High Isotropic, Balanced SSFP 3D Radial Imaging for Hip Joint Assessment at 3.0T

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Target Audience: Clinicians and imaging scientists interested in achieving high isotropic resolution imaging of the hip joint.

Purpose: Patients with femoracetabular impingement and other hip disorders may benefit from surgical interventions if labral tears and cartilage degeneration are detected during the earlier stages of the disease process (1). However, evaluating the hip joint with magnetic resonance (MR) imaging is extremely challenging due to the thin articular cartilage and spherical geometry of the femoral head and acetabulum. Conventional two-dimensional (2D) fast spin-echo (FSE) sequences require a large field of view, acquire anisotropic voxels, and utilize relatively thick slices with large inter-slice gaps, producing images that suffer from suboptimal in-plane resolution and partial volume artifact. VIPR-ATR is a rapid three-dimensional (3D) MR technique that utilizes the high signal achieved by steady-state free-precession (SSFP) in order to obtain high isotropic resolution. VIPR–ATR uses a dual half-echo radial k–space trajectory called vastly undersampled isotropic projection reconstruction (VIPR) which allows for almost continuous data acquisition and nearly twice the resolution achievable with a Cartesian trajectory during a constrained repetition time (2). Fat-suppression is achieved using 2 different alternating length repetition times (ATR) combined with 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 2D FSE sequences for evaluating the hip joint.

Methods: The hip joints of 24 patients with unilateral hip pain were imaged using a 3.0T Discovery MR750 scanner (GE Healthcare, Waukesha WI) and 8-channel phased-array cardiac coil. Each MR exam consisted of the following sequences acquired after the intra-articular administration of gadolinium contrast material: coronal and axial-oblique fat-suppressed 2D T1-weighted FSE (T1-FSE) sequences with 0.6 x 0.9 x 4.0 mm voxel size and 3.8 minute scan time, coronal and axial fat-suppressed 2D T2-weighted FSE sequences (T2-FSE) with 0.6 x 0.9 x 4.0 mm voxel size and 3.5 minute scan time, sagittal fat-suppressed 2D proton density-weighted FSE (PD-FSE) sequence with 0.6 x 0.8 x 5.0 mm voxel size and 4.3 minute scan time, and axial 3D VIPR-ATR sequence with 0.5 x 0.5 x 0.5 mm voxel size and 7.7 minute scan time. VIPR-ATR images were reformatted with 2 slice averages in the sagittal, coronal, axial, axial-oblique, and radial planes to generate 1.0 mm thick contiguous slices with 0.5 x 0.5 in-plane resolution. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) efficiency measurements were performed on all sequences in 10 randomly chosen MR exams, and the measured values were normalized to voxel volume. Paired t-tests were used to compare differences in normalized SNR and CNR efficiency values between sequences. A musculoskeletal radiologist reviewed the MR exams of all patients to assess the ability of the multi-planar 2D FSE and VIPR-ATR images to assess the labrum and articular cartilage of the hip joint.

Results: VIPR-ATR produced high quality multi-planar images of the hip joint following a single 7.7 minute acquisition. VIPR-ATR had significantly higher ($p<0.05$) normalized SNR efficiency for cartilage and fluid and significantly higher ($p<0.05$) normalized CNR efficiency between cartilage and fluid and cartilage and bone when compared to T1-FSE, T2-FSE, and PD-FSE (Figure 1). The multi-planar VIPR-ATR images had similar ability as the multi-planar T1-FSE, T2-FSE, and PD-FSE images for detecting labral tears and improved ability for identifying and characterizing cartilage lesions on the acetabulum and femoral head (Figures 2 and 3).

