T2 values.

Literature cited
8. Limchaichana, N., A. Petersson, and M. Rohlin, The efficacy of magnetic resonance imaging in the diagnosis of degenerative and inflammatory


Questions:

1) What tissue characteristics do UTE MR imaging sequences evaluate?
   a) short T2 tissues
   b) long T2 tissues
   c) all tissues

Answer: a