INTRODUCTION: Articular cartilage has a zonal architecture, with uncalcified layers atop and a calcified layer that anchors itself to the underlying bone. Joint diseases may involve abnormalities near the junction between cartilage and bone, yet this region of joint has been virtually unexplored by MRI due to its intrinsically short T2 characteristics and the inability of conventional pulse sequences to acquire data in this range. With the advent of Ultrashort Time-to-Echo (UTE) MR imaging techniques, tissues with short T2 relaxation times at the osteochondral junction became visible. It remains to be established which tissue structures near the osteochondral junction are reflected in the UTE MR images. Thus, the objective was to describe UTE MR signature of human osteochondral tissues at the cartilage-bone interface, including uncalcified cartilage (UC), calcified cartilage (CC) and subchondral bone (Bone), and identify those contributing to UTE MR signal.

METHODS: Sample Preparation. To identify sources of UTE MR signal in osteochondral tissues, samples were prepared to include specific components. Two 3 mm slices of cadaveric (62 yrs, female) patellae were obtained and imaged using DIR UTE as described below. Each slice was divided into 5 pieces, from which the bulk of UCC (samples #1, Fig.1D) was released. The remaining osteochondral fragments (#2, #3, and #4, n=6), comprising the deepest layer of UCC, CC and bone, were subjected to: no treatment (#2); digestion of just UCC with 125 mg/mL papain solution (3) (#3); or a partial removal of CC and bone by an oblique cutting (#4). From a distal femur, a sample with a chondral defect (but intact CC) was surgically prepared (#5, and a sample containing an eburnated region was obtained (#6). The released UCC pieces (n=7) were not treated. UTE MR Imaging. Apparatus. GE 3T Signa Twinspeed MR scanner with modified transmit/receive switch (capable of detecting of a signal 8 μs after the RF pulse) was used with 1° quadrature coil. Dual Inversion Recovery UTE (DIR UTE) Imaging. 2-D UTE method described previously was modified to achieve a strong suppression of long T2 components and the fat, by applying two independent adiabatic inversion pulses. UTE acquisition starts at a delay times of TI1=135 and TI2=95 ms for the inverted water and fat protons, respectively, to reach a common null point. This provides a high contrast for the unsuppressed short T2* component in tissues. The following additional parameters were used: FOV=6 or 7 cm, slice thickness=0.7 or 1.0 mm, readout=r=512, number of projections=899, TR=300 ms, TE=8 μs, BW=150 kHz, NEX=2. Conventional MR Imaging. For comparison to UTE images, conventional methods were also used to image the same samples. Fast spin echo proton density-weighted with fat-suppression (PDFS; FOV=6 cm, TR=2300 ms, TE=34 ms, echo train length (ETL)=7, matrix=512×512, slice=1.7 mm, NEX=2) and T1-weighted sequence (T1; FOV=6 cm, TR=700 ms, TE=10 ms, ETL=2, matrix=512×512, slice thickness=1.7 mm, NEX=2) were performed. Histology. To validate tissue components in each sample, histology was performed. The samples were fixed in 10% buffered formalin, decalcified in TBD-2 decalifier (ThermoShandon), paraffin-embedded, sectioned (3 μm), stained with Safranin-O and fast green, and digitally imaged on a microscope. MR Image Evaluation. All images were analyzed by two musculoskeletal radiologists. Specifically, the presence of a high-intensity linear signal was noted. Statistics. To determine the tissue sources of the UTE signal, the presence of the UTE signal in specific sample types (Fig.1D) was compared to hypothesized outcomes (Table 1). In addition, the frequency of the outcome in each type of sample was assessed using a contingency table and chi-square test (z=0.05).

RESULTS: In conventional PDFS (Fig.1A) and T1 (Fig.1B) images of human patellae, osteochondral junction had the appearance of dark subchondral bone apposing isointense cartilage tissue. In contrast, DIR UTE images (Fig.1C) exhibited a high intensity linear signal near the osteochondral junction. In the prepared samples, the DIR UTE appearance varied with treatment or pathology. UCC samples (#1) exhibited a linear signal that faded from the deep to the superficial layer (up-arrows, Fig.1OPQR). In the untreated osteochondral sample (#2), containing both UCC (red area, Fig.1T) and CC (purple area, Fig.1T), the UTE MR signature was preserved (down-arrows, Fig.1O). Oblique cutting effectively removed both CC and a thin layer of bone (#3, Fig.1O), and resulted in the loss of UTE signal in the cut region (Fig.1P). Papain treatment resulted in a sample (#4) with only UCC (purple area, Fig.1V) and bone, and preservation of the UTE signature (down-arrows, Fig.1Q). In the sample with a surgical treatment (#5) to remove UCC while retaining CC (purple area, Fig.1W), the UTE signature was also preserved (down-arrows, Fig.1R). The eburnated sample (#6) exhibited the UTE signature (down-arrows, Fig.1S) only in the region covered with cartilage (asterisk, Fig.1X). Conventional MR images (Fig.1E-N) did not exhibit such signatures. These findings were consistent with a hypothesized outcome D (Table 1) for the case of UCC and CC, but not Bone, contributing to the UTE MR signal. The frequency of the observed outcome were different (p<0.05) from the null hypothesis (equal frequency).

DISCUSSION: These results indicate that the high intensity linear signal of DIR UTE images of human articular cartilage joints originate from the CC and the deepest layer of the UCC, without definite contribution from the bone. Additional challenges remain, to resolve CC and UCC, since the present UTE method results in similar signal intensities between them, and the thickness of CC (~100 μm) further confounds the matter. There are technical hurdles related to fast RF switching and radial trajectory. While it remains to be established how UTE MR signature changes with disease and injury, the present work is useful for interpretation of UTE signal of the osteochondral junction, and offers new opportunities to examine this previously unexplored region using MRI.

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