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Ultrashort echo (UTE) versus pointwise encoding time reduction with radial acquisition (PETRA) sequences at 3 Tesla for knee meniscus: A comparative study

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ABSTRACT

Purpose: The purposes of this study were to (1) correlate the ultrashort echo time (TE) signal intensity of the pointwise encoding time reduction with radial acquisition (PETRA) sequence with that of the ultrashort echo (UTE) sequence using *in vivo* meniscal ultrashort TE imaging of the knee with a 3-Tesla (3 T) clinical magnetic resonance imaging (MRI) scanner and (2) compare the two ultrashort TE sequences in three groups of patients with normal, degenerated, and torn knee menisci.

Materials and methods: Following institutional review board approval, we analyzed 47 knee MRIs of 46 patients who presented with knee pain and underwent knee MRIs, including both the prototype 3D PETRA sequence knee MRI (TE: 70 μs) and the prototype 3D UTE sequence (TE: 70 μs) using a 3 T MRI scanner (MAGNETOM Trio, Siemens, Erlangen, Germany). The study group was classified into three subgroups: (1) normal meniscus on conventional MRI, with no positive meniscus-related physical examination on medical records; (2) meniscal degeneration; and (3) meniscal tear. For quantitative assessment, the mean signal intensities inside user-drawn regions of interest (ROIs) for each image set were drawn on the medical menisci as well as on the bone marrow of medical femoral condyle. For statistical analyses, the Pearson correlation test was used for correlation of the ultrashort TE signal intensity on the UTE and the PETRA sequences, and one-way ANOVA with post-hoc analysis using the Scheffe test was conducted to compare groups.

Results: The correlation test showed moderate correlation between the mean signal intensity values of the two ultrashort TE sequences (Pearson's coefficient: 0.4817; $P < 0.05$; 95% CI: 0.3113–0.6221). The normalized mean signal intensity values were lower for patients with meniscal degeneration and tear on both the PETRA and the UTE images. The PETRA images showed the significantly difference between normal and tear groups and between degeneration and normal groups ($P < 0.05$) whereas the UTE images showed significantly difference between normal and tear groups ($P < 0.05$).

Conclusion: Both the PETRA sequence and the UTE sequence can visualize the short T2 tissue. We demonstrated that there was significantly lower signal intensity on the ultrashort TE UTE and the PETRA images of patients with meniscal tear.

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1. Introduction

Magnetic resonance image (MRI) provides a good contrast between the different soft tissues of the body, which makes it especially useful for musculoskeletal imaging. However, the capabilities of MRI are limited for use on musculoskeletal tissues such as ligaments, tendon, meniscus, and bone, which contain a majority of the short T2 time constants [1–4]; there is little or no signal obtained from these tissues when using conventional MRI techniques.

Meniscal degeneration and tearing are well-known cofactors in the pathogenesis of osteoarthritis [5]. To evaluate these meniscal pathologies, elevations of ultrashort-T2* values are important, even in patients with subclinical meniscus degeneration [6–8]. The ultrashort echo time (TE) sequence allows MRI to be applied to these short T2 tissues.

Ultrashort-T2* values in the menisci have changed significantly in subjects without clinical evidence of subsurface meniscal abnormality, which suggested that ultrashort-T2* mapping is sensitive to subclinical meniscus degeneration [6,7]. Recently, in clinical 3-Tesla

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(3 T) MRI scanners, two kinds of ultrashort TE sequences can be applied: the conventional 3D ultrashort echo (UTE) sequence of a "koosh-ball" trajectory [9] and the pointwise encoding time reduction with radial acquisition (PETRA) sequence that incorporates both radial and Cartesian acquisition [10–13].

In this study, we examine whether the ultrashort echo time (TE) sequence is a solution to the visualization limitations of the short T2, particularly for early diagnosis and proper treatment of degenerative joint diseases, including osteoarthritis. To our knowledge, no previous studies have compared the PETRA sequence with the UTE sequence for visualizing knee meniscus. Therefore, the purposes of this study were (1) to compare the prototype PETRA sequence with the prototype UTE sequence using *in vivo* meniscal ultrashort TE imaging of the knee with a 3 T clinical MR scanner, and (2) to compare the two ultrashort TE sequences among three groups with normal, degenerated, and torn knee menisci.

2. Materials and methods

2.1. MRI protocol

All MR scans were performed using a Siemens 3 T scanner (MAGNETOM Trio, Siemens, Erlangen, Germany) with a maximum gradient amplitude of 40 mT/m and a maximum slew rate of 200 mT/m/ms. An eight-channel dedicated knee coil (InVivo, Gainesville, FL, USA) was used. Routine knee MRI sequence consists of T2-weighted sagittal images, T1-weighted axial images, fat-saturated T2-weighted axial images, fat-saturated T2-weighted coronal images, fat-saturated intermediated-weighted 3D SPACE isovoxel images, the 3D UTE sequences, and the 3D PETRA sequences.

