Imaging of the Zone of Calcified Cartilage (ZCC) Using 3D Ultrashort TE Pulse Sequences

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INTRODUCTION

The zone of calcified cartilage (ZCC) is a highly modified mineralized region of articular cartilage that forms an important interface between cartilage and bone (1). It is a region that may change dramatically in osteoarthritis (OA) (2-5). Scanning electron micrograph of femoral heads showed a steady decrease from ~240 μm to ~80 μm in the thickness of the ZCC and a steady increase in the number of tidemarks from 1.0 to >1.5 with increasing age (2). Histochemical staining and biochemical analysis showed a marked change in the proteoglycan content of the matrix at the tidemark (3). The results of different studies show that the ZCC may contribute to OA via altered growth plate-like behavior of the cells of the deep zone and bony remodeling (4, 5). However, all current clinical sequences show a signal void for the ZCC because of its very short T2. Here we describe the use of 3D UTE sequences for ZCC imaging using hard pulse excitation and 3D radial sampling (6). The feasibility of these techniques was tested on five cadaveric patella specimens using a clinical 3T scanner.

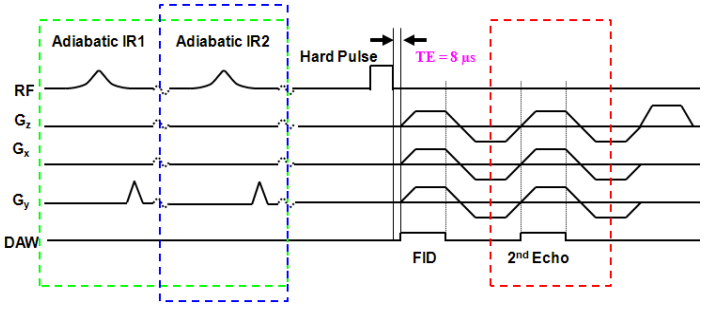

Fig 1 *Data acquisition schemes for 3D UTE imaging of the ZCC using a hard pulse excitation followed by radial ramp sampling with three contrast mechanisms: (1) dual echo acquisition and subtraction (red box); (2) single inversion recovery (SIR, blue box) with long T2 water and fat inverted and suppressed simultaneously; (3) dual inversion recovery (DIR, green box) with long T2 water and fat inverted and nulled by IR1 and IR2, respectively.*

MATERIALS AND METHODS

The 3D UTE sequence with either dual echo acquisition or long T2 suppression preparation pulses (Figure 1) were implemented on a 3T Signa TwinSpeed scanner (GE Healthcare Technologies, Milwaukee, WI) with a maximum gradient performance of 40 mT/m and 150 mT/m/ms to evaluate cadaveric patellar cartilage in five specimens. A short hard pulse (40 μs) was followed by 3D radial ramp sampling for data acquisition. Three different contrast mechanisms were investigated: (i) 3D dual echo acquisition and echo subtraction; (ii) single adiabatic inversion (SIR) and nulling of long T2 signals and (iii) dual adiabatic inversion (DIR) and nulling of long T2 signals. In SIR a single adiabatic inversion pulse (8.64 ms) with relatively broad spectral bandwidth (~1.4 kHz) was employed to invert and null long T2 water and fat signals. This was followed by a 3D UTE acquisition to image the ZCC. In DIR two adiabatic inversion pulses with longer duration (16~25 ms) and narrower spectral bandwidth (~500 Hz) were employed to invert and null long T2 water and fat respectively. A 1-inch diameter birdcage coil was used for signal excitation and reception. The acquisition parameters were: FOV = 4~8 cm, TE = 8 μs, flip angle = 15°, BW = ±31.25 to ±62.5 kHz, readout = 384, number of projections = 40 K for dual echo or 20 K for SIR/DIR, TR of 58 ms for dual echo and 300 ms SIR/DIR, TI of 110 ms for SIR, TI of 80 ms and 130 ms for DIR, total scan time 40 minutes for dual echo, and 100 minutes for SIR/DIR.

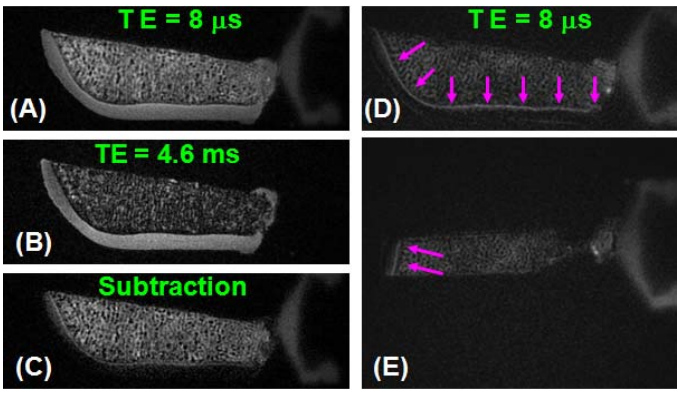

Fig 2 *Dual echo 3D UTE imaging of a patellar with a TE of 8 μs (A), 4.6 ms (B) and echo subtraction (C), and DIR UTE imaging in the axial (D) and sagittal (E) reprojections. Both techniques provide high isotropic (0.2×0.2×0.2 mm^3) imaging of the ZCC (plus deep radial cartilage due to partial volume), with superior contrast with the DIR approach.*

RESULTS AND DISCUSSION

Figure 2 shows the 3D UTE imaging of a patellar using dual echo and DIR approaches, respectively. Both techniques provide high contrast imaging of the ZCC with isotropic spatial resolution (0.2×0.2×0.2 mm^3) and isotropic coverage. Figure 3 shows 3D UTE imaging of another patellar using dual echo and SIR approaches, respectively with a higher isotropic spatial resolution of 0.16×0.16×0.16 mm^3. Excellent image contrast was achieved for the ZCC. Ultrahigh spatial resolution of the order of 800×800×800 nm^3 is also feasible but requires a significantly longer scan time (more than 3 hours) to gain enough SNR.

CONCLUSIONS

The 3D UTE sequence combined with (i) dual echo acquisition and subtraction, (ii) SIR or (iii) DIR approaches is able to provide high isotropic spatial resolution and high contrast imaging of the ZCC with excellent suppression of the long T2 signals from the superficial layers of cartilage and marrow fat. This technique may produce a non-invasive way of evaluating the involvement of ZCC in OA at different stages.

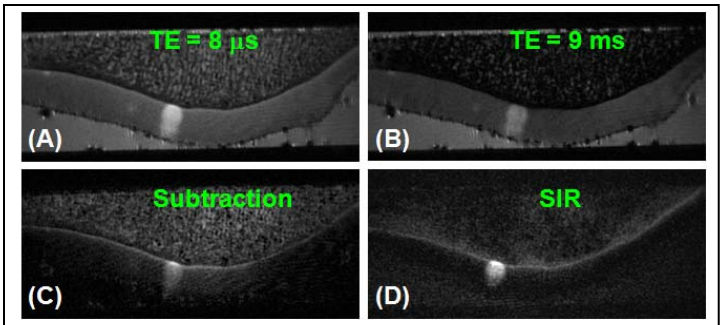

Fig 3 *Dual echo 3D UTE imaging of a patellar with a TE of 8 μs (A), 9 ms (B) and echo subtraction (C), and 3D SIR UTE imaging (D). Both techniques provide isotropic (0.16×0.16×0.16 mm^3) imaging of the ZCC (plus deep radial cartilage due to partial volume). The high signal region extending through the thickness of the cartilage might be due to calcification.*

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