CAIPIRINHA accelerated simultaneous multi-slice TrueFISP real-time imaging

D. Stäb[1], M. Gutberlet[1], F. Breuer[2], M. Blaimer[2], D. Hahn[1], and H. Köstler[1]

[1]Institut für Roentgendiagnostik, Universitätsklinikum Würzburg, Würzburg, Bavaria, Germany, [2]Research Center Magnetic Resonance Bavaria, Würzburg, Bavaria, Germany

Introduction:

CAIPIRINHA multi-slice imaging offers the possibility to acquire several imaging slices simultaneously while maintaining the image quality (1), allowing a high acceleration of the imaging procedure. By providing the individual slices with different RF-phase cycles, the simultaneously excited slices are shifted with respect to each other in the FOV, facilitating the separation of the overlapping slices in a post-processing step using parallel imaging reconstruction algorithms.

However, due to the constraint to keep the steady state condition, TrueFISP sequences require also a RF-phase cycle (3), rendering the implementation of CAIPIRINHA difficult. Previously presented approaches (2) utilizing a segmented acquisition in order to maintain the steady state in the individual slices are not practicable for real-time experiments or experiments with magnetization preparation.

TrueFISP sequences provide high intrinsic signal-to-noise ratio (SNR) and advantageous contrast for many imaging applications. Hence the purpose of our study was to develop a technique combining CAIPIRINHA multi-slice imaging with TrueFISP by providing steady state for each of the individual slices.

Material and methods:

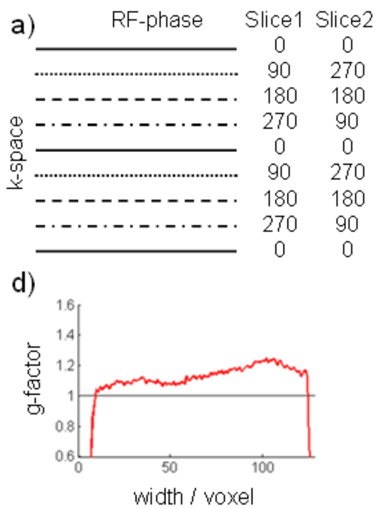
With a TrueFISP sequence using evenly spaced RF-pulses with constant flip angle, a steady state can be realized, if the phase of the m^{th} RF-pulse satisfies the condition $\Phi(m) = A + Bm + Cm^2$, with m = 0,1,2,… and A, B, C being arbitrary constants (5). For CAIPIRINHA an individual shift in the FOV is required for each simultaneously excited slice, achievable by implementing multi-slice RF-pulses, satisfying the condition $\Phi_n(m) = A + B_n \cdot m$ individually for each simultaneously excited slice n ($B_i \neq B_j$). Hence, to realize CAIPIRINHA phase cycles and to meet the steady state condition of the sequence at the same time, for each of the simultaneously excited slices individual dedicated constant phase increments Δ_n between succeeding multi-slice RF pulses were implemented.

Phantom and real-time cardiac experiments in humans were performed on a Siemens Symphony 1,5T system using an 8 channel body array for signal reception. In order to perform two-slice experiments, optimized dual-band RF-pulses were integrated into the sequence. The first of the two simultaneously excited slices employed a phase increment of $\Delta_1 = +90°$, (0°,90°,180°,270°,0°, … RF phase cycle) and the second slice $\Delta_2 = -90°$ (0°,270°,180°,90°,0°, … RF phase cycle) resulting in a shift of ½ FOV between the two slices (fig 1).

The Sequence equipped with view sharing employed the following parameters: FOV: 320x320mm; Matrix: 128x64; shared phases: 27; slice thickness: 10mm; TR 3.3ms; TE 1.64ms; flip angle: 33°; 8.2 images/s; slice distance: 30mm. An adapted offline GRAPPA (4) reconstruction (R=3) in combination with a calibration scan was used to separate the overlapping slices. In order to examine the noise enhancement introduced by the parallel imaging reconstruction, g-factor-maps were calculated for the phantom-experiments according to Breuer et al. (6).

Results:

Using a dedicated TrueFISP sequence cardiac real-time imaging could be performed in two slices simultaneously. The results of the phantom and in vivo study are shown in fig. 1 and fig. 2 respectively. The adapted GRAPPA reconstruction separated the overlapping slices in both, phantom and in vivo experiments without visible reconstruction artifacts. g-factor maps calculated for the phantom study revealed low g-values. Thus, no significant noise enhancement was introduced by the GRAPPA reconstruction with R=3 using an 8-channel receiver array. A cross-section of the g-factor-map calculated for the experiment displayed in fig. 1 is shown in fig. 1 (d).



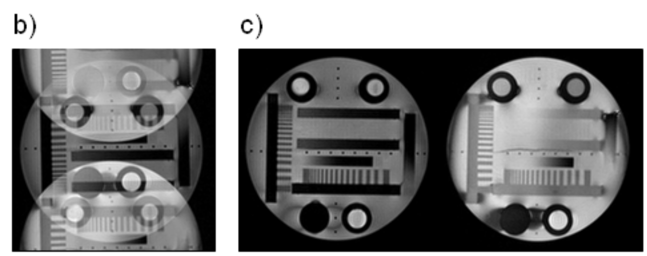


Fig. 1: (a) RF-phase cycles applied in the simultaneously excited slices during k-space acquisition. **(b)** Image reconstructed by performing a simple fourier transform of the acquired k-space. The two slices are shifted by ½ FOV with respect to each other. **(c)** Images of the two slices reconstructed using GRAPPA (R=3). **(d)** Cross-section of the g-factor-map calculated for the phantom experiment displayed in (b) and (c). The cross-section was placed through the center of the object.

Conclusion:

A new approach for combining CAIPIRINHA multi-slice imaging with TrueFISP is presented. In previously presented concepts steady states for the individual slices are realized by segmented acquisitions. In this work the steady state for each slice is maintained by applying a dedicated individual phase cycle in each individual slice. Thus segmenting the acquisition is not required and real-time imaging applications can be realized.

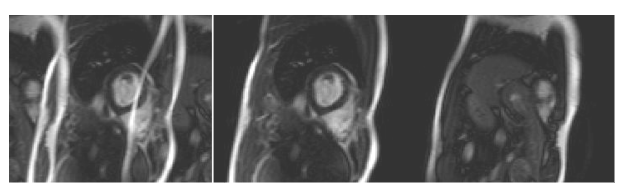


Fig. 2) Images of a two-slice in-vivo cardiac real-time experiment. Two short-axis-slices of the heart were imaged simultaneously. Displayed are the two overlapping simultaneously excited slices **(left)** and the corresponding reconstruction of the two slices using the adapted GRAPPA-algorithm **(right)**.

References:

[1] Breuer, Magn Reson Med 53: 684-691 (2005)
[2] Bretschneider, Proc. ESMRMB 21 (2004), #272
[3] Scheffler, Concepts Magn Reson 11: 291-304 (1999)
[4] Griswold, Magn Reson Med 47: 1202-1210 (2002)
[5] Sobol, J Magn Reson Imag 6: 384-398 (1996)
[6] Breuer, Proc ISMRM 16 (2008), #10