# 2-in-1: Simultaneously $T_2/T_2^*$ Weighted Double Echo Fast Spin Echo Imaging

Katharina Fuchs[1], Fabian Hezel[1], Sabrina Klix[1], and Thoralf Niendorf[1,2]

[1]*Berlin Ultrahigh Field Facility (B.U.F.F.), Max-Delbrueck Center for Molecular Medicine, Berlin, Germany,* [2]*Experimental and Clinical Research Center, a cooperation of the Charité Medical Faculty and the Max-Delbrueck Center for Molecular Medicine, Berlin, Germany*

**Target audience:** This work is of interest for clinicians, clinical scientists, basic researchers and engineers interested in novel rapid acquisition schemes that are sensitive to multiple contrast mechanisms.

**Purpose:** Fast Spin Echo (FSE; RARE [1]) imaging is frequently applied in clinical practice due to its excellent contrast and speed. $T_2$ weighted FSE is commonly used for anatomical imaging, for the diagnosis of ischemic events and for the detection of edema including a broad range of neurovascular and cardiovascular applications. A modified FSE approach (displaced UFLARE, [2]) offers means to probe for blood oxygenation, microscopic susceptibility changes or iron content. $T_2$* sensitized FSE has been applied for first pass bolus perfusion imaging [3], for functional brain mapping [4] and for myocardial $T_2$* mapping [5]. An FSE approach which combines $T_2$ and $T_2$* weighting has not been reported yet. Realizing this opportunity this abstract proposes a dual contrast ($T_2/T_2$*) FSE sequence, which will be referred to *two-in-one* FSE for reasons of brevity. The applicability of two-in-one FSE is carefully examined in phantom and *in vivo* studies and benchmarked versus conventional $T_2$ and $T_2$* weighted FSE.

**Methods:** A modified FSE sequence was implemented to separate spin echoes and stimulated echoes (Fig.1). For this purpose, an unbalanced readout dephasing gradient [6] is used (Fig.1). To preserve the initial separation extra spoiling gradients [7] are applied (Fig.1) in conjunction with a reversal of the phase encoding gradient for every other phase encoding step [7]. As a result, pure spin echoes and pure stimulated echoes are acquired without mixing both. After the first refocusing pulse an evolution time $\tau$ is inserted to achieve $T_2$* weighting. It is apparent that any desired $T_2$* weighting can be introduced with $\tau$ starting from zero upwards. Hence the duration of $\tau$ can be adjusted to $T_2$* to maximize functional or tissue contrast-to-noise ratio. Since magnetization which will form the stimulated echo is stored in the longitudinal axis during this period, it is not affected by the evolution time $\tau$ and remains $T_2$ weighted. Experiments were performed on a 3.0 T whole body MR system (Magnetom Verio, Siemens Healthcare, Germany) using a 32ch head coil (Siemens) and on a 7.0 T whole body system (Magnetom, Siemens Healthcare, Germany) employing a 1chTx/24chRx head coil (Nova Medical Inc., USA). The current implementation uses: TR = 1000 ms, TE = 25 ms, echo spacing = 13 ms or 7 ms, echo train length = 8, receiver bandwidth = 130 Hz/Pixel or 651 Hz/Pixel, acquisition matrix = 1024x512, $\tau$ = 15 ms. For comparison conventional FSE ($T_2$ weighting) and displaced UFLARE ($T_2$* weighting) were applied using identical imaging parameters. Data were reconstructed offline using MATLAB (The MathWorks, Inc, USA). The algorithm halves the k-space at the center frequency, aligns both sub-data sets and performs a zero filling to obtain the original resolution. Fourier transformation performed after reshuffling of k-space data forms one image which is built of echoes originating from the primary spin echo and another image, which comprises refocused magnetization of only the primary stimulated echo. Therefore, the first image is $T_2$* weighted and the second image is $T_2$ weighted.

**Results:** To demonstrate the separation of spin echo and stimulated echo groups together with their independent weighting, two consecutive k-space lines are shown in Fig.2. For this purpose phase encoding was switched off. $T_2$ and $T_2$* weighting can be appreciated for each echo group due to the difference in the echo width. Swapping of the spin and stimulated echoes along the read-out direction for odd and even RF refocusing pulses is also shown in Fig. 2. This behavior required rearrangement of k-space lines into spin and stimulated echo sub-data sets to avoid mixing of both. Phantom images acquired with conventional FSE and two-in-one FSE are shown in Fig.3 for 3.0 T (left) and 7.0 T (middle). The $CuSO_4$ doped agarose phantom includes a water tube (arrow in Fig.3(left)) and a small capillary filled with air (arrowhead) to induce microscopic susceptibility gradients at the interfaces visible in the $T_2$* sensitized images derived from conventional FSE and from the proposed two-in-one FSE approach. *In vivo* images of the human brain derived from two-in-one FSE acquisitions at 3.0 T are depicted in Fig.3 (right) in comparison to conventional $T_2$ and $T_2$* weighted images.

