Rapid Multi-Planar Assessment of the Articular Cartilage of the Knee Joint Using Isotropic Resolution VIPR-ATR Imaging

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Purpose: Acquiring multi-planar high resolution magnetic resonance (MR) images of articular cartilage in a reasonable scan time is important for cartilage assessment in osteoarthritis research studies. At our institution, we have developed a rapid MR technique called VIPR-ATR for obtaining three-dimensional fat-suppressed MR images of the knee joint with steady-state free-precession (SSFP) tissue contrast and high isotropic resolution (1). VIPR–ATR uses a dual half echo radial k–space trajectory called vastly undersampled isotropic projection reconstruction (VIPR) which allows for almost continuous acquisition of data and provides twice the resolution achievable with a Cartesian trajectory during the constrained repetition time (2). VIPR–ATR uses two different alternating length repetition times (ATR) and radiofrequency phase cycling to create a null for off–resonance fat signal during the SSFP acquisition (3). This study was performed to compare VIPR-ATR with currently used three-dimensional MR pulse sequences for evaluating the articular cartilage of the knee joint.

Methods: An MR examination was performed on the knees joint of 7 asymptomatic volunteers and 3 patients with OA using a 3.0T scanner (Discovery MR750, GE Healthcare, Waukesha, WI) and an 8-channel phased-array extremity coil. All MR examinations consisted of the following 5 sequences performed in the sagittal plane: FSE-Cube (0.6 mm x 0.6 mm x 0.6 mm voxel size and 5 minute scan time), IDEAL-GRASS (0.4 mm x 0.7 mm x 1.0 mm voxel size and 5 minute scan time), IDEAL-SPGR (0.4 mm x 0.7 mm x 1.0 mm voxel size and 5 minute scan time), VIPR-ATR (0.4 mm x 0.4 mm x 1.2 mm effective voxel size with 3 slice averaging of 0.4 mm isotropic images in each dimension and 5 minute scan time), and high resolution (HR) VIPR-ATR (0.3 mm x 0.3 mm x 0.9 mm effective voxel size with 3 slice averaging of 0.3 mm isotropic images in each dimension and 8 minute scan time). Signal-to-noise ratio (SNR) efficiency and contrast-to-noise ratio (CNR) efficiency measurements were performed on all MR examinations and were normalized to voxel volume. Paired t-tests were used to compare differences in normalized SNR and CNR efficiency values between sequences. Two musculoskeletal radiologists independently reviewed all MR examinations and ranked the sequences based upon the following qualitative measures of image quality: 1) tissue contrast, 2) clarity of articular surface, 3) cartilage lesion conspicuity, and 4) overall image quality.

Results: VIPR-ATR and HR VIPR-ATR produced high quality multi-planar images of the knee joint following a single 5 to 8 minute acquisition (Figure 1).

Figure 1: Multi-planar HR VIPR-ATR images of the knee joint with 0.3 mm isotropic resolution.

VIPR-ATR and HR VIPR-ATR had similar (p=0.08-0.26) cartilage SNR efficiency as FSE-Cube and IDEAL-SPGR and significantly higher (p<0.05) cartilage SNR efficiency than IDEAL-GRASS. VIPR-ATR and HR VIPR-ATR had significantly higher (p<0.05) fluid SNR efficiency than FSE-Cube, IDEAL-GRASS, and IDEAL-SPGR, but significantly lower (p<0.05) suppression of bone marrow signal than FSE-Cube and IDEAL-SPGR (Figure 2). VIPR-ATR and HR VIPR-ATR had significantly higher (p<0.05) CNR efficiency between cartilage and fluid than FSE-Cube, IDEAL-GRASS, and IDEAL-SPGR, but significantly lower (p<0.05) CNR efficiency between cartilage and bone marrow than FSE-Cube and IDEAL-SPGR (Figure 3). On subjective analysis, HR VIPR-ATR followed by VIPR-ATR had the highest rank for tissue contrast, clarity of articular surface, cartilage lesion conspicuity, and overall image quality (Figure 4).
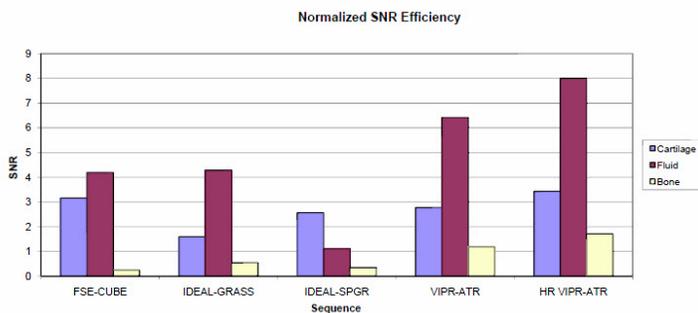

