RF Pulse Design for High-Resolution Imaging with FLASE

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Introduction: The Fast Large Angle Spin Echo (FLASE) sequence has been used with a surface transmit coil to provide high-resolution imaging of the skin [1-3]. On most clinical scanners however, it is preferable to use the body coil for transmit. The main challenge then is to adapt the large-angle pulse to bear with peak B1 limitations, while keeping the pulse duration short. Indeed, the main components of interest, namely the epidermis and dermis, have a T2 of about 30 ms [4]. Furthermore, the overall scan time should stay sufficiently short. In this work, we show that using a non-linear-phase pulse instead of a minimum-phase pulse allows a reduction in pulse length by a factor of 3, minimizing through-slice chemical shift artifacts, while preserving the spatial selectivity.

Methods: The balanced-FLASE pulse sequence features 3D encoding, partial fractional-echo sampling and a large flip-angle excitation pulse refocused by a non-selective 180° phase-cycled pulse (Fig. 1). Projection onto Convex Sets (POCS) was used for partial-Fourier reconstruction.

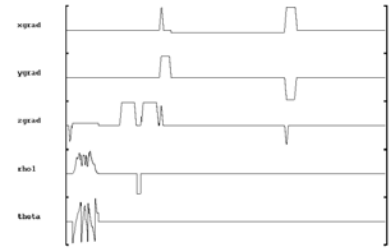

Figure 1.
Fast Large Angle Spin Echo sequence.

With flip-angle pulses greater than 90°, the challenge is to excite a well-defined slice profile. A high bandwidth is desirable to keep the unavoidable overshoot of the magnetization profile on the slice boundaries ('rabbit ears' in Fig. 2c and 2d) within a couple of slice encodes.

The encoding along the slice direction makes the phase dispersion of non-linear pulses and its induced signal loss negligible [5]. Song *et al.* [2] used a 150° Shinnar-Le Roux (SLR) minimum-phase RF pulse [6], which has the shortest isodelay, making it the ideal choice for short-T2 imaging. However, when using the body coil for transmit, peak B1 limitations make it undesirably long (Fig. 2a). We designed a minimum-peak non-linear-phase pulse by inverting pass-band roots of the minimum-phase SLR pulse, as described in [7].

All experiments were performed on a GE 1.5 T scanner with 40 mT/m maximum gradient amplitude and 150 mT/m/ms maximum slew rate. A 4-cm Doty Scientific surface coil was used as the receiver coil.

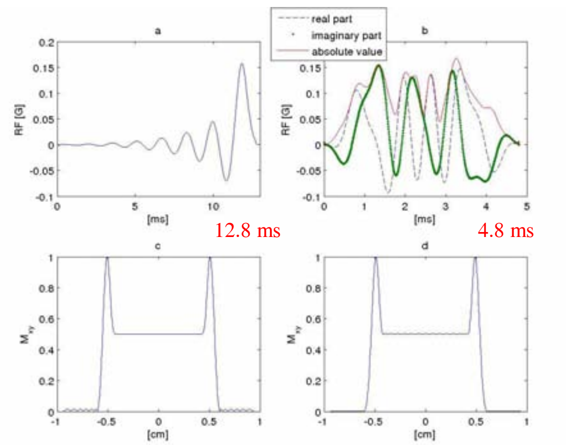

Figure 2.
Top: 12.8 ms minimum phase SLR (a) vs. 4.8 ms non-linear-phase(c). Bottom: 1.08 cm excited profiles. TBW=16, 150° flip angle for both.

Results and Discussion: A 4.8 ms pulse is achieved with 17 µT maximum B1 (Fig. 2b). It presents a profile very similar to the original one (Fig. 2c and 2d). To check that we maintained the uniform excitation achieved by the minimum-phase pulse, we imaged chicken muscle. TE and TR were kept the same for SNR comparison, but the time left by the shorter pulse could have been used to reduce TR. Chemical shift in the slab-select direction led to fat displacement of 6 slices (out of 32) with the minimum-phase pulse (1.25 kHz bandwidth) and only 2 with the non-linear-phase pulse (3.33 kHz bandwidth): the fat visible on the non-linear-phase image is gone on the minimum-phase one (arrows on Fig. 3). This effect will be more pronounced at higher field systems.

Specific absorption rate (SAR) increases from 0.35 to 0.89 W/kg, but is still well below the limit of 4 W/kg for any 15 minute-period.

At 4 kHz readout bandwidth, with 512 pixels, fat is shifted by 14 pixels. Integrating the quadratic pulse designed here into a spatial-spectral pulse would allow effective fat suppression in a reasonable amount of time, while preserving slice selectivity, which is not possible with linear spatial-spectral pulses.

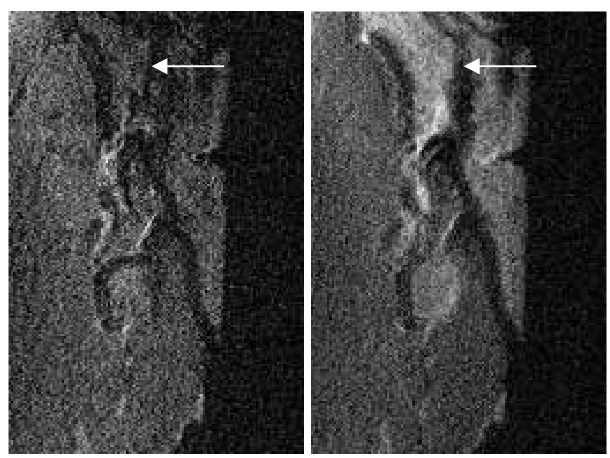

Figure 3.
*FLASE image with minimum-phase (left) and non-linear-phase (right) pulse. Reconstructed matrix size 256*256*32, slice # 26. Zoom on a 2*3 cm region. 156*156*800 µm resolution. BW 4 kHz, TE 20 ms, TR 60 ms, 8:16 scan time.*

Conclusion: We have shown that a non-linear-phase design enables shorter pulses for use in 3D FLASE sequence, without incurring an SNR penalty, and greatly reducing through-slice chemical shift artifacts. FLASE is thus a promising sequence for clinical high-resolution imaging.

References:

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