# Asymmetric Echoes for Robust Fast Spin-Echo "Dixon" Water-Fat Separation

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**Introduction:** Fast spin-echo (FSE) imaging is used routinely for musculoskeletal, abdominal and neurological imaging. Unfortunately, fat is bright with FSE and may obscure underlying pathology, so spectrally selective fat-saturation pulses are routinely used to suppress fat signal. Non-uniform fat-saturation is often encountered because of $B_o$ and $B_1$ inhomogeneities. "Dixon" imaging is a water-fat decomposition method that has gained popularity in combination with FSE, owing to its uniform fat-suppression and high signal to noise ratio (SNR) performance (1-4). Conventional Dixon methods acquire three echoes that are centered symmetrically about the spin-echo, and have shown excellent promise for the uniform separation of water from fat. In some images, however, close examination shows structured noise artifacts in tissues containing both water and fat, as well as irregular water/fat interfaces.

We have recently shown that the noise performance of water-fat decomposition from symmetric acquisitions deteriorates when water and fat within a voxel are found in equal amounts (5). Such voxels commonly occur along water/fat interfaces as a result of partial volume effects and chemical shift in the readout direction. Water and fat may also coexist in approximately equal amounts in normal or abnormal tissue such as fatty liver. FSE-Dixon techniques with echoes symmetrically centered about the spin-echo may lead to erroneous estimates of water and fat in these voxels. We now demonstrate theoretically and with *in vivo* images that asymmetrically acquired echoes will decompose water from fat in all proportions, preventing artifacts that degrade noise performance in locations where water and fat are equal.

**Theory:** In our previous analysis, we showed that decomposition of water and fat from symmetrically acquired echoes depends on the relative proportion of water/fat, *independent* of the echo spacing. However, the judicious choice of echo times with asymmetrically acquired echoes can improve stability of estimation methods at all proportions of water/fat. Fig. 1 plots the effective number of signal averages (NSA), a useful measure of noise performance for Dixon imaging (6,4), as a function of the echo shift (for 1.5T) with respect to the spin-echo for the first image ($TE_1$) and the third image ($TE_3$), when (a) water>>fat, and (b) water=fat. The second image ($TE_2$) is acquired at the spin-echo ($TE_2$=0). From Fig. 1b, it can be appreciated that there are many possible solutions that will provide estimates of water and fat with good SNR performance, and many combinations where decomposition performance will be poor. Symmetric echoes ($|TE_1|=|TE_3|$) lie along the dashed lines.

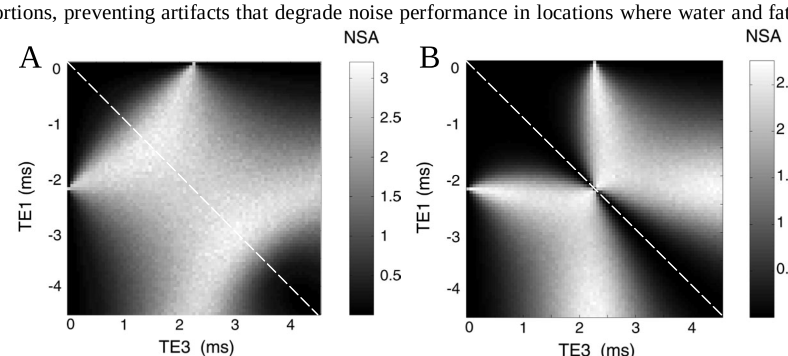


**Figure 1**: Effective number of signal averages plotted against phase shift from first echo ($TE_1$) and third echo ($TE_3$) assuming the central echo occurs at the spin-echo and (a) water:fat=1:0, and (b) water:fat=1. The dashed lines represent symmetric echoes.