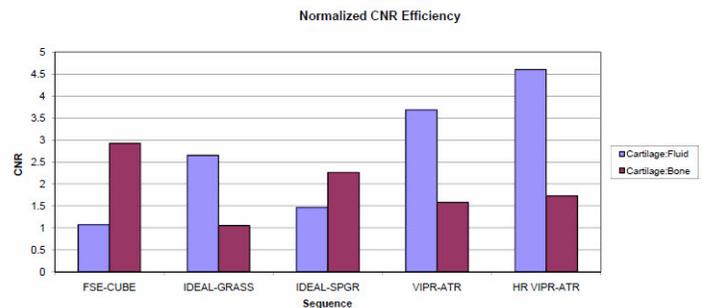Figure 2: Normalized SNR efficiency for cartilage imaging sequences.

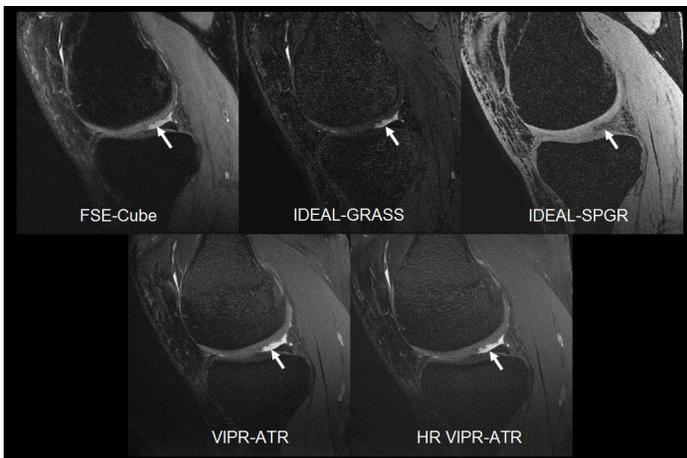Figure 3: Normalized CNR efficiency for cartilage imaging sequences.

Figure 4: Appearance of a superficial partial thickness cartilage lesion (arrows) on different cartilage imaging sequences.

Conclusion: VIPR-ATR produces high quality multi-planar images of the knee joint with 0.4 mm isotropic resolution in 5 minutes and 0.3 mm isotropic resolution in 8 minutes. In contrast, the water excitation dual-echo steady-state (DESS) sequence used for cartilage assessment in the Osteoarthritis Initiative produces images of the knee joint with 0.4 mm x 0.5 mm x 0.7 mm voxel size in 10.6 minutes (4). VIPR-ATR has high cartilage SNR efficiency and high contrast between cartilage and adjacent joint structure which makes it optimal for evaluating the articular cartilage of the knee joint. Due to its highly versatile SSFP tissue contrast (5), VIPR-ATR can also be used to evaluate the menisci, ligaments, bone marrow, and other joint structures which can be sources of pain in patients with osteoarthritis. Additional studies are needed to determine whether VIPR-ATR can provide rapid "whole-organ" joint assessment and cartilage volume analysis in osteoarthritis research studies.

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