A Robust Way to Make Good Contrast in the Deeper Layer of Articular Cartilage using UTE imaging

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Target Audience: MR physicists and radiologists

Purpose: MR imaging has been used for diagnosis of articular cartilage, most of MR imaging techniques have mainly focused on the superficial layers because the deeper layers, including radial and calcified zone, have been challenging to capture signals due to a majority of short $T_2^{(*)}$ components, not enabling accurate demarcation of articular cartilage (1). Recently, ultrashort echo-time (UTE) imaging techniques have been used for imaging articular cartilage, covering the deeper layers. In doing so, the subtraction between minimum TE_1 (~50-200 μs) and longer TE_2 (>~5ms) images was typically performed to provide a better contrast from the deeper layers of cartilage. Here, we show that decreasing ΔTE is more critical to enhance the image contrast of the deeper layers of articular cartilage rather than minimizing TE_1 when the subtraction method is used with UTE imaging. This was demonstrated by simulation and UTE imaging.

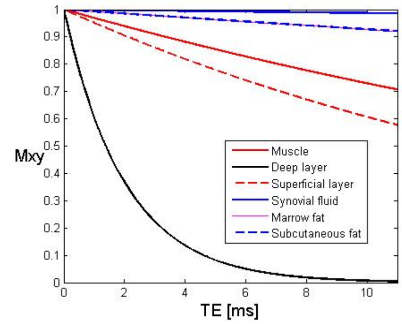

Fig.1. T_2 decay curves of several tissue components in and around the cartilage.

Methods: Articular cartilage has four layers, including the superficial, middle (or transitional), radial, and calcified zone. The superficial layer has T_2^* of ~20ms (2) and the calcified layer has ~2ms (3). Simulation was performed using T_2^* decay curves (Fig.1) to evaluate the effect of TE_1 and ΔTE on the relative contrast between two tissues with different T_2^*, especially between the superficial layer and the deep layer. For experiment, human knee imaging of a healthy volunteer was performed on a 3T Trio scanner (Siemens Magnetom Trio, Erlangen, Germany) with an eight-channel knee coil. For UTE imaging, a recently proposed CODE (COncurrent Dephasing and Excitation) sequence was used (4). CODE is a gradient-echo-based 3D radial UTE sequence where the pre-dephasing gradient is applied during the RF excitation. The minimum TE of 0.1ms used for simulation was not available in CODE. Scan parameters were as follows: TR/TE = 4.75/0.25, 0.5, 1 ms, FOV = 240mm^3, FA = 5°, number of projections = 100k, and isotropic resolution = 0.8mm^3. A sinc pulse with a 50-μs duration was used. Images were reconstructed offline with a home-built MATLAB (ver. 7.12.0; R2011a) program using gridding algorithm.

Table.1. Relative contrast ratio between the superficial layer and the deep layer

TE_1 [ms]	TE_2 [ms]	ΔTEs [ms]	Relative contrast ratio [%]
0.1	0.25	0.15	89.18
0.1	0.35	0.25	88.94
0.1	11	10.9	55.86
0.25	0.5	0.25	88.17
0.25	1	0.75	86.83
0.5	1	0.5	86.02

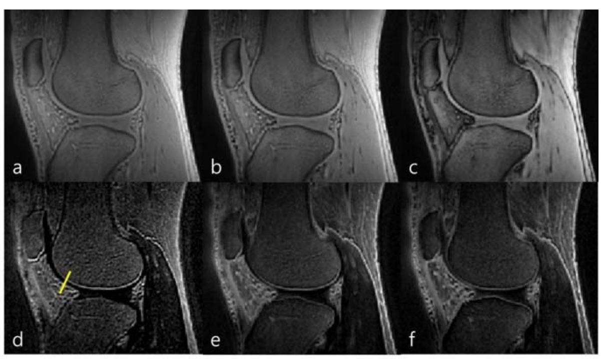

Fig.2. Sagittal images of knee images obtained with TE_1 = (a) 0.25ms, (b) 0.5ms, (c) 1ms and subtraction images (d, e, f). (d): (a) − (b). (e): (a) − (c), (f): (b) − (c). The line profile was obtained along the yellow line in (d) and was plotted in Fig.3.

Results: As shown in Table.1, the relative contrast ratio between the superficial layer and the deep layer significantly increased when ΔTE < 1ms. The smaller ΔTE, the better relative contrast, despite a slight enhancement in contrast when ΔTE < 1ms. Decreasing TE_1 only makes a slight enhancement in contrast less than 1%. Figure 2 shows sagittal knee images acquired with TE_1 = 0.25ms (a), 0.5ms (b), 1ms (c). Figures 2d, e, and f are the subtracted images, i.e., (d): (a) − (b), (e): (a) − (c), and (f): (b) − (c). As shown in Fig.3, Fig.2d shows the largest relative contrast of the deep layer, effectively removing the superficial layer and synovial fluid by subtraction. For more detailed descriptions, the signal-intensity profile was obtained along the yellow line representatively drawn in Fig.2d and plotted in Fig.3. The relative contrast of the deep layer was the best in the case of TE_1 = 0.25ms and TE_2 = 0.5ms, confirming that decreasing ΔTE is most important to enhance the relative tissue contrast of interest.

Discussion and Conclusion: In the UTE range, to enhance the relative contrast from short T_2* component of tissues such as cortical bones, ligaments, tendons, lung parenchyma, deep zone for articular cartilage, and so on, subtraction images have been usually obtained using some of dual echo sequences without specific consideration to TEs. Then, we described herein the relation between minimum TE and later TE from a simulation and *in vivo* knee imaging. Therefore, enhancement in contrast resulting from decreasing TE_1 and ΔTE deserves the fullest consideration for assessment of short T_2^* species.

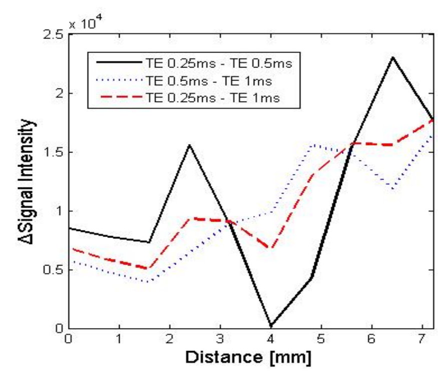

Fig.3. Comparison of signal intensity profiles among Fig.2.d (solid black line), e (dashed red line), f (dotted blue line) from the yellow line in Fig.2.d. In case of the smallest TE and ΔTE (solid black line), remained deep layer has much higher signal intensity and shorter distance.

Reference: [1] Gao S, Bao S, et al., Ultrashort TE(UTE) Imaging of the Knee Cartilage at 3T, OMICS J Radiol 2013;2:118. [2] Andreisek G, Weiger M, T_2^* mapping of articular cartilage: current status of research and first clinical applications, Invest Radiol 2014;49:57-62. [3] Du J, Carl M, et al., Dual Inversion Recovery Ultrashort Echo Time(DIR-UTE) Imaging and Quantification of the Zone of Calcified Cartilage(ZCC), Osteoarthritis Cartilage;21:77-85. [4] Park J-Y, Moeller S, Goerke U, et al., Short Echo-Time 3D Radial Gradient-Echo MRI Using Concurrent Dephasing and Excitation. Mag Reson Med 2012;67:428-436. [5] Beatty P.J, Nishimura D.G, et al., IEEE 2005;24:799-808.

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