Comparison of different flip angle variation functions for improved signal behavior in SSFP sequences

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Introduction

The signal amplitude of a SSFP (steady state free precessing) sequence (such as TrueFISP, FIESTA, b-FFE) shows strong oscillations during the transient phase at the beginning of an MRI measurement. The signal oscillations from on-resonant spins can be suppressed using $\alpha/2$-preparation [1]. By using a magnetization preparation with linear increasing flip angle before data acquisition [2,5,6] also the signal oscillations from off-resonant spins can be reduced significantly. At higher B0 fields the maximum flip angle is often limited by the specific absorption rate (SAR). Therefore applications use variable flip angles during data acquisition in order to reduce RF power deposition [4,7]. Other methods like TIDE(=transition into steady state) use the flip angle dependence to modify contrast during the measurement by using variable flip angles [3]. We have performed a study to compare different strategies for initialization of the steady state with the purpose to identify the best approach to avoid initial signal fluctuations caused by off-resonance spins.

Method

In this work four different flip angle variation functions were compared concerning the signal behavior from on and off-resonant spins and effects on MR imaging:

Linear flip angle shape (**LFA**) [2,5,6]:

$$\alpha_{LFA}(n) = \frac{\alpha_{\max} - \alpha_{\min}}{m} \cdot n + \alpha_{\min}$$

Modified linear flip angle shape (**MFA**) [3]:

$$\alpha_{MFA}(n) = \frac{\alpha_{\max} - \alpha_{\min}}{m-1} \cdot (n - ½) + \alpha_{\min}$$

Gauss flip angle shape (**GFA**) [4]:

$$\alpha_{GFA}(n) = (\alpha_{\max} - \alpha_{\min}) \cdot \exp\left(-\left(\frac{n-m}{\sigma}\right)^2\right) + \alpha_{\min}$$

Sinusoidal flip angle shape (**SFA**):

$$\alpha_{SFA}(n) = ½(\alpha_{\max} - \alpha_{\min}) \cdot \left(1 - \cos\left(\frac{\pi}{m} n\right)\right) + \alpha_{\min}$$

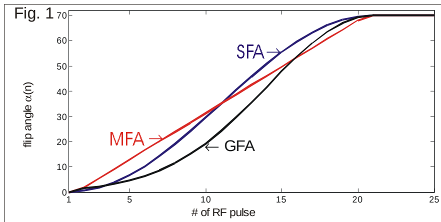

Figure 1: flip angle over the number of RF pulses running from αmin=0° to αmax=70° in m=20 steps using different functions: MFA, GFA and SFA.

The flip angles are varied between $\alpha_{\min}$ and $\alpha_{\max}$ over *m* steps. When using the GFA shape the minimal value of the additional parameter σ can be calculated from: $\sigma_{\min}$ = m/(sqrt(-log(1/($\alpha_{\max} - \alpha_{\min}$)))); higher values of σ produce leaps in the flip angle shape in the beginning, smaller values produce a hard crossover in the transition into $\alpha_{\max}$. Figure 1 shows the MFA, GFA and SFA with the parameters $\alpha_{\max}$ =70°, $\alpha_{\min}$=0°, m=20 and σ=15.

Corresponding simulations with different parameter sets for the relaxation times T_1/T_2, flip angles $\alpha_{\min}/\alpha_{\max}$ and steps m were done in Matlab (the Mathworks, Natick, USA). A standard TrueFISP sequence was expanded with the magnetization preparation using the four different variation functions. The repetition time (TR) and echo time (TE) in the sequence were equispaced for all pulses, the phase was altered with 180°. Experimental measurements with different parameter sets were done on a 1.5T system (Siemens Sympony, Siemens Medical Solutions, Erlangen, Germany).

Results

Simulations showed strong signal oscillation for LFA with few steps m (m=5..10). For higher m (m>=20) the oscillations can be minimized but not completely reduced [2]. Also GFA showed heavy oscillations if sigma was not chosen properly. With proper sigma, GFA as well as SFA and MFA showed nearly no oscillations.

Simulations were confirmed by experiments. Figure 2 shows the results of phantom experiments with different steps m (m=5, 8, 20, 32). All measurements were done without phase encoding.

LFA shows heavy oscillations for small m. For higher m (m=20, 32) even GFA shows some oscillation in the beginning, but a smooth transition into the steady state. SFA and MFA show nearly no oscillations.

Figure 3 shows a cutout of abdomen MRI taken from a healthy volunteer. LFA preparation causes some banding artifacts (white arrows) which can be reduced by the MFA preparation. Measurement parameters: TR/TE= 5.75/2.88ms, m=5, $\alpha_{\max}/\alpha_{\min}$ =70°/0°, 1.25x1.25x6mm, bandwidth 300Hz/Px). Other volunteer measurements gave similar results.

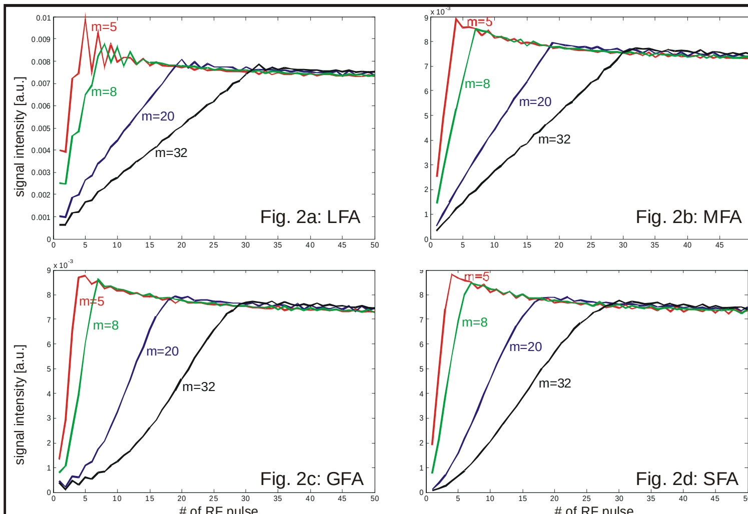

Figure 2: Experiemtally measured signals with LFA (a), MFA (b), GFA (c), and SFA (d) preparation for m=5, 20, 32.

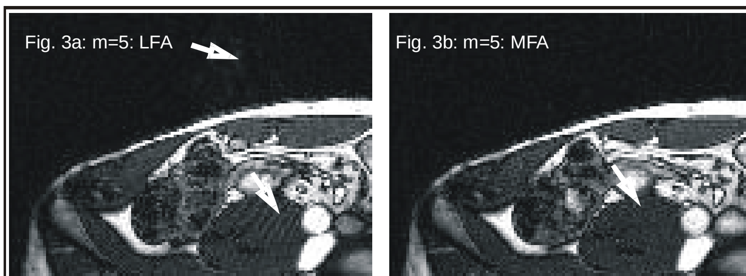

Figure 3: MR images (1.5T) of the abdomen of a healthy volunteer. Left figure: LFA preparation (m=5 steps) and right figure: MFA preparation (m=5 steps). The arrows point to the area with banding artefacts (LFA) resp. less artefacts (MFA).

Discussion

It is demonstrated, that unwanted artifacts in MR imaging can be avoided by adequate flip angle variation. For few steps m (m<10) the MFA function based on a continuous transition of the magnetization vector (3) to the steady state has proven to be optimal producing less artifacts MR image. For higher values for m (m>=10) the signal oscillation is still minimal for MFA, but artifacts from SFA and GFA functions are very low.

References

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