**Methods:** Whole knee image acquisition was performed at 1.5T (Signa TwinSpeed, GEMS, Milwaukee, WI) in two healthy male volunteers (30, 36yo) with approval of our IRB and informed consent. We used a modified T2W FSE pulse sequence to acquire three images with different echo shifts. For a three-point symmetric acquisition, we used echo times of –1.2ms, 0, and 1.2ms at 1.5T. These echo times are slightly shorter than those that maximize SNR performance (-1.5ms, 0, 1.5ms) and reduce the minimum time between refocusing pulses (echo spacing) with minimal SNR penalty for pixels containing only water or fat (Fig. 1a, (4)). Based on Fig. 1b, asymmetric echo times of -1.8ms, 0, and 2.5ms, were chosen. Fat-saturated T2-weighted FSE images were acquired for comparison. The same echo spacing was used for all imaging (15.6ms) for direct comparison.

Imaging parameters for all sequences included: 25 sagittal images, TR=5s, BW=±31kHz, FOV=16cm, slice=2.5mm, 0.5mm gap, $N_x$=512, $N_y$=256, echo train length=10, effective echo time ($TE_{eff}$) was 45.7ms and total scan time 5:05min. Three signal averages (NSA) were used for the FS-FSE technique to maintain constant scan time. Both sets of Dixon images were reconstructed on-line, based on the iterative least-squares algorithm, which easily accommodates arbitrary echo times (4).

**Results:** Overall, image quality for both symmetrical (Fig. 1a) and asymmetrical (Fig. 1b) acquisitions was excellent, especially when compared with fat-saturated FSE (Fig. 1c), which demonstrates areas of poor saturation anteriorly, and attenuation of water signal posteriorly. Closer inspection of these images (Figs 1d-f) shows structured noise within the bone marrow and subcutaneous tissues, and irregular borders between water and fat, in the symmetric echo image. These abnormalities are markedly improved with the asymmetric acquisition, with minimal structured noise and smooth, anatomic borders between water and fat.

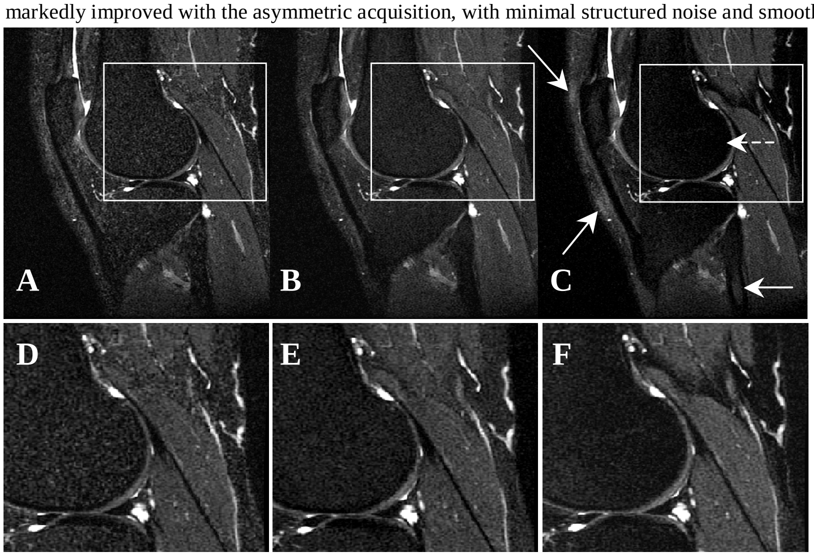


**Figure 2:** Calculated T2-weighed FSE water images for symmetric (a) and asymmetric (b) acquisitions, and FS-FSE (c) for comparison. Figs. 2d-f show magnified regions of Figs. 2a-c. Structured noise is seen in the marrow and soft tissue of the symmetric echo, and irregular interfaces between muscle and fat are best seen in (d). Failure of fat saturation is seen in the FS-FSE image (arrows), as well as shading within the posterior aspect of the lateral femoral condyle (dashed arrow).

**Discussion:** In this work we present a new asymmetric echo acquisition scheme for FSE "Dixon" water-fat separation, that improves noise performance of water-fat decomposition in voxels where water and fat are found in equal proportions. By acquiring echoes asymmetrically about the spin-echo, interfaces between water and fat were free of artifacts, and structured noise within the bone marrow was reduced. The main disadvantage of asymmetric echoes is the longer echo spacing, which may cause some blurring in the phase encode direction. Future work will analyze different echo time combinations that maintain adequate noise performance at all proportions of water and fat, while minimizing echo spacing.

**References:**

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