Improving Isotropic 3D FSE Methods for Imaging the Knee

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INTRODUCTION: Musculoskeletal MR imaging of the knee, especially for cartilage evaluation, requires high spatial resolution [1]. While two-dimensional fast-spin-echo (2D-FSE) at 3T is becoming increasingly common for imaging meniscal, ligamental and cartilage injury, 2D techniques are limited by anisotropic voxel dimensions, blurring from T2 decay and magnetization transfer from slice selection pulses [2-4]. Recently a 3D isotropic FSE sequence featuring an extended echo train using refocusing flip angle modulation (3D-FSE-Cube) was developed to address the limitations of 2D imaging [5,6]. In this study a 3D-FSE-Cube was optimized for musculoskeletal evaluation of the knee at 3T.

METHODS: The right knees of 8 healthy volunteers (mean age 26 yrs, range 21–32 yrs) were imaged using a GE Signa 3T MRI scanner (GE Healthcare, Waukesha, WI) and an 8-channel transmit-receive knee coil (Invivo Inc., Gainesville, FL). All scans were sagittal proton-density 3D-FSE-Cube acquisitions with fat saturation and the following acquisition parameters: 35ms TE_{eff}, 256x256 matrix, 16cm FOV, 180 slices at 0.6mm slice thickness and scan times ranging from 4m42s to 5m11s. One subject received a single scan, to be used as a standard quality reference, with TR 2750, BW ±83.33kHz, ETL 90, NEX 1 and autocalibrated parallel imaging acceleration factor of 3.75. The remaining 7 subjects each received 20–22 3D-FSE-Cube sequences with different TR, BW, ETL, NEX and acceleration factor combinations for a total of 146 scans. Imaging parameter ranges used were TR 1000–5750ms, BW ±31.25–125kHz, ETL 45–120, NEX 0.5–2 and acceleration factor 1–3.75. The resulting images were scored by two fellowship-trained musculoskeletal radiologists for overall image quality with respect to the reference scan. On all images, signal was measured in volumes of interest in muscle, cartilage and synovial fluid . Noise was measured via noise-only images acquired with RF excitation disabled and reconstructed using a processing pipeline identically to signal data with the exception of signal-dependent steps such as parallel imaging calibration, partial Fourier homodyne phase correction and multiple coil image combination. Signal-to-noise ratio (SNR) in all tissues was calculated, and contrast-to-noise ratios (CNR) were calculated for fluid and cartilage. To assess the effects of acquisition parameters on image quality, SNR and CNR, separate regressions of (a) overall image quality ratings and (b) SNR and CNR on TR, ETL, acceleration factor, NEX, and bandwidth were performed, with additional quadratic predictors for nonlinearity (ETL^2 and $acceleration^2$). Statistical analysis was performed using Stata Release 9.2 (StataCorp LP, College Station, TX).

RESULTS: At a bandwidth of ±83.33kHz, the maximum rated image quality occurred near the reference scan parameter combination of TR 2750ms, ETL 90, NEX 1 and acceleration factor of 3.75, which is similar to current clinical practice (see Figure 1). Image quality dropped off sharply as scan parameters moved away from this combination in any direction ($p<.001$; Figure 2). A similar pattern was found for varying bandwidths with the quality of the standard setting combination higher at bandwidth ±31.25kHz and lower at bandwidth ±125kHz ($p<.001$). Thus, for a constant scan time, decreasing the bandwidth appears preferable to changing alternative parameters. Parameter combination effects on SNR and CNR also followed predictable trends based on acquisition parameters of TR, NEX, parallel imaging and bandwidth, with the highest average tissue SNR measured at TR 3500ms, ETL 120, NEX 0.5, and an acceleration factor of 1.94 at ±31.25kHz bandwidth.

CONCLUSION: This study used a systematic approach to optimize the many imaging parameters in 3D-FSE-Cube. For a constant scan time, decreasing the bandwidth appears preferable to altering alternative acquisition parameters. Highest image quality ratings were achieved with long TR, full k-space sampling and longer echo trains. As a result of this study, imaging parameters can be optimized for high-quality isotropic acquisitions, which will improve future studies of 3D-FSE-Cube in symptomatic patient populations.

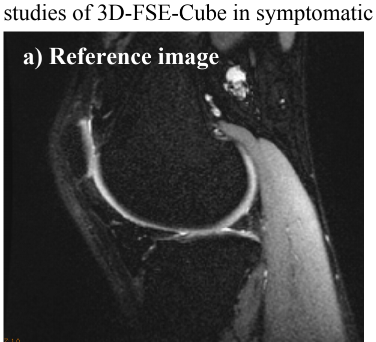
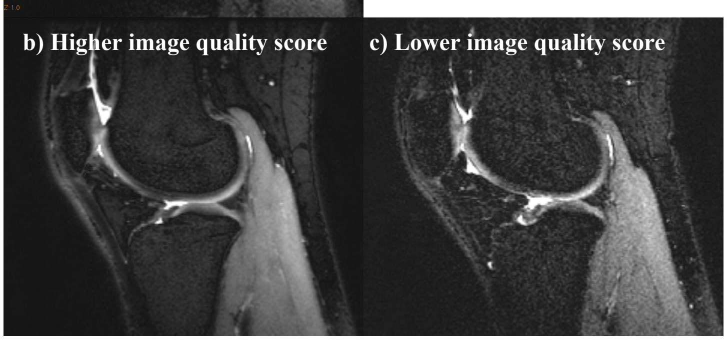


Figure 1. Example 3D-FSE-Cube acquisitions: (a) reference image, (b) image scored with higher overall quality (TR 3250ms, BW ±31.25kHz, ETL 105, NEX 1, acceleration 3.75), (c) image scored with lower overall quality (TR 4250ms, BW ±125kHz, ETL 75, NEX 0.5, acceleration 3.65).



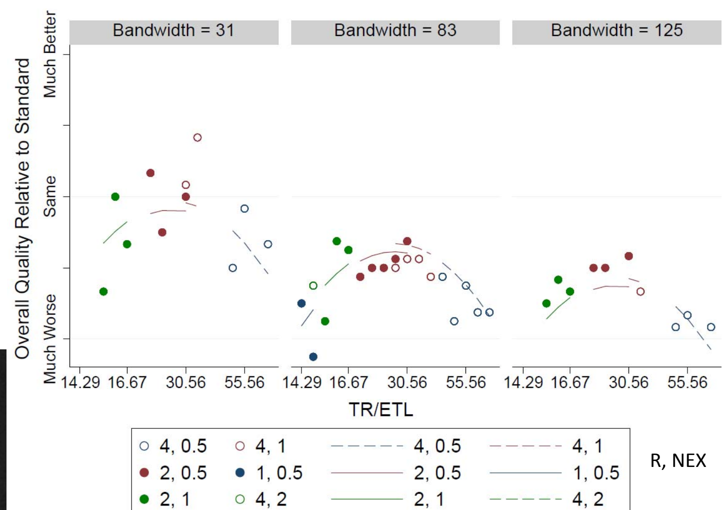


Figure 2. Image quality scores (points) and regression results (curves) organized by bandwidth. TR/ETL ratio is shown along the x-axis, and parallel imaging factor (R =1, 2, or 4) and NEX (2, 1 or 0.5) combinations are shown in the figure legend. Quality drops off as parameters are adjusted away from the reference scan parameter combination and as bandwidth is increased.

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