

## THREE-DIMENSIONAL FAST SPIN-ECHO IMAGING OF JOINTS

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Magnetic resonance (MR) imaging is one of the most commonly utilized imaging modality for evaluating patients with joint pain in clinical practice. Musculoskeletal MR protocols at most institution consist of two-dimensional intermediate-weighted and T2-weighted fast spin-echo (FSE) sequences repeated in multiple planes. These sequences have high in-plane spatial resolution and excellent tissue contrast which can be used to evaluate all joint structures. However, two-dimensional FSE sequences produce images with relatively thick slices and gaps between slices which may obscure joint pathology secondary to partial volume averaging.

Three-dimensional FSE sequences have also been used to evaluate patients with joint pain. Three-dimensional FSE sequences have many potential advantages over two-dimensional FSE sequences for evaluating the musculoskeletal system. Three-dimensional FSE sequences produce thin continuous images with high in-plane spatial resolution which limit the effects of partial volume averaging. In addition, multi-planar reformat images can be created from the volumetric source data which eliminates the need to repeat sequences with identical tissue contrast in different orientations. The use of three-dimensional FSE sequences in clinical practice would significantly decrease MR examination times which would improve patient comfort, reduce motion artifact, and optimize the clinical efficiency of the MR scanner. This lecture will review the clinical applications of three-dimensional sequences FSE sequences in musculoskeletal MR imaging.

### Three-Dimensional Knee Joint Imaging

#### Cartilage Imaging

Three-dimensional FSE sequences such as fast spin-echo Cube (FSE-Cube, GE Healthcare) and sampling perfection with application oriented contrasts using different flip angle evolutions (SPACE, Siemens Medical Systems) have been used to evaluate the articular cartilage of the knee joint. These sequences utilize flip angle modulation to constrain T2 decay over an extended echo train which allows intermediate-weighted images of the knee joint with isotropic resolution to be acquired with minimal blurring. Three-dimensional FSE sequences typically use frequency selective fat-saturation to suppress signal from adipose tissue (1, 2). However, FSE-Cube has recently been combined with IDEAL fat-water separation to provide more robust fat-suppression in areas of magnetic field inhomogeneity (3). FSE-Cube and SPACE have lower in-plane spatial resolution and greater image blurring when compared to other three-dimensional cartilage imaging sequences with similar acquisition times which may decrease the conspicuity of superficial cartilage lesions (4, 5). However, these sequences provide excellent visualization of high contrast structures such as small cartilage fissures surrounded by joint fluid (6).

Multiple previous studies have compared image quality of three-dimensional FSE sequences with other cartilage imaging sequences for evaluating the knee joint at 3.0T. Friedrich and associates compared water excitation FLASH, water excitation true-FISP, water excitation DESS, and fat-saturated intermediate-weighted SPACE sequences in 10 asymptomatic volunteers and found that water-excitation DESS had the highest contrast-to-noise ratio (CNR) between cartilage and synovial fluid and the greatest overall performance on qualitative cartilage assessment (4). In a study comparing fat-saturated intermediate-weighted FSE-Cube, IDEAL-SPGR, IDEAL-GRASS, multi-echo in steady-state acquisition (MENSA), coherent oscillatory state acquisition for manipulation of image contrast (COSMIC), and VIPR-SSFP sequences in 5 asymptomatic volunteers and 5 patients with osteoarthritis, Chen and associates found that FSE-Cube had the highest cartilage SNR, highest CNR between cartilage and synovial fluid, and top rank for cartilage lesion conspicuity (5). Only one previous study has compared three-dimensional FSE sequences with other cartilage imaging sequences for detecting surgically confirmed cartilage lesions within the knee joint. In this study, Kijowski and associated found that fat-saturated intermediate-weighted FSE-Cube had similar sensitivity and specificity as two-dimensional fat-saturated FSE sequences for detecting cartilage lesions in 100 patients with surgical correlation at 3.0T (7). Additional studies are needed to determine whether three-dimensional FSE sequences have superior diagnostic performance than other two-dimensional and three-dimensional sequences for evaluating the articular cartilage of the knee joint.

