Let's do the Time Warp again - Slice Profile Evolution of Adiabatic Pulses at 7 Tesla

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Introduction

Adiabatic pulses are commonly used to overcome B_1 inhomogeneity which is particularly important at ultra-high magnetic fields due to standing wave effects. In slice-selective adiabatic pulses, the frequency sweep causes $B_{eff,z}$-dependent off-resonances leading to an asymmetric evolution of the slice profile. Here, we present a detailed temporal analysis of the magnetization manipulation during slice-selective adiabatic pulses by comparing measured and simulated data.

Material & Methods

The hyperbolic secant pulse [1] was selected as the most frequently used representative of the adiabatic pulse family. Three different sets of shape parameters (side-to-width parameter μ, modulation angular frequency β) and pulse duration τ [2,3] were applied at 9 different B_1 amplitudes (Table).

Slice profiles were acquired at a 7T whole body MR system (Siemens, Erlangen, Germany) using a 1-channel birdcage Tx/Rx coil. The regional adiabatic inversion was applied to a 32 mm thick slice perpendicular to readout direction of a segmented (9 k-space lines per inversion), centrically reordered FLASH sequence with minimum TE and long repetition times. The following imaging parameters were used: FOV: 192×192 mm^2, matrix: 384×384 px^2, slice thickness: 5 mm, α: 9°, TE: 3.98 ms, BW: 290 Hz/px, acq. time: 3:40 min. Inversion pulses were aborted at intervals of 100 μs to visualize the evolution of the longitudinal magnetization. By subtracting the raw data from a non-prepared scan and subsequent normalization, the inversion profiles were obtained.

shaping	τ [ms]	B_1 [μT]
μ=5.00 β=674.10 rad/s	10.24	1:3:25
μ=6.25 β=692.31 rad/s	13.00	1:3:25
μ=10.00 β=800.00 rad/s	15.00	1:3:25

Table: *Inversion pulse parameters.*

Measurements were acquired in two different spherical phantoms (oil/water) as both extremes of RF field distribution. In vivo validation was performed at a slower temporal sampling rate with regards to measurement time and volunteer comfort. The slice profiles with respective pulse parameters and phantom material properties, including relaxation, were simulated with a self-developed numerical Bloch solver in MATLAB.

Results & Discussion

All slice profiles show the evolution characteristics as predicted by the simulation (Fig 2). Inversion efficiencies and resulting slice profile widths are in good agreement with literature values [4]. Measured slice profiles show deviations from simulation data at the beginning of the pulse (Fig 3). This is most pronounced to high B_1 amplitudes and can be attributed to B_1 inhomogeneity and its impact on off-resonance behavior. At the end of all pulses, slice profiles are fully evolved and independent of RF field distributions (Fig 1,4).

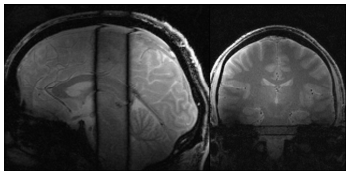

Fig 1: *Inversion slices acquired in vivo. Slice profiles are fully evolved despite B_1 inhomogeneity.*

These measurements do not find a deviation of the final slice profile from that predicted by simulations. However, it is shown that for those techniques, where the magnetization dynamics during the pulse is essential (e.g. in the SWIFT technique [4]), substantial differences might be found that need to be taken into account during image reconstruction.

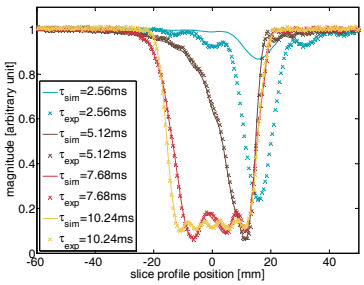

Fig 2: *Superimposed experimental and simulated slice profiles for a pulse with μ=5, β=674.10 rad/s, B_1=7 μT. The asymmetric evolution is well predictable for low B_1 amplitudes; for blue data see Fig. 2.*

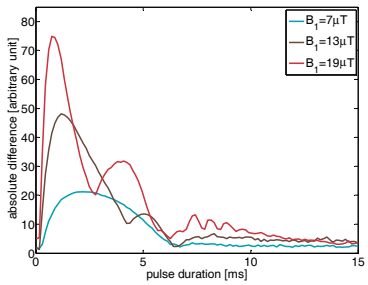

Fig 3: *Absolute difference of measurement and simulation for pulses with μ=5, β=674.10 rad/s, τ=10.24 ms. Deviations at the beginning are caused by off-resonance effects driven by varying B_1 amplitudes.*

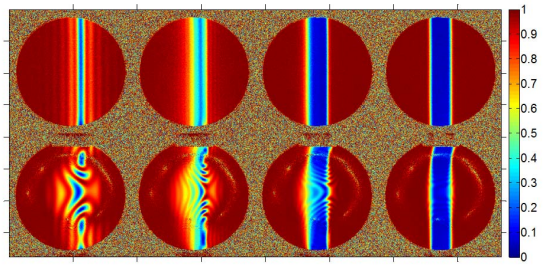

Fig 4: *Pulse with μ=5, β=674.10rad/s, B_1=13μT, τ=10.24ms in steps of quarter τ (left to right); inversion in oil (top), water (bottom) phantom. The ring artifacts at spatial positions of low B_1 amplitudes still result in a rectangular slice profile.*

References

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