Routine Three-Dimensional MR Imaging of Joints

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Most currently used musculoskeletal MR protocols consist of two-dimensional fast spin-echo sequences repeated in multiple planes. These sequences have excellent tissue contrast and high in-plane spatial resolution. However, they have relatively thick slices and gaps between slices which can lead to partial volume artifact. Three-dimensional sequences can reduce partial volume averages by acquiring thin, continuous slices through joints. Three-dimensional sequences can also be used to create multi-planar reformat images which allow joints to be evaluated in different orientations following a single acquisition.

Cartilage Imaging of the Knee Joint

Three-dimensional sequences have been primarily used in clinical practice to evaluate the articular cartilage of the knee joint. Most three-dimensional cartilage imaging sequences are gradient-echo sequences. These sequences include spoiled gradient recalled-echo (SPGR), unspoiled gradient recalled-echo acquired in the steady-state (GRASS), dual-echo in the steady-state (DESS), driven equilibrium fourier transfer (DEFT), and various balanced steady-state free-precession (SSFP) sequences such as true fast imaging with steady-state precession (FISP), fluctuating equilibrium magnetic resonance (FEMR), and vastly undersampled isotropic projection steady-state free-precession (VIPR-SSFP). When combined with SNR efficient methods of fat-suppression such as water excitation, linear combination, and IDEAL fat-water separation, three-dimensional gradient-echo sequences have been shown to have higher cartilage SNR and higher contrast between cartilage and adjacent joint structures than two-dimensional fast spin-echo sequences (1-12). With the recent availability of high field strength scanners, multi-channel coils, and parallel imaging techniques, three-dimensional fast spin-echo sequences such as 3D-FSE-Cube (GE Healthcare) and 3DFT-TSE (Philips Medical System) have also been developed for evaluating articular cartilage (13). The diagnostic performance of three-dimensional sequences for detecting cartilage lesions within the knee joint in clinical trials with arthroscopic correlation are summarized below.

Sequence	Field Strength	Patients	Sensitivity	Specificity
Fat-suppressed SPGR (10)	1.5T	114	80%	95%
Water Excitation SPGR (11)	1.5T	35	68%	84%
Water Excitation DESS (11)	1.5T	35	64%	86%
Water Excitation True-FISP (11)	1.5T	35	61%	87%
DEFT (12)	1.5T	24	69%	93%
VIPR-SSFP (14)	1.5T	95	77%	92%
IDEAL-GRASS (15)	3.0T	95	69%	93%
FSE-Cube (16)	3.0T	100	73%	88%

Cartilage Imaging of the Hip Joint

Three-dimensional gradient-echo sequences have been also been used to evaluate the articular cartilage of the hip joint during MR arthrography. In one study, a sagittal water excitation DESS sequence was found to have similar sensitivity and specificity as a sagittal fat-suppressed T1-weighted FSE sequence at 1.5T for detecting 26 cartilage lesions within the hip joint in 21 patients (17). In a larger study performed at 3T involving 35 patients with 72 cartilage lesions, a sagittal IDEAL-SPGR sequence with multi-planar reformats was found to have significantly higher sensitivity ($p<0.05$) for detecting low grade cartilage lesions and similar sensitivity for detecting high grade lesions within the hip joint when compared to axial, sagittal, and coronal two-dimensional T1-weighted fast spin-echo sequences. Specificity values in this study were similar for both the IDEAL-SPGR and fat-suppressed T1-weighted FSE sequences (18).

Internal Derangement of the Knee Joint

Providing comprehensive knee joint assessment in clinical practice requires the use of three-dimensional sequences with isotropic resolution which can be reformatted in multiple planes following a single acquisition. At 1.5T, high isotropic resolution in clinically feasible scan times has only been achieved using balanced-SSFP sequences. In a preliminary study performed on 35 patients with arthroscopic correlation, three-dimensional, isotropic resolution water excitation true-FISP had similar sensitivity and specificity as a routine MR protocol for detecting cartilage lesion, anterior cruciate ligament tears, and meniscal tears (19). However, a larger study performed on 95 patients with arthroscopic correlation showed potential weaknesses of the T2/T1-weighted tissue contrast of balanced-SSFP sequences. In this study, three-dimensional, isotropic resolution VIPR-SSFP was found to have similar sensitivity and specificity as a routine MR protocol for detecting cartilage lesions, anterior cruciate ligament tear, posterior cruciate ligament tears, medial collateral ligament tears, lateral collateral ligament tears, and medial meniscal tears but signicantly lower ($p<0.05$) sensitivity for detecting lateral menscal tears and bone marrow edema lesions (14).

