

# Flexible and Efficient Data Acquisition Technique for 3D-FSE-IDEAL

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**Introduction:** In FSE-IDEAL, the three echoes required for fat-water separation are commonly acquired in separate repetitions (1). This increases the total scan time, especially for a 3D acquisition. Recent methods acquired multiple gradient echoes within a repetition to reduce total scan time. Li et. al. (2) acquired four echoes in a single repetition using “bipolar” readout gradients, however, this requires additional phase

correction and limits the spatial resolution, if optimal echo times are desired. Similarly, Madhuranthakam et. al. (3) acquired four echoes in two repetitions using “unipolar” readout gradients, however, this utilized the “ideal”  $2\pi/3$  echo spacing (4) and was similarly limited in the achievable spatial resolution. It was previously shown for a gradient-echo  $T_1$ -weighted acquisition that the “ideal”  $2\pi/3$  gradient echo spacing is not required to maximize SNR for all combinations of fat and water when greater than three IDEAL echoes are acquired (5). In this work, we hypothesize that the increased flexibility in echo spacing afforded by a 4<sup>th</sup> echo can be combined with the previously proposed approach of acquiring two unipolar echoes per TR (hereafter, 2-echoes/TR), to achieve higher SNR in reduced scan times compared to a 3-echo approach with one echo acquired per TR (hereafter, 1-echo/TR). NSA values are determined using phantom experiments and in vivo results are demonstrated in 3D-FSE-IDEAL breast and knee applications.

**Methods:** Number of signal average (NSA) plots were generated for both 3-echo and 4-echo FSE-IDEAL using multi-peak approach (MP) (fig. 1). The plotted values represent the minimum NSA for all combinations of fat and water as a function of gradient echo spacing ( $\Delta TE$ ) and first echo time ( $TE_1$ ). With 4-echo FSE-IDEAL, instead of choosing the ( $TE_1$ ,  $\Delta TE$ ) to yield maximum NSA, we chose to acquire 2-echoes/TR with  $TE$ s selected to be symmetric on either side of the spin echo. This minimizes the increase in RF echo spacing while providing an improvement in the achievable spatial resolution. The selected ( $TE_1$ ,  $\Delta TE$ ) are shown in fig. 1b (black line). The NSA acquired with 4-echo FSE-IDEAL with any of these combinations is at least 3.2, which is greater than the maximum NSA of 3, achieved using a 3-echo FSE-IDEAL.

The flexible gradient echo spacings (black line in Fig. 1b) are longer than the “ideal”  $2\pi/3$  echo shifts, and hence increase the RF echo spacing. If one uses the same echo train length (ETL) as 3-echo FSE-IDEAL, then this would lead to increased  $T_2$  blurring. Instead, we reduce the ETL to maintain a fixed data acquisition window. Although, this increases the total number of repetitions compared to the  $2\pi/3$ , 1-echo/TR implementation, the total scan time is still reduced because only 2 TRs are required for 2-echoes/TR approach as opposed to 3 TRs with 1-echo/TR approach (Fig. 2).

A fat/water phantom was scanned twice at 1.5T with 4-echo 3D-FSE-IDEAL using 2-echoes/TR to allow NSA measurements with varying  $\Delta TE$ s ( $2\pi/3$ ,  $0.75\pi$ ,  $0.85\pi$ ,  $0.95\pi$ , and  $1.05\pi$ ) and symmetric acquisitions as described above. It was also repeated with a 1-echo/TR approach and 3-echoes using a ( $-\pi/6$ ,  $2\pi/3$ ) combination. The signals and noise from the phantom images were measured and NSA calculated using the equation on the right. 3-echo 3D-FSE-IDEAL, with 1-echo/TR and the corresponding 4-echo 3D-FSE-IDEAL with 2-echoes/TR for the same acquisition parameters were used to acquire 3D  $T_2$ -weighted breast and knee images with uniform water and fat separation at 1.5T.

**Results:** The scan times for 4-echo phantom studies using 2-echoes/TR, varied from 3:19 to 4:39 minutes, compared to 5:35 minutes with 1-echo/TR approach using 3-echoes (Fig. 2). All different combinations of ( $TE_1$ ,  $\Delta TE$ ) provided uniform fat-water separation. The experimental NSA measurements with 4-echoes were between 3.6 and 4.0 while it was 2.92 with 3-echoes (in agreement with theoretical NSA). The water-only breast images acquired in the axial orientation and reconstructed with MP-IDEAL are shown in different orientations in fig. 3. The 4-echo images using 2-echoes/TR were acquired in 5:19 minutes, while the 3-echo images using 1-echo/TR were acquired in 8:17 minutes. Similarly, sagittal knee images are shown in fig. 4, where the 4-echo (2-echoes/TR) acquisition took 5:47 minutes while the 3-echo (1-echo/TR) acquisition took 8:05 minutes.

