Steady State BURST: Signal Amplitudes and the Influence of Gradient and RF Spoiling

C. Boller[1], K. Scheffler[1]

[1]MR-Physics, Dep. Med. Radiology, University of Basel, Basel, Switzerland

Introduction.

Since its introduction(1), clinical application of BURST imaging has been limited by its intrinsically low SNR(2). This problem stems from the fact that in a series of N low flip angle pulses only about 1/N of the magnetization is excited within one voxel and can be alleviated by using RF phase modulation techniques(3,4) which ideally increase this fraction to 1/sqrt(N). For 3D BURST variants such as URGE(5) where short TRs have to be used in the interest of scan time, steady-state effects cannot be neglected. Here, we describe the steady-state behavior of the URGE sequence and investigate on the effect of gradient and RF spoiling on the signal amplitudes in theory and practice.

Methods.

The URGE sequence(5) was implemented on a clinical 1.5T scanner. The echo magnitudes of the raw k-space signal were measured on a small (5cm diameter) water-filled sphere phantom (T1=780 ms, T2=580 ms). Parameters were:256 repetitions, 8 pulses/BURST, RF pulse spacing 1.52 ms, TR=30 ms, TE_1=1.81 ms, echo spacing 1.26 ms. The corresponding simulation was based on the extended phase graph algorithm(6) and included relaxation with timing values equal to those used in the experiment.

Results.

After a BURST excitation of eight low flip angle pulses the excited magnetization is predominately found in the first eight (zero to sevenfold dephased) states. After gradient reversal and readout of all eight echoes, the FID of the last sub-pulse is dephased by $\pm\pi/2$ in every voxel. Even if a further dephasing of $\pm\pi/2$ per voxel is induced by an additional gradient, echoes from subsequent BURST excitations will contain significant contributions from the previous one. To separate the echo pathways, a dephasing gradient of twice the magnitude of the read gradient (but opposite polarity) can be used (Fig. 1). Alternatively, the magnetization can be refocused (to the k-space position where the last echo was read out) and a dephasing gradient (of a full $\pm\pi$ per voxel) can be applied on a different axis. Other spoiling gradient moments have been evaluated and found to lead to less effective separation of echo pathways.

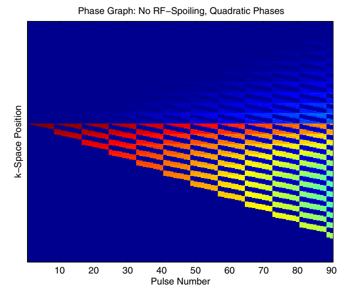

Fig. 1. Phase graph representation of the magnetization (magnitude) after a repeated 8-pulse BURST experiment with gradient spoiling as described in the text.

After a single BURST excitation the use of quadratic phase increments in between sub-pulses is known to increase the maximum signal (for which the individual echoes still are of comparable strength) from about M_0/N at 90°/N flip angle to up to M_0/sqrt(N) at 90°/sqrt(N) flip angle(3,4). In Fig. 2, the flip angle dependence of the simulated steady-state BURST echo amplitudes are shown after 200 excitation BURSTs (blue lines) and complemented with measured results (blue dots) scaled to fit the M_0=1 in the simulation (same scaling factor for all four figures).The green line represents the single pulse FISP signal magnitude. Our data shows that under steady-state conditions, the above relation still holds true if the 90° flip angle is replaced by the flip angle yielding maximum signal in the FISP sequence and M_0 by that signal magnitude (red crosses in Fig. 2). For the case of RF spoiling (quadratic phase increments in between repetitions of the BURST excitation), the same signal behavior is observed with the 90° flip angle replaced by the Ernst angle and M_0 by the maximum FLASH signal magnitude (Fig. 3).

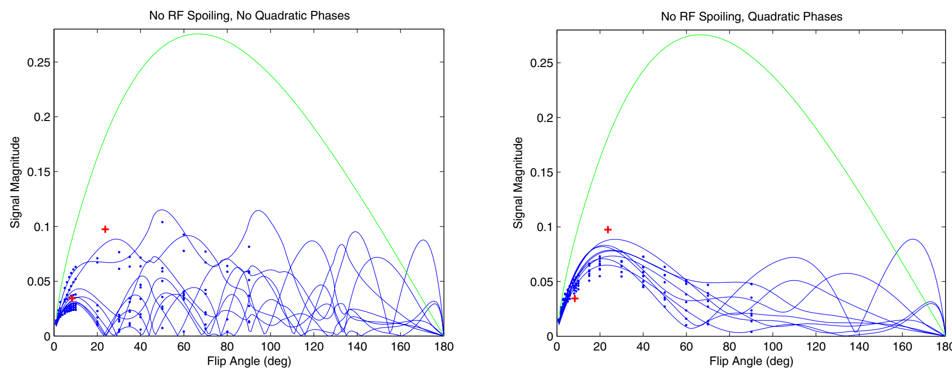

Fig. 2. Steady-state signal amplitudes vs. flip angle after 200 repetitions of an 8-pulse BURST excitation. No RF spoiling was used between BURSTs, with zero phase sub-pulses (left) and quadratic phase increment (right).

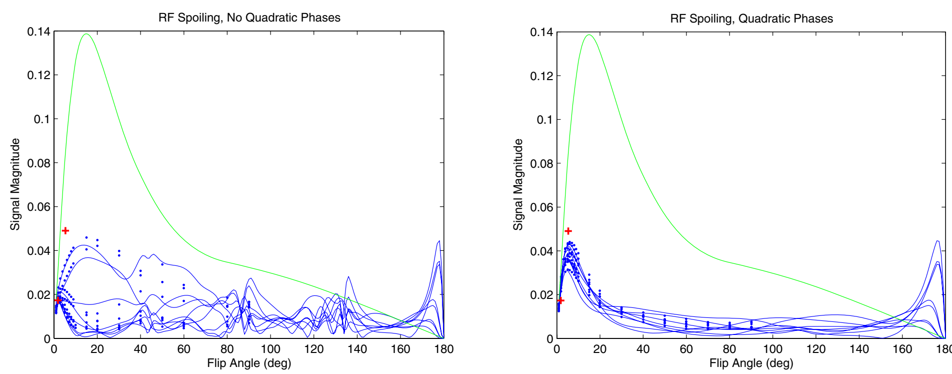

Fig. 3. As figure 2, but with RF Spoiling (quadratic phase increment between BURSTs, increment=50°). The green line indicates the single pulse FLASH signal magnitude.

Discussion.

We expect these insights to be useful for the optimization of steady-state gradient echo BURST imaging variants, for which we have demonstrated the crucial importance of suitable gradient spoiling. The usability of RF spoiled URGE sequences for applications where T1-weighted contrast is desired is subject to further investigation.

References.

1. Hennig J, Hodapp M. Burst Imaging. Magma 1993;1:39-48.
2. Doran SJ, Bourgeois ME, Leach MO. Burst imaging - Can it ever be useful in the clinic? Concepts in Magnetic Resonance Part A 2005;26A(1):11-34.
3. Heid O. BURST excitation pulses. Magn Reson Med 1997;38(4):585-590.
4. Le Roux P, Pauly J, Macovski A. Burst Excitation Pulses. 1991; San Francisco, USA. p 269.
5. Heid O, Deimling M, Huk WJ. Ultra-rapid gradient echo imaging. Magn Reson Med 1995;33(1):143-149.
6. Scheffler K. A pictorial description of steady-states in rapid magnetic resonance imaging. Concepts in Magnetic Resonance 1999;11(5):291-304.