At 3.0T, three-dimensional fast spin-echo sequences with isotropic resolution can be used to provide comprehensive knee joint assessment. These sequences have intermediate-weighted contrast, which is by far the most versatile and widely utilized tissue contrast mechanism in clinical musculoskeletal MR imaging. In one study performed on 100 patients with arthroscopic correlation, three-dimensional, isotropic resolution, intermediate-weighted 3D-FSE-Cube with multi-planar reformats was found to have similar sensitivity and specificity as a routine MR protocol for detecting anterior cruciate ligament tears, posterior cruciate ligament tears, medial collateral ligament tears, lateral collateral ligament tears, meniscal tears, and bone marrow edema lesions. For the detection of cartilage lesions, 3D-FSE-Cube had significantly higher sensitivity ($p<0.05$) but significantly lower specificity ($p<0.05$) than the routine MR protocol (16).

Internal Derangement of the Shoulder Joint

One study with arthroscopic correlation has shown that a three-dimensional, isotropic resolution T1-weighted gradient-echo sequence with multi-planar reformats has similar sensitivity and specificity as axial, sagittal, and coronal two-dimensional T1-weighted

fast spin-echo sequences for detecting rotator cuff tears and labral tears during MR arthrography. The use of three-dimensional sequences with isotropic resolution during MR arthrography could significantly reduce examination times by eliminating the need to repeat two-dimension sequences in multiple planes (20). Another study has demonstrated the feasibility of using a three-dimensional, isotropic resolution, intermediate-weighted fast spin-echo sequence for evaluating the rotator cuff tendon. In this study, 3D-FSE-Cube with multi-planar reformats was found to have moderate agreement with a routine MR protocol for grading the rotator cuff tendon in 15 symptomatic patients (21).

Internal Derangement of the Ankle Joint

Two studies performed on a small number of asymptomatic volunteers have demonstrated the feasibility of using three-dimensional, isotropic resolution, intermediate-weighted fast spin-echo sequences for evaluating the ankle joint. The thin, continuous slices of the three-dimensional sequences and the ability to view images in oblique and curved planes may improve depiction of anatomy and diagnosis of disease within the ankle joint (22, 23).

Bibliography

1. Siepmann DB, McGovern J, Brittain JH, Reeder SB. High-Resolution 3D Cartilage Imaging with IDEAL SPGR at 3 T. Am. J. Roentgenol. 2007; 189:1510-1515.
2. Gold GE, Reeder SB, Yu H, et al. Articular Cartilage of the Knee: Rapid Three-dimensional MR Imaging at 3.0 T with IDEAL Balanced Steady-State Free Precession--Initial Experience. Radiology 2006; 240:546-551.
3. Gold GE, Hargreaves BA, Vasanawala SS, et al. Articular Cartilage of the Knee: Evaluation with Fluctuating Equilibrium MR Imaging--Initial Experience in Healthy Volunteers. Radiology 2006; 238:712-718.
4. Kijowski R, Tuite M, Passov L, Shimakawa A, Hu H, Reeder SB. Cartilage imaging at 3.0T with gradient refocused acquisition in the steady-state (GRASS) and IDEAL fat-water separation. J Magn Reson Imaging 2008; 28:167-174.
6. Kornaat PR, Doornbos J, van der Molen AJ, et al. Magnetic resonance imaging of knee cartilage using a water selective balanced steady-state free precession sequence. J Magn Reson Imaging 2004; 20:850-856.
7. Vasanawala SS, Pauly JM, Nishimura DG. Fluctuating equilibrium MRI. Magn Reson Med 1999; 42:876-883.
8. Vasanawala SS, Pauly JM, Nishimura DG. Linear combination steady-state free precession MRI. Magn Reson Med 2000; 43:82-90.
9. Kijowski R, Lu A, Block W, Grist T. Evaluation of the articular cartilage of the knee joint with vastly undersampled isotropic projection reconstruction steady-state free precession imaging. J Magn Reson Imaging 2006; 24:168-175.
10. Disler DG, McCauley TR, Kelman CG, et al. Fat-suppressed three-dimensional spoiled gradient-echo MR imaging of hyaline cartilage defects in the knee: comparison with standard MR imaging and arthroscopy. AJR Am J Roentgenol 1996; 167:127-132.

