

Optimized 3D Fast Spin Echo imaging at 7T

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Purpose: Fast Spin Echo (FSE) imaging is increasingly used for fast T_2 weighted imaging applications. However, at 7T, the sequence is heavily limited by SAR considerations, severely reducing its time efficiency. Flip angle modulation schemes like SPACE and XETA [1-2], have been proposed for 3D FSE that enable the use of longer echo-train-lengths and help lower SAR due to reduced refocusing flip angles. We optimized the 3D XETA refocusing flip angle train for T_2 weighted brain imaging at 7T based on SAR, signal intensity, contrast and point spread function (PSF) considerations, using T_1 and T_2 values of white/grey matter at 7T. Additionally, we explored the use of composite excitation pulses to mitigate signal loss from B_1 inhomogeneity effects. Whole brain 3D T_2 -weighted imaging was performed on patients using these modifications.

Methods: The XETA refocusing flip angle train [2] depends on three critical flip angle variables - α_{\min} , α_{mid} and α_{end} which together determine the signal modulation and the resulting PSF as well as influence signal intensity, contrast and SAR. An extended phase graph (EPG) simulation was used to study the effect of these variables on the parameters of interest. The normalized echo amplitude at the center of the echo-train was used to approximate average signal intensity ($\text{Signal}_{\text{norm}}$) while the relative difference between grey and white matter signal intensity was used as a measure of contrast ($\text{Cont}_{\text{norm}}$). A weighted, normalized cost function $C = \mu \text{Cont}_{\text{norm}} + \lambda \text{Signal}_{\text{norm}} + (1-\lambda-\mu)(1-\text{SAR}_{\text{norm}})$ with $(\lambda, \mu) < 1$, was used to determine the optimal parameters at 7T with T_1 and T_2 values assumed to be 2000 and 50 ms (grey matter at 7T), respectively. From EPG simulations, the signal was found to be far less sensitive to variations in the refocusing flip angles compared to variations in the excitation flip angle, with other parameters optimized. Hence, we explored the use of B_1 insensitive composite excitation pulses to study their effect on minimizing image shading. Since whole brain imaging permits the use of non-selective pulses for excitation, we tested two different non-selective composite pulses (Garwood-Ke 90₀-180₂₂₅-90₀ and Levitt 90₀-180₁₂₀-180₁₈₀, where the subscripts refer to the phase offset) and compared it to a simple hard pulse excitation. All experiments were performed on GE HDx 7T scanner (GE Healthcare, Waukesha, WI). Patients with possible cognitive deficits/early onset Alzheimer's disease were scanned after informed consent. A 3D coronal slab covering the whole brain was acquired using XETA with the following parameters- matrix 224x224x256, FOV 17 cm, 0.8 mm thick, ETL 128, TE/TR 70ms/5R-R, ARC parallel imaging 2x2 acceleration, scan time ~ 5 min. The hard pulse width was ~300us and that of the composite excitation pulses ~1.2ms. Refocusing pulses were also rectangular hard pulses of ~600us duration to minimize echo spacing. XETA was acquired with the optimized refocusing flip angle train as well as the default flip angle train with the latter having an $[\alpha_{\min} \alpha_{\text{mid}} \alpha_{\text{end}}]$ of (10°, 70°, 70°). Scans were also performed with the simple hard pulse excitation as well as with the composite excitation pulses.

Results: Figure 1 shows the normalized cost function C as a function of α_{\min} and α_{mid} yielding optimal values of (10°, 45°) for α_{\min} and α_{mid} . C was relatively insensitive to α_{end} , which was fixed at 25°. Figure 2 compares corresponding sections from a coronal whole brain 3D XETA volume acquired using the default flip angle train (a) and the optimized flip angle train (b). Note that the SAR for the optimized flip angle train XETA scan was 1/4th of the SAR recorded for the default flip angle train XETA scan (0.5 vs. 2.2 W/kg) with minimal observable difference in image quality. Figure 3 shows comparable sections from a coronal whole brain XETA volume acquired using a conventional hard pulse excitation (a) and Levitt composite excitation (b). Note the mitigation in signal loss in the inferior aspect in (b) when using the Levitt composite excitation pulse (arrows)

Discussion: XETA was optimized at 7T to yield significantly lower SAR (<0.5 W/kg vs. default >2 W/kg) with minimal impact in image quality. The use of non-selective composite excitation pulses, possible with whole-brain imaging, helped mitigate shading artifacts from B_1 inhomogeneities. Future developments include the use of parallel transmit rf excitation pulse for more uniform signal excitation.

References: [1] Mugler et al. Radiology 2000;216:891–899 [2] Busse et al. Magn Reson Med 2006;55:1030–1037

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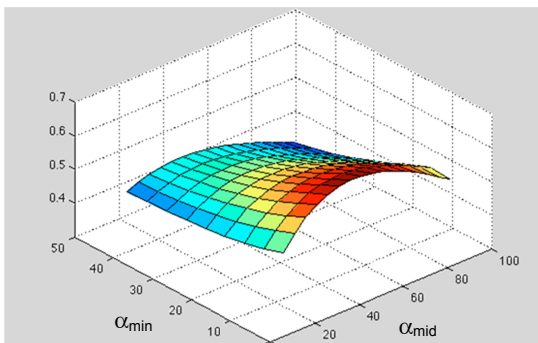


Figure 1. Normalized cost function C as a function of α_{\min} and α_{mid} yielding an optimal set of (10°, 45°) for α_{\min} and α_{mid} . The cost function takes into account signal intensity, contrast and SAR. α_{mid} was set at 25° due to its minimal effect on C.

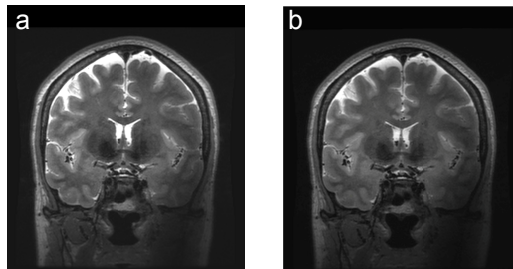


Figure 2 (top). Corresponding sections from a coronal whole brain 3D XETA volume acquired using the default flip angle train (a) and the optimized flip angle train (b). Note that SAR for the optimized flip angle train XETA scan was 1/4th of that recorded for the default flip angle train XETA scan (0.5 vs. 2.2 W/kg).

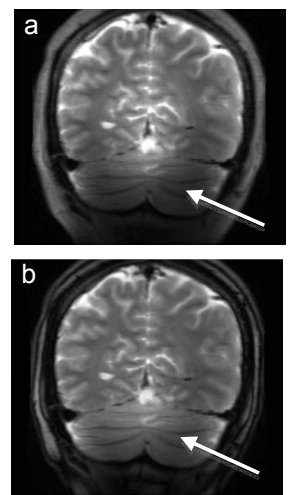


Figure 3 (top right) Section from a coronal whole brain XETA volume acquired using conventional hard pulse excitation (a) and Levitt composite pulse excitation (b). Blue arrows show mitigation of signal loss due to B_1 inhomogeneity using the composite pulse.