Rapid Isotropic Resolution Imaging of the Articular Cartilage of the Knee Joint at 3.0T Using VIPR-IDEAL

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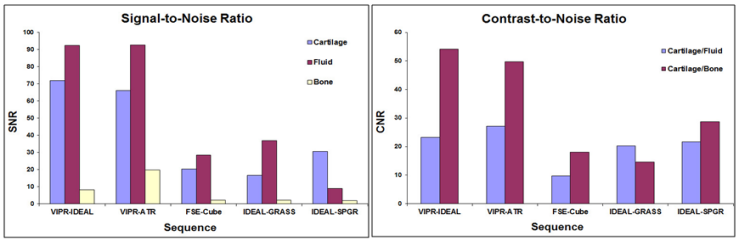
Purpose: VIPR-IDEAL is a new 3D balanced SSFP sequence which produces images of the knee joint with mixed T2/T1 contrast, bright fluid, and isotropic resolution that can be reformatted in any orientation. Fat/water decomposition using iterative decomposition of water and fat with echo asymmetry and least squares estimates (IDEAL) [1] provides more robust fat-suppression than alternating repetition time (ATR) methods that manipulate the SSFP frequency spectrum to create fat nulls [2, 3]. VIPR-IDEAL uses the highly SNR efficient vastly undersampled isotropic projection reconstruction (VIPR) radial k-space trajectory to obtain high resolution while maintaining a short TR for SSFP imaging [3-5]. This study was performed to compare VIPR-IDEAL with other 3D cartilage imaging sequences for evaluation of the articular cartilage of the knee joint at 3.0T.

Methods: VIPR-IDEAL utilizes a two-pass data collection scheme to acquire 4 TEs in two separate TRs. This allows for the collection of high resolution image data while keeping the TR short to avoid banding artifact and to maintain fat and water centered in separate pass bands. Fat/water decomposition is performed using the IDEAL algorithm [1]. VIPR-IDEAL uses a 4.6 ms TR, TEs of 0.5, 1.35, 2.23, and 3.09 ms, 15° flip angle, 125 kHz bandwidth, 15 cm field of view, and 256 x 256 matrix to produce 0.6 mm isotropic resolution images of the knee joint in 5 minutes. To compare the performance of VIPR-IDEAL with other 3D cartilage imaging techniques, an MRI examination was performed on both knees of four volunteers and one patient with osteoarthritis using a 3.0T scanner (Discovery MR750, GE Healthcare, Waukesha, WI) and 8-channel phased-array extremity coil (In Vivo, Orlando, FL). All MRI examinations consisted of the following 5 sequences performed twice in the sagittal plane: VIPR-IDEAL (0.6 x 0.6 x 0.6 mm voxel size), VIPR-ATR (0.6 x 0.6 x 0.6 mm voxel size), FSE-Cube (0.6 x 0.6 x 0.6 mm voxel size) , IDEAL-GRASS (0.4 x 0.7 x 1.0 mm voxel size), and IDEAL-SPGR (0.4 x 0.7 x 1.0 mm voxel size) [3, 6]. All sequences were optimized to produce 0.6 mm isotropic resolution images or as close as possible while maintaining a 5 minute scan time and adequate image quality. SNR and CNR measurements were performed on the 8 MRI examinations of the 4 volunteers using a double acquisition addition/subtraction method previously described for parallel imaging techniques [7]. T-tests were used to compare SNR and CNR values between sequences. A VIPR-IDEAL sequence with 0.4 mm isotropic resolution and 5 minute scan time was also performed in the sagittal plane on the knee joint of one volunteer to determine the maximal spatial resolution achievable by the imaging technique.