11. Duc SR, Pfirrmann CW, Schmid MR, et al. Articular cartilage defects detected with 3D water-excitation true FISP: prospective comparison with sequences commonly used for knee imaging. Radiology 2007; 245:216-223.
12. Gold GE, Fuller SE, Hargreaves BA, Stevens KJ, Beaulieu CF. Driven equilibrium magnetic resonance imaging of articular cartilage: initial clinical experience. J Magn Reson Imaging 2005; 21:476-481.
13. Gold GE, Busse RF, Beehler C, et al. Isotropic MRI of the knee with 3D fast spin-echo extended echo-train acquisition (XETA): initial experience. Radiology 2007; 188:1287-1293.
14. Kijowski R, Blankenbaker D, Klaers J, et al. Vastly undersampled isotropic projection steady-state free precession (VIPR-SSFP) imaging of the knee joint: diagnostic performance compared to conventional MR imaging. Radiology, In Press.
15. Kijowski R, Blankenbaker DG, Woods MA, et al. Evaluation of the articular cartilage of the knee joint at 3T using unspoiled gradient recalled-echo acquired in the steady-state and IDEAL fat-water separation (IDEAL-GRASS). Presented at the 44th Radiologic Society of North America Scientific Assembly and Annual Meeting. Chicago, Illinois. December 3, 2008.
16. Kijowski R, Davis KD, Woods M, et al. Comprehensive knee joint assessment at 3T using an isotropic resolution three-dimensional fast spin-echo sequence (3D-FSE-Cube). Presented at the 44th Radiologic Society of North America Scientific Assembly and Annual Meeting. Chicago, Illinois. December 2, 2008.
17. Knuesel P, Pfirrman CW, Noetzli HP, et al. MR arthrography of the hip: diagnostic performance of a dedicated water-excitation 3D double-echo steady-state sequence to detect cartilage lesions. Am. J. Roentgenol. 2004; 183:1729-1735.
18. Ulrick SA, Blankenbaker DG, Kijowski R, et al. MR arthrography of the hipr: comparison of a dedicated IDEAL-SPGR sequence with standard MR sequences in the detection of cartilage lesions. Accepted for presentation at the American Roentogen Ray Society Annual Meeting. Boston, Massachusetts. April 26, 2009.
19. Duc SR, Pfirrmann CW, Koch PP, et al. Internal knee derangement assessed with 3-minute three-dimensional isovoxel true-FISP MR sequence: Preliminary study. Radiology 2008; 246:526-535.
20. Magee T. Can isotropic fast gradient echo imaging be substituted for conventional T1-weighted sequences in shoulder MR arthrography at 3 tesla? J Magn Reson Imaging 2007; 26;118-122.
21. Hill JA, Myers RE, Busse RF, et al. MR imaging of the rotator cuff tendon at 3T using 3D-FSE-Cube. Accepted for presentation at the Society of Skeletal Radiology Annual Meeting
22. Yao L, Pitts JT, Thomasson D. Isotropic 3D fast spin-echo with proton-density-like contrast: a comprehensive approach to musculoskeletal MRI. Am. J. Roentgenol 2007; 188:199-201.
23. Steven KJ, Busse RF, Han E, et al. Ankle: isotropic MR imaging with 3D-FSE-Cube- initial experience in healthy volunteers. Radiology 2008. 249:1026-1033.