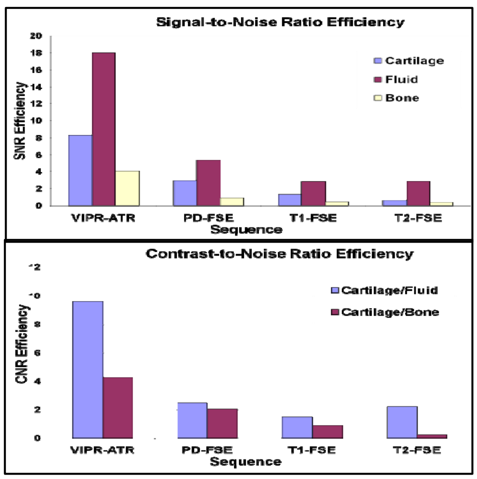

Figure 1: Comparison of normalized SNR and CNR efficiency. VIPR-ATR had significantly higher normalized SNR and CNR efficiency than the 2D FSE sequences.

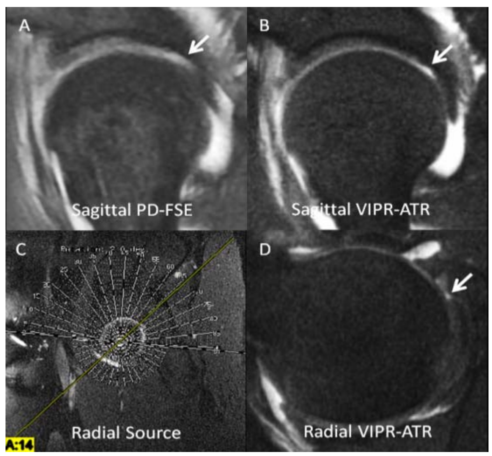

Figure 2: (A) Partial volume effect in this Sagittal PD-FSE image seems to depict healthy tissue (arrow) whereas the thinner slices of Sagittal (B) and radial (C and D) VIPR-ATR reformat images show a small focal full-thickness cartilage lesion on the acetabulum (arrows in B & D).

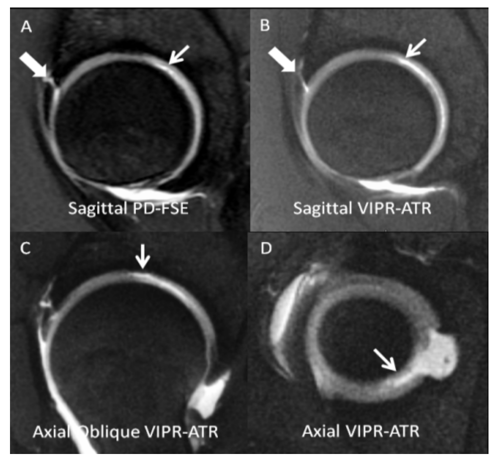

Figure 3: (A) Sagittal PD-FSE image shows a labral tear (large arrow) and contrast between the articular surfaces suggesting a cartilage lesion (small arrow). (B) Sagittal VIPR-ATR image shows the labral tear (large arrow) and improved visualization of a small focal partial-thickness cartilage lesion on the femoral head (small arrow). (C) Axial-oblique and (D) axial VIPR-ATR images show a small focal full-thickness cartilage lesion on the acetabulum (arrow in C) and small focal partial-thickness cartilage lesion on the femoral head (arrow in D).

Conclusions: All previous studies describing the use of 3D sequences for evaluating the hip joint have used spoiled gradient-echo (SPGR) sequences with anisotropic resolution (4-5). VIPR-ATR has been shown to have higher SNR efficiency than other currently used 3D techniques (6) and thus can produce high quality multi-planar images of the hip joint with 0.5 mm isotropic resolution in 7.7 minute scan time which has never been previously performed. VIPR-ATR has high cartilage and fluid SNR efficiency and high contrast between cartilage and adjacent joint structures. VIPR-ATR acquires thin continuous slices with high in-plane resolution which reduces partial volume averaging, and its ability to create reformat images in any plane is especially useful when evaluating the complex anatomic structures of the hip joint. The ability of VIPR-ATR to acquire small voxel volumes and then reformat images in any orientation with minimal amounts of slice averaging produces 50% higher in-plane resolution, 90% reduction in voxel volume, and higher SNR and CNR efficiencies in exchange for a 100% increase in scan time. However, a single 7.7 minute VIPR-ATR scan may be able to replace a conventional 25 minute MR examination. Additional studies are needed to determine the potential applications of VIPR-ATR for whole-volume comprehensive assessment of the hip joint in clinical practice.

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