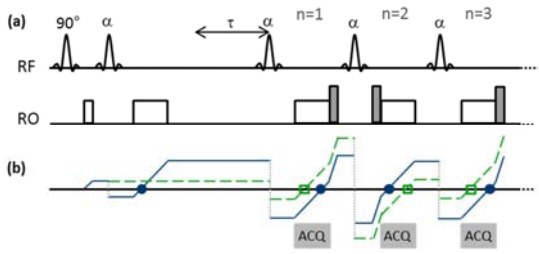


**Figure 1**: **(a)** Basic principle of the proposed two-in-one FSE, showing the radiofrequency pulses (RF) and the readout scheme (RO). An evolution time $\tau$ is inserted after the first refocusing pulse. **(b)** The echo formation is shown for the spin echo (solid, blue line) and for the primary stimulated echo (dashed, green line). From the second echo spacing (ES) on two echoes occur: refocused spin echo (bold blue circle) and the refocused stimulated echo (open green square).

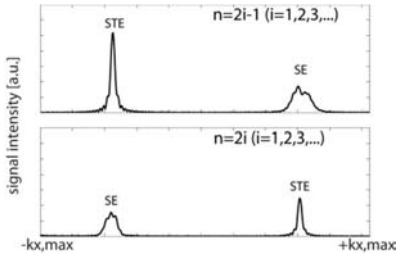


**Figure 2**: Two consecutive k-space lines (phase encoding was turned off during acquisition). The separated and differently weighted echo groups (spin echo (SE), stimulated echo (STE)) are clearly visible. Additionally, the change of position from one echo spacing to the next is demonstrated.

**Discussion:** The proposed two-in-one FSE technique affords simultaneous acquisition of images sensitive to two contrast mechanisms ($T_2$ vs. $T_2$* or proton density vs. $T_2$*). Admittedly, the off-center $k_x$-space position of the separated stimulated and spin echo introduces an insignificant $T_2$* weighting to the spin echo which can be reduced if not eliminated by shifting the spin echo towards the center of k-space. Signal attenuation of the stimulated echo due to $T_1$ relaxation during the storage in the longitudinal axis is less than 1% for $T_1 \approx 1$s and $\tau \approx 15$ms and hence can be neglected. The current implementation for off-line reconstruction of two-in-one FSE data showed residual Gibbs ringing artifacts which can be easily reduced by multiplying the data in the spatial frequency domain with a generalized Hamming filter.

**Conclusion:** Our preliminary results demonstrate the feasibility of simultaneously $T_2$ and $T_2$* weighted FSE by separating spin echoes and stimulated echoes and hence present a valuable alternative to sequential $T_2$ and $T_2$* weighted FSE acquisitions. The two-in-one FSE approach provides more information per unit time and offers a speed gain over conventional $T_2/T_2$* weighted FSE which can be put to use for simultaneous $T_2/T_2$* mapping. Two-in-one FSE holds the promise to eliminate slice mis-registration artifacts frequently encountered in sequential $T_2/T_2$* weighted acquisitions. Obviously, the proposed 90-$\alpha$-$\tau$-$\alpha$ preparation can be combined with other rapid imaging modules such as EPI, GRASE and FLASH and is compatible with non-Cartesian phase encoding. Apparently, the initial excitation pulse can be substituted by any spin preparation that provides transverse magnetization. The proposed two-in-one FSE approach is not limited to brain imaging shown here but also meets the needs of cardiac imaging including $T_2$ imaging/mapping of myocardial edema and myocardial $T_2$* mapping, as well as abdominal and liver imaging.

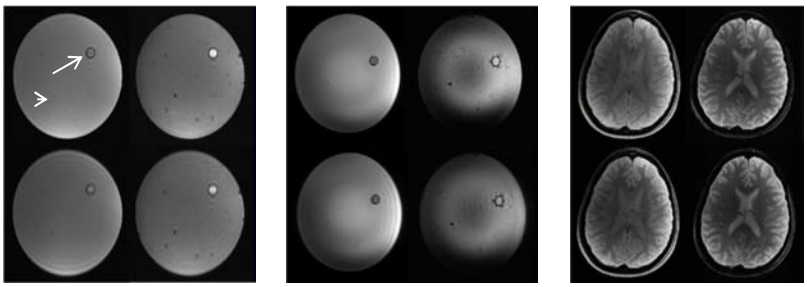

**Figure 3**: **(left)** Phantom images obtained at 3.0 T, **(middle)** phantom images measured at 7.0 T, **(right)** *in vivo* brain images of a healthy volunteer acquired at 3.0 T. For each subplot the upper row was reconstructed from a standard FSE sequence (left) and a $T_2$* weighted FSE sequence (right) using the split approach [6]. The images in the lower row are generated by the proposed two-in-one sequence, producing both contrasts within one protocol.

**References:** [1] Hennig et al, *Magn Reson Med* 1986, 3:823; [2] Norris et al, *Magn Reson Med* 1992, 27:142; [3] Norris et al, *Magn Reson Imaging* 1993, 11:921; [4] Niendorf, *Magn Reson Med* 1999, 41:1189; [5] Heinrichs et al, *Magn Reson Med* 2009, 62:822; [6] Schick, *Magn Reson Med* 1997, 38:638; [7] Norris, *Magn Reson Med* 2007, 58:643.