**Discussion:** The flexibility provided by the 4-echo 3D-FSE-IDEAL with 2-echoes/TR yields increased SNR and greater flexibility in spatial resolution in shorter scan times. This is particularly important at 3.0T field strength, where the increased fat-water frequency makes it challenging to acquire multiple echoes in a repetition. This flexibility makes it possible to acquire volumetric  $T_2$ -weighted images with uniform fat suppression in clinically feasible scan times.

**Reference:** 1) Reeder et. al. MRM 54: 636-644 (2005); 2) Li et. al. MRM 57: 1047-1057 (2007); 3) Madhuranthakam et. al. ISMRM 17: 4131 (2009); 4) Pineda et. al. MRM 54: 625-635 (2005); 5) Yu et. al. ISMRM 15: p. 3358 (2007)

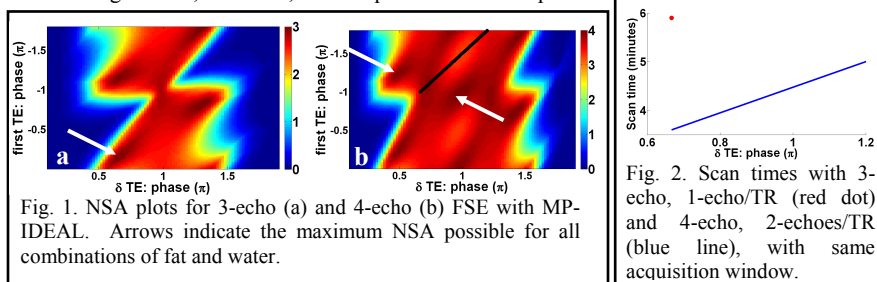


Fig. 1. NSA plots for 3-echo (a) and 4-echo (b) FSE with MP-IDEAL. Arrows indicate the maximum NSA possible for all combinations of fat and water.

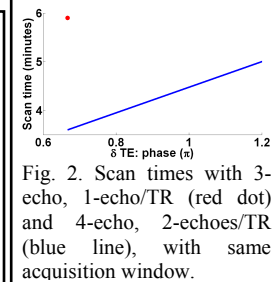


Fig. 2. Scan times with 3-echo, 1-echo/TR (red dot) and 4-echo, 2-echoes/TR (blue line), with same acquisition window.

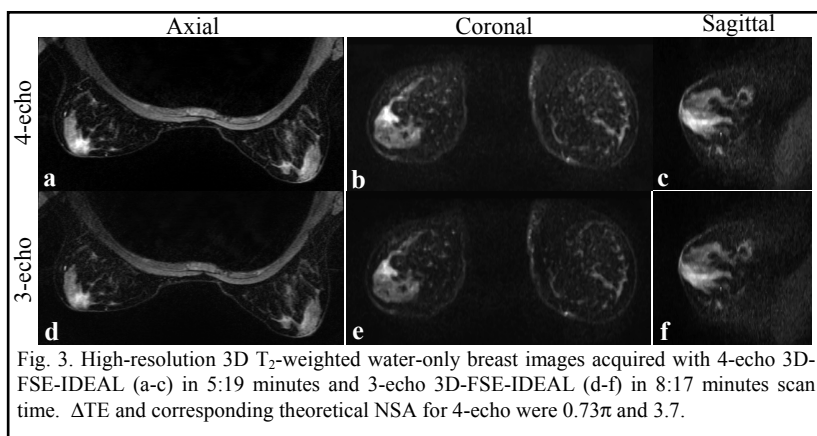


Fig. 3. High-resolution 3D  $T_2$ -weighted water-only breast images acquired with 4-echo 3D-FSE-IDEAL (a-c) in 5:19 minutes and 3-echo 3D-FSE-IDEAL (d-f) in 8:17 minutes scan time.  $\Delta TE$  and corresponding theoretical NSA for 4-echo were  $0.73\pi$  and 3.7.

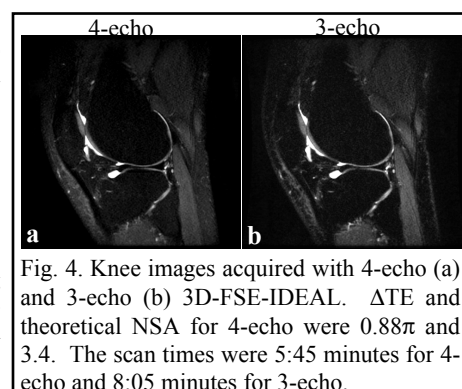


Fig. 4. Knee images acquired with 4-echo (a) and 3-echo (b) 3D-FSE-IDEAL.  $\Delta TE$  and theoretical NSA for 4-echo were  $0.88\pi$  and 3.4. The scan times were 5:45 minutes for 4-echo and 8:05 minutes for 3-echo.