Typical acquisition parameters of the 3D UTE were as follows: field of view (FOV), 160 × 160 × 160 mm^3; repetition time (TR), 6.02 ms; TE, 70 μs and 3.82 ms; bandwidth/pixel, 500 Hz/pixel; flip angle, 14°; acquisition matrix, 176 × 176 × 176; isotropic spatial resolution, 0.91 × 0.91 × 0.91 mm^3; and 50,000 projection numbers (phase encoding steps), with a total scan time of 5 min and 1 s.

The 3D PETRA sequence consisted of a 60-μs non-selective radiofrequency pulse followed by a 40-μs transmit/receive switch time and a 100% asymmetric data acquisition from the center to the surface of a sphere. In order to achieve the shortest possible TE, the readout gradients are already switched on during the excitation pulse. Thus, the encoding of k-space starts with the excitation. During the time needed for the transmit/receive switch center, k-space points are missed with the radial trajectory. These missed points are acquired within the Cartesian single-point acquisition of the sequence to prevent a gap in the center of k-space [10]. Typical acquisition parameters of PETRA were as follows: FOV, 225 × 225 × 225 mm^3; TR, 5.03 ms; TE, 70 μs and 2.3 ms; bandwidth/pixel, 540.36 Hz/pixel; flip angle, 6°; acquisition matrix, 256 × 256 × 256; isotropic spatial resolution, 0.88 × 0.88 × 0.88 mm^3; and 50,000 projection numbers (phase encoding steps), with a total scan time of 5 min and 5 s.

2.2. Study population

Forty six patients who underwent knee MRI scans, including both the 3D UTE sequence (TE: 70 μs) with fat-saturation and the 3D PETRA sequence (TE: 70 μs) with fat-saturation on a 3 T MRI scanner between January 2013 and May 2013, were retrospectively evaluated. Fat-saturations were performed in both 3D UTE and 3D PETRA sequences. Inclusion criteria were: (1) patients who underwent knee MRI for knee pain, and (2) patients who underwent imaging with both the 3D UTE sequence and the 3D PETRA sequence. The study protocol was reviewed and approved by our institutional review board.

Based on the medical records and conventional knee MRI findings of the medial menisci, the study population was classified into three groups: (1) normal meniscus on conventional MRI scans, with no positive meniscus-related physical examination on medical records; (2) meniscal degeneration; and (3) meniscal tear.

2.3. Image analyses

All image sets were assessed by a musculoskeletal fellowship-trained radiologist with ten years of MRI experience. Quantitative assessments were performed using 8–12 mm^2 region-of-interest (ROI) drawings at both the anterior and posterior horns of the menisci. We drew the ROIs on medial femoral condyle which showed no marrow edema on fat-saturated T2-weighted MR images. For both the UTE and the PETRA sequences, the ultrashort TE signal intensities were normalized by dividing the bone marrow signal intensity of the adjacent medial femoral condyle on same image slice, respectively.

2.4. Statistical analyses

For statistical analyses, one-way ANOVA with post-hoc analysis using the Scheffe test were conducted to compare groups. The Pearson correlation test for correlation of the ultrashort TE signal intensity on the UTE and the PETRA sequences. All statistical analyses were performed using statistical software (R package 3.1.2; The R Foundation for Statistical Computing, Vienna, Austria). A P value of less than 0.05 was considered to indicate statistically significant differences.

3. Results

Seventeen patients were male and 29 were female. The age range of the 46 patients was 19–67 years (mean age ± SD: 45.2 ± 16.6 years). A total of 47 knee MRIs from the 46 patients are summarized in Table 1.

The correlation test of the mean signal intensity values of the two ultrashort TE sequences showed moderate correlation (Pearson's coefficient: 0.4817; $P < 0.05$; 95% CI: 0.3113–0.6221) (Fig. 1). In all image sets, the normalized mean signal intensity values were lower for patients with meniscal degeneration and tear on both the PETRA and the UTE images (Figs. 2 and 3). The normalized signal intensity values of the PETRA sequences were lower than those of the UTE sequences in each horn of the medial meniscus. The signal intensity change is larger significantly in the posterior horn of the medial meniscus in both the PETRA and the UTE images ($P < 0.05$). The PETRA images showed the significantly difference between normal and tear groups and between degeneration and normal groups ($P < 0.05$) whereas the UTE images showed significantly difference between normal and tear groups ($P < 0.05$) (Fig. 3). The mean, standard deviations, and p-values are shown in Table 2.

For the group with normal menisci, the ultrashort TE signal intensities on both the PETRA and the UTE images (Fig. 4) showed high signal intensity. For the group with meniscal degeneration, the ultrashort TE signal intensities showed low signal intensity relative to normal meniscus (Fig. 5). For the group with meniscal tear, the ultrashort TE signal intensities showed generalized low signal intensity and linear high signal intensity (Fig. 6).

Table 1
Summary of patient groups.

	Normal	Degeneration	Tear	Total
Anterior horn	42	2	3	47
Posterior horn	18	17	12	47

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