High-Resolution Diffusion-Weighted Imaging of Cartilage Using PROPELLER

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INTRODUCTION: Previous studies have demonstrated that diffusion-weighted MRI may be useful for the detection of osteoarthritis [1,2]. However, a major challenge for the *in vivo* use of diffusion-weighted cartilage imaging is the high spatial resolution required. Since cartilage thickness is typically ≈ 1mm, submillimeter resolution is necessary to provide relevant diagnostic information. Unfortunately, achieving such resolutions with conventional diffusion-weighted imaging techniques, namely single-shot EPI (SS-EPI), is challenging. The primary difficulty is that SS-EPI requires a relatively long readout window (≥ 100 ms) to achieve high resolution. This can lead to artifacts (e.g. distortions, signal voids) caused by off-resonance effects (e.g. susceptibility differences, B_0 inhomogeneity), as well as blurring due to T_2 and T_2^* decay. In this study, an attempt will be made to overcome these limitations by employing the recently-developed diffusion-weighted PROPELLER sequence [3]. PROPELLER uses a series of short fast-spin-echo (FSE) readout trains to acquire bands around the centre of k-space. Each subsequent FSE readout train is rotated to acquire a different portion of the outer k-space region (a central k-space region is common to all FSE readout trains). With PROPELLER, off-resonance sensitivity is minimized due to the use of FSE. Blurring caused by T_2 and T_2^* decay is reduced relative to SS-EPI since PROPELLER is a multi-shot technique, and thus capable of employing shorter readout periods. These advantages have already been demonstrated for diffusion-weighted imaging in the brain [3]. The objective of this study is to investigate the use of diffusion-weighted PROPELLER in the context of high-resolution cartilage imaging.

METHODS: High-resolution *in vivo* diffusion-weighted imaging of the knee was performed using both PROPELLER and conventional SS-EPI. The sequence parameters were: matrix size= 256 x 256, FOV = 24 cm (⇒ spatial resolution = 0.9 x 0.9 mm), slice thickness = 4 mm, number of slices = 10, TR = 4 s, and b = 600 s/mm^2. For the PROPELLER scans: echo train length (ETL) = 20, NEX = 1.5 (due to the oversampling of the k-space centre), and echo time (TE) = 120.9 ms. For SS-EPI: TE = 70.2 ms, and NEX = 5. All scanning was performed on a 1.5T Twin Excite MRI (GEMS, Milwaukee, WI) using a transmit/receive extremity coil. A total of 3 healthy subjects were imaged with both protocols.

RESULTS: Figures 1a,b are representative diffusion-weighted images of the knee acquired with PROPELLER and SS-EPI respectively. The PROPELLER images provide a significantly sharper depiction of the cartilage and subchondral bone. In contrast, blurring was observed on the SS-EPI images, likely caused by T_2 and T_2^* apodization of the k-space data during the lengthy SS-EPI readout. To evaluate off-resonance sensitivity, the diffusion-weighted images were compared to FGRE images of the same anatomy (Fig. 1c). The overall shape of the anatomy depicted in the PROPELLER images was found to correspond to that in the FGRE images, thus implying minimal geometric distortion. In contrast, the SS-EPI images appear to exhibit significant elongation. This distortion is even more apparent on SS-EPI images acquired with the diffusion-encoding gradients turned off (i.e. b = 0 s/mm^2) (Fig. 1d). This severe warping is likely due to B_0 inhomogeneity and susceptibility differences over the tissue.

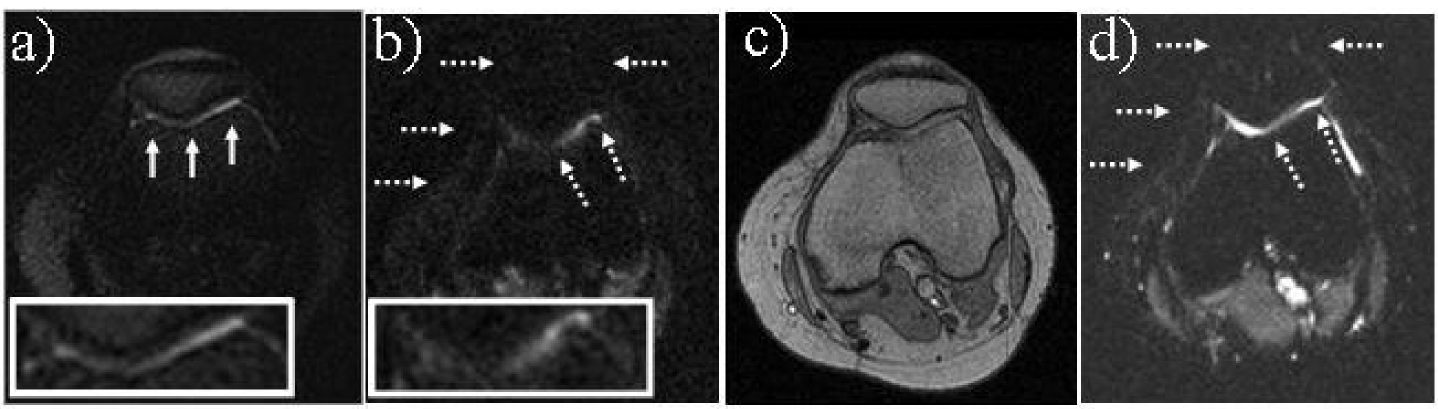

Figure 1: Diffusion-weighted images (b = 600 s/mm^2) of the knee acquired with (a) PROPELLER and (b) SS-EPI. The solid arrows in (a) indicate the cartilage and subchondral aspect of the femoral trochlear. The boxes in the lower left corners depict zoomed- in views of the cartilage region. (c) Non-diffusion-weighted image of the same anatomy acquired with FGRE. (d) Image of the knee acquired with SS-EPI, but without diffusion weighting (i.e. b = 0 s/mm^2). Prominent areas of geometric distortion are indicated by the dashed arrows in (b) and (d).

DISCUSSION: The results of this study demonstrate that diffusion-weighted PROPELLER is effective at generating high-resolution images of cartilage. Relative to conventional SS-EPI, artifacts due to off-resonance effects were suppressed due to the use of an FSE readout. Image blurring due to T_2 and T_2^* was reduced due to the use of shorter echo trains. However, a significant drawback of PROPELLER relative to conventional techniques is reduced efficiency. The PROPELLER scans in the present study required 5.8 min, while the SS-EPI studies lasted only 32 s (for a single NEX). Part of the reason for PROPELLER's reduced efficiency is the oversampling of the central k-space region (the other reason is the FSE readout, vs. a GRE readout in SS-EPI). In the future, greater efficiency may potentially be achieved by optimizing the FSE echo train length and/or by implementing a parallel acquisition strategy. However, even with reduced efficiency, the improvement in image quality provided by PROPELLER may ultimately make it the preferred method for high-resolution diffusion-weighted imaging of cartilage.

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