### Comprehensive Joint Assessment

Three-dimensional isotropic resolution FSE sequences have also been used to provide comprehensive knee joint assessment. These sequences produce images with intermediate-weighted contrast which is the most versatile and commonly utilized tissue contrast in musculoskeletal MR imaging (8-12). Multiple studies with surgical correlation have compared the diagnostic performance of two dimensional and three-dimensional intermediate-weighted FSE sequences for evaluating the knee joint at 3.0T. Kijowski and associated found that fat-saturated FSE-Cube had similar sensitivity and specificity as two-dimensional FSE sequences for detecting cartilage lesions, cruciate and collateral ligament tears, meniscal tears, and bone marrow edema lesions in 100 patients with surgical correlation (7). Jung and associates also found no significant difference between a three-dimensional isotropic resolution FSE sequence and two-dimensional FSE sequences in the sensitivity and specificity for detecting surgically confirmed cruciate ligament and meniscal tears in 85 patients (13). Additional studies performed by Notohamiprodjo and associates on 18 patients with surgical correlation (2) and by Subhas and associates on 100 patients with surgical correlation (14) found that fat-saturated SPACE sequences had similar diagnostic performance as two-dimensional FSE sequences for detecting cartilage lesions, cruciate and collateral ligament tears, and meniscal tears.

Preliminary studies on the use of three-dimensional isotropic resolution FSE sequences for providing comprehensive knee joint assessment are promising. However, Ristow and associates performed a detailed subjective comparison of a fat-saturated intermediate-weighted FSE-Cube sequence and two-dimensional FSE sequences in 50 patients at 3.0T and described potential limitations of using FSE-Cube for evaluating the knee joint. In this study, FSE-Cube was found to have significantly lower image quality when compared to the two-dimensional sequences with a greater degree of blurring and indistinctness of structural edge which may limit the detection of low contrast structures such as meniscal tears and bone marrow edema lesions (6). In a study involving 250 patients with surgical correlation, Kijowski and associates found that a fat-saturated intermediate-weighted FSE-Cube sequence had similar sensitivity and specificity for detecting medial meniscal tears and similar specificity

for detecting lateral meniscal tears at 3.0T when compared to two-dimensional FSE sequences. However, FSE-Cube had significantly lower sensitivity for detecting lateral meniscal tears which was mainly attributed to its decreased ability to detect tears of the posterior root of the lateral meniscus (15). At the current time, there is strong evidence to suggest that three-dimensional isotropic resolution FSE sequences can be used to provide rapid comprehensive knee joint assessment in patients with severe pain or claustrophobia who cannot tolerate a long MR examination. However, the slight reduction in image quality of three-dimensional FSE sequences may limit the detection of subtle joint pathology. Additional large clinical studies are needed before three-dimensional isotropic resolution FSE sequences can replace two-dimensional FSE sequences in clinical practice.

### Three-Dimensional Ankle Joint Imaging

There has been recent interest in using three-dimensional FSE sequences for providing rapid comprehensive ankle joint assessment. Yao and associates described the use of a three-dimensional isotropic resolution Fourier transform FSE sequence with intermediate-weighted contrast for evaluating the ankle joint at 3.0T (16). The authors emphasized the unique advantage of the three-dimensional isotropic resolution sequence was its ability to create high quality reformat images in arbitrary planes tailored to specific anatomic regions of interest. In addition, Stevens and associates compared intermediate-weighted FSE-Cube and two dimensional FSE sequences for evaluating the ankle joint in 10 healthy volunteers at 3.0T and found that FSE-Cube had significantly higher SNR efficiency of cartilage, synovial fluid, and muscle. Image blurring was noted to be significantly greater for FSE-Cube, but there was no significant difference between the two-dimensional and three-dimensional sequences in the degree of artifact or overall image quality (17). No previous study has compared three-dimensional FSE sequences with currently used two-dimensional sequences for evaluating the cartilage, ligaments, tendons, and osseous structures of the ankle joint. For this reason, it is unknown whether the thin, continuous slices of the three-dimensional sequences and their ability to view complex anatomy in oblique and curved planes can improve the detection of ankle joint pathology.

### Three-Dimensional Shoulder Joint Imaging

There has been much recent interest in using three-dimensional FSE sequences to decrease the time required to evaluate the shoulder joint during MR arthrography. Multiple studies with surgical correlation have compared three-dimensional isotropic resolution FSE sequences with currently used multi-planar two-dimensional fat-saturated T1-weighted FSE sequences for detecting shoulder joint pathology during MR arthrography. Rybak and associates compared a fat-saturated intermediate-weighted SPACE sequence with two-dimensional FSE sequences for evaluating the shoulder joint during MR arthrography in 28 patients at 1.5T and found that the three-dimensional sequence provided significantly better visualization of the biceps tendon anchor, subscapularis tendon insertion, and articular cartilage and equivalent visualization of other joint structures. SPACE was also found to have similar sensitivity but significantly lower specificity than the two-dimensional FSE-sequences for detecting cartilage lesions, rotator cuff tears, and labral tears in the 11 patients with surgical correlation (18). In addition, Jung and associates found that a fat-saturated intermediate-weighted SPACE sequence had similar diagnostic performance as two-dimensional FSE sequences during MR arthrography at 3.0T for detecting surgically confirmed rotator cuff tears in 87 patients. However, SPACE was found to have

significantly lower accuracy than the two-dimensional FSE sequences for predicting the exact depth and location of the rotator cuff tears (19).

