Demonstration of meniscal fiber structure in vivo by radial imaging with minimal phase excitation and adiabatic fat suppression pulses at high field

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Introduction

The human meniscus consists primarily of collagen fibers that contribute to important mechanical functions of the knee, such as load distribution, but is also strongly correlated with the progression of osteoarthritis (OA) [1]. Although assessing the zonal heterogeneity is helpful for clinical diagnosis and treatment, conventional MR imaging does not yield adequate signal from the meniscus due to short T2 of the water in this highly collagenous structure. Although a previous study demonstrated the micro-structure of the cadaveric meniscus using UTE sequence [2], it is difficult to obtain similar images with adequate contrast and SNR to visualize collagen fiber orientation [3]. Conversely, STIR fat suppression is critical for improving image contrast, but the method is sensitive to B1 inhomogeneity. This problem can be overcome with adiabatic pulses [4]. The purpose of this study was to design a 3D radial sequence with minimal phase excitation in order to reduce TE in conjunction with an adiabatic suppression pulse for improved contrast of the human meniscus imaging at high field.

Theory & Method

Minimal phase RF pulse is one of the non-linear phase pulses that can be designed by the SLR algorithm, and is suitable for imaging short T2 components with reduced echo time. With the characteristic of minimal phase accumulation, only about 16% of the slice selection gradient moment is required for rephrasing [5]. In order to find the optimal inversion time (TI) for fat suppression, low-resolution images were acquired with a GRE sequence combined with an adiabatic inversion pulse to empirically optimize TI for fat suppression. Adiabatic inversion with optimized TI and minimal phase RF excitation was then incorporated into the 3D hybrid-radial UTE pulse sequence shown in Fig. 1. The pulse sequence and Cartesian slice encoding. Three healthy subjects (2 men, 1 women; mean age ~ 25 years) were imaged in supine position at 3T (TIM TRIO, Siemens Medical Solutions, Erlangen, Germany) with an eight-channel knee coil using the modified 3D radial imaging method with flip angle = 70^0, TR = 700ms, TE = 750 μs, number of slice = 4, slice thickness = 5mm, projection number = 512, readout per projection = 512, in-plane resolution = 0.24×0.24 mm^2, total acquisition time = 23m53s. All the data sets then were reconstructed using a nonuniform fast Fourier transform method.

Results

The results of the low resolution images are shown in Fig. 2. The image of TI = 110 ms shows optimal fat suppression (smallest mean fat signal) for the designed adiabatic inversion pulse. Although a previous paper indicated the optimal TI ranges to be from 180 to 220 ms at 3T our results varied due to the choice of a different TR to reduce scan time. A sagittal image acquired from one of the subjects using the optimized adiabatic fat suppression pulse and minimal phase excitation pulse is displayed in Fig. 3. The images shows detailed fiber architecture representative of the multi-directional loading with fibers running mainly parallel anteriorly but perpendicular to the articular surface in the posterior horn.

Discussion

The study illustrates the feasibility of combining an adiabatic inversion pulse with minimal phase excitation pulse to achieve improved image quality for enhanced visualization of the fiber architecture in the human meniscus. Adiabatic inversion is useful for optimizing contrast between variably oriented collagen fibers of the meniscus by virtue of the pulse's relative insensitivity to B1 imhomogeneity. In addition, the radial acquisition method provides a means to obtain high SNR from a substantially reduced echo acquisition time as well as dense sampling around the center of k-space. Our study also indicates less blurring in radial acquisition as compared to Cartesian acquisition, the reason of which remain to be investigated. To minimize artifacts caused by imperfect gradient performance, no ramp sampling was used in this study. In conclusion, our preliminary findings that the proposed method allows detailed visualization of structural details of the human meniscus, including fiber orientation and may provide opportunities for diagnosing early degenerative changes for possible intervention.

References

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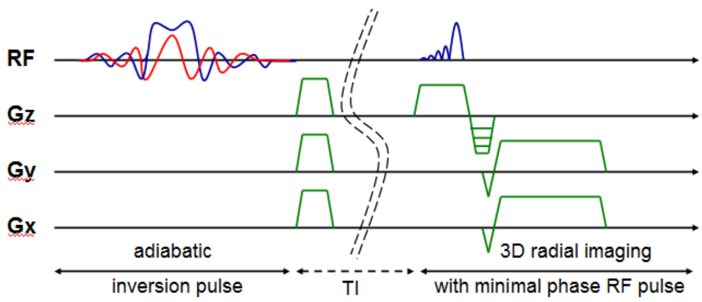

Figure 1 Illustration of pulse sequence used in this study.

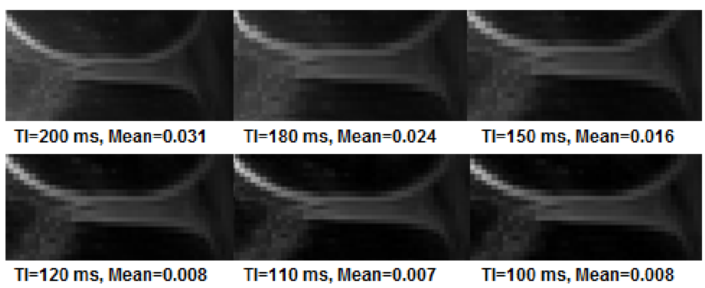

Figure 2 GRE images acquired with adiabatic inversion to determine optimal TI for fat suppression.

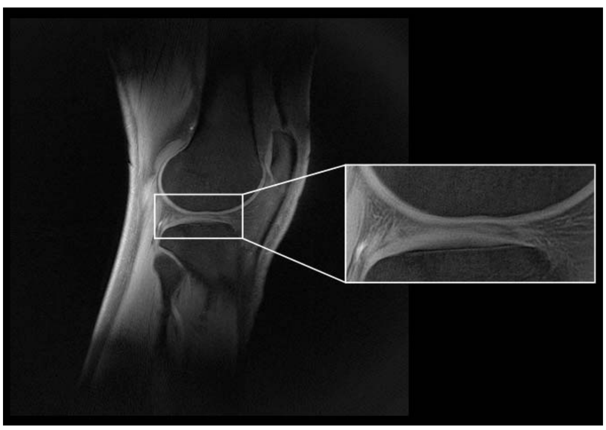

Figure 3 3D radial UTE image of the human meniscus in one of the volunteers showing detailed fiber architecture.