Results: As shown in Figure 1, VIPR-IDEAL had similar (p=0.66-0.69) cartilage and fluid SNR as VIPR-ATR and significantly higher (p<0.01) cartilage and fluid SNR than FSE-Cube, IDEAL-GRASS, and IDEAL-SPGR. VIPR-IDEAL had significantly greater (p<0.01) suppression of bone marrow fat signal than VIPR-ATR but significantly lower (p<0.01) suppression of bone marrow fat signal than FSE-Cube, IDEAL-GRASS, and IDEAL-SPGR. VIPR-IDEAL had similar (p=0.06-0.99) cartilage/fluid CNR as the other sequences. VIPR-IDEAL had similar (p=0.12) cartilage/bone CNR as VIPR-ATR and significantly (p<0.01) higher cartilage/bone CNR than FSE-Cube, IDEAL-GRASS, and IDEAL-SPGR. As shown in Figure 2, cartilage lesions within the knee joint were well visualized on VIPR-IDEAL images. Due its high SNR efficiency, VIPR-IDEAL was able to produce fat-suppressed images of the knee joint with 0.4 mm isotropic resolution in 5 minutes which provided improved visualization of articular cartilage with no drop in image quality as demonstrated in Figure 3.

Figure 1: Comparison of SNR and CNR between sequences.



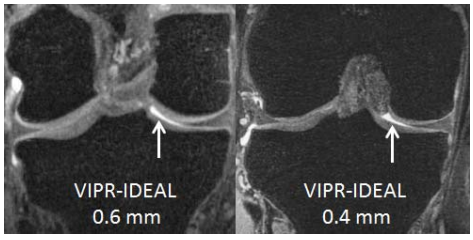
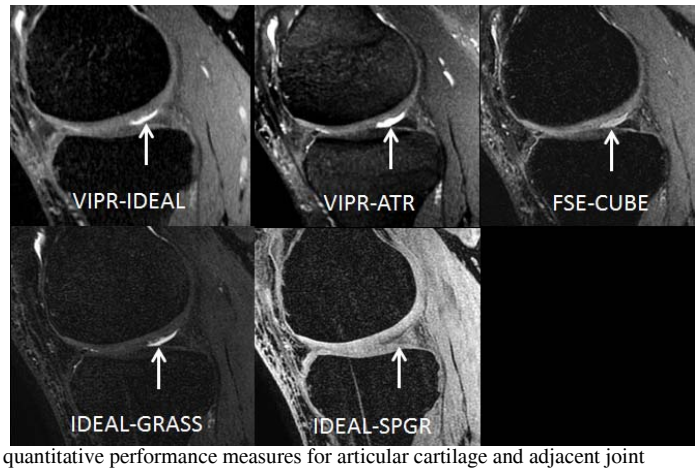


Figure 3: VIPR-IDEAL reformat images with 0.6mm and 0.4 mm isotropic resolution. Note the clearer articular surface and more well-defined cartilage/fluid interface (arrows) on the higher resolution image.

Figure 2: Appearance of a partial-thickness cartilage lesion (arrows) on different sequences. Note the higher signal of cartilage and fluid on the VIPR-IDEAL VIPR-ATR images with decreased noise.



Discussion: VIPR-IDEAL utilizes the strengths of high SSFP signal to produce strong quantitative performance measures for articular cartilage and adjacent joint structures when compared to other 3D cartilage imaging sequences. Fitting and removing the multiple peaks of fat with IDEAL [1] results in greater suppression of fat signal and better bone/cartilage interfaces than achievable by manipulating the SSFP frequency spectrum to create fat nulls as in VIPR-ATR [3]. Thus, VIPR-IDEAL has the same high SNR efficiency as VIPR-ATR but provides superior fat-suppression. Due to its highly versatile SSFP tissue contrast [8], VIPR-IDEAL 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. The improved fat-suppression of VIPR-IDEAL may provide better detection of bone marrow edema lesions, meniscal tears, and ligamentous injuries when compared to VIPR-ATR. One major advantage of VIPR-IDEAL is the ability of the IDEAL algorithm to provide robust fat-suppression in areas of magnetic field inhomogeneity. This is especially important when imaging post-operative patients with metallic orthopedic hardware and large patients whose knee must be placed well away from the scanner isocenter. In conclusion, VIPR-IDEAL produces high quality 0.4 mm to 0.6 mm isotropic resolution images of the knee joint in 5 minutes at 3.0T which are well suited for evaluating articular cartilage and other joint structures. Additional studies are needed to determine whether VIPR-IDEAL can provide improved detection of cartilage lesions in clinical practice and more rapid and accurate "whole-organ" joint assessment and cartilage volume analysis in osteoarthritis research studies.

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