Three-dimensional FSE sequences have also been used to evaluate the shoulder joint during non-contrast MR imaging. However, these sequences have been used much less extensively during non-contrast MR imaging than during MR arthrography with only one study reported thus far in the literature. Hill and associates compared a fat-saturated T2-weighted FSE-Cube sequence and multi-planar two-dimensional fat-saturated T2-weighted FSE sequences for evaluating the shoulder joint in 19 patients at 3.0T and found that the sequences had fair to good agreement and similar confidence level for grading the rotator cuff tendon. The authors also described the use of a novel reformat plane called the radial oblique coronal plane in which thin continuous images perpendicular to each portion of the rotator cuff tendon could be obtained from the FSE-Cube source data. The authors postulated that the curved oblique reformat images could reduce the effects of partial volume averaging which would be particularly helpful for identifying tears within the far anterior portion of the rotator cuff tendon (20). There are many potential benefits of using three-dimensional isotropic resolution sequences for evaluating the shoulder joint including their ability to produce thin continuous images in any orientation following a single acquisition. However, no previous studies with surgical correlation have compared three-dimensional isotropic resolution sequences and currently used two-dimensional FSE sequences for detecting shoulder joint pathology during non-contrast MR imaging.

#### Three-Dimensional Elbow Joint Imaging

A recent study has investigated the use of three-dimensional FSE sequences for evaluating the elbow joint. Shapiro and associates compared fat-saturated intermediate-weighted FSE-Cube and two-dimensional FSE sequences for evaluating the elbow joint in 10 asymptomatic volunteers at 3.0T. FSE-Cube was found to have significantly higher synovial fluid SNR and significantly higher CNR between cartilage and synovial fluid than the two-dimensional sequence but had slightly worse overall image quality and greater blurring on subjective analysis. (21). Three-dimensional FSE sequences produce high quality multi-planar reformat images which allow the complex anatomy of the elbow joint to be evaluated in any orientation following a single acquisition. However, additional studies are needed to determine whether the improved visualization of elbow joint anatomy can lead to better detection of elbow joint pathology.

#### Three-Dimensional Wrist Joint Imaging

Three-dimensional sequences produce images with thinner slices and higher in-plane resolution than two-dimensional sequences and thus appear better suited for assessing the thin articular cartilage and small ligaments and fibrocartilage structures of the wrist joint. However, few previous studies have directly compared various two-dimensional and three-dimensional sequences for detecting wrist joint pathology. Meier and associates compared two-dimensional fat-saturated intermediate-weighted and T2-weighted FSE sequences, a fat-saturated intermediate-weighted FSE-Cube sequence, a three-dimensional fat-saturated ultra-fast gradient-echo (FGRE) sequence, and a three-dimensional fat-saturated multiple echo recombined gradient-echo (MERGE) sequence for evaluating articular cartilage in 5 cadaveric wrist joints at both 1.5T and 3.0T. The FGRE sequence acquired at 3.0T was found to be best imaging technique and had the highest cartilage SNR, highest CNR between cartilage and bone, and highest diagnostic performance for detecting surgically confirmed cartilage lesions. The anisotropic

resolution FGRE sequence had higher in-plane spatial resolution and decreased image blurring when compare to the isotropic resolution FSE-Cube sequence which provided better detection of subtle cartilage lesions within the wrist joint (22).

Only one study has investigated the use of three-dimensional FSE sequences for evaluating the wrist joint. Stevens and associates compared fat-saturated intermediate-weighted FSE-Cube and two-dimensional FSE sequences for evaluating the wrist joint during non-contrast MR imaging in 10 asymptomatic volunteers at 1.5T. FSE-Cube was found to have similar cartilage and synovial fluid SNR and similar CNR between cartilage and adjacent joint structures as the two-dimensional sequences. While the coronal FSE-Cube source images had significantly better overall image quality on subjective analysis than the two-dimensional FSE images, the axial FSE-Cube reformat images were degraded by blurring due to T2 decay over the extended echo train (23). The use of three-dimensional FSE sequences could decrease the time required to evaluate the wrist joint by eliminating the need to repeat sequences with identical tissue contrast in multiple planes. An additional advantage of these sequences is their ability to create high quality oblique reformat images through the carpal ligaments and triangular fibrocartilage complex which may improve the detection of subtle tears. Additional studies are needed to document the clinical benefits of using three-dimensional isotropic resolution sequences for evaluating the wrist joint.

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