Ultra-Fast Steady State Free Precession and its Application to In Vivo 1H Lung Imaging

Oliver Bieri[1]

[1]Division of Radiological Physics, Department of Radiology and Nuclear Medicine, University of Basel Hospital, Basel, Switzerland

Introduction. In this work, the speed limit for three-dimensional (3D) Cartesian steady state free precession (SSFP) imaging is pushed towards repetition times close to or even below 1ms; in the following referred to as ultra-fast SSFP imaging. Ultra-fast SSFP imaging provides especially for balanced SSFP, a neat and robust way for successful banding artifact reduction: for repetition times TR ~ 1ms, the pass-band extends over more than ±333Hz (±1/3TR). As a result, imaging with ultra-fast balanced SSFP can provide artifact free images even for targets with severe susceptibility variations, such as the lung.

Materials & Methods. Measurements were performed on a clinical 1.5T whole body system, equipped with actively shielded gradient coils of maximal amplitude and slew rate of 40mT/m and 200T/m/s, respectively. Minimal TR for SSFP was achieved by (*i*) using non-slice selective (i.e., hard) RF pulses, (*ii*) exploiting the limit of peripheral nerve stimulation, and (*iii*) using strong asymmetric echoes (given by its relative echo position: a symmetric readout refers to a relative echo position of 50%, whereas a fully asymmetric readout refers to 0%). With ultra-fast balanced SSFP smooth (or paired) 3D trajectories were used (1) to mitigate eddy-current related image artifacts. Asymmetric data sets were reconstructed using a projection onto convex sets (POCS) (2).

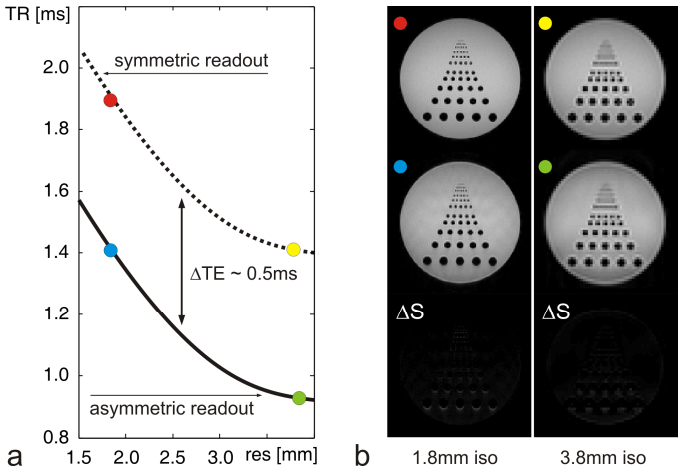

Fig. 1: (a) Ultra-fast SSFP repetition times as a function of resolution. The TR of SSFP is further reduced by about 0.5ms using partial echoes, i.e., strong asymmetric echoes (solid line), as compared to a symmetric readout (dotted line), and even falls below 1ms for resolutions > 3mm. (b) SSFP images with symmetric (top row) or asymmetric readout (middle row) and the corresponding signal difference (bottom row). (Scan parameters: α = 25°; red: TR = 1.9ms, TE = TR/2; blue: TR = 1.4ms, TE = 0.5ms; yellow: TR = 1.4ms, TE = TR/2; green: TR = 0.9ms, TE = 0.3ms).

Results. After optimization, repetition times ranging from 1.4ms (with 1.8mm isotropic resolution) down to 0.9ms (with 3.8mm isotropic resolution) could be achieved for SSFP using Cartesian sampling (see Fig. 1a). Asymmetric echoes (with a relative echo position ~ 15%) allowed an overall reduction in TR by about 0.5ms, as compared to the full readout (i.e., with TE = TR/2). Generally, non-selective excitation pulses (with durations of 60µs up to 100µs) were used, allowing flip angles $\alpha \leq 30°$ for TRs ~ 1ms, which seems sufficient for most applications (i.e., for tissues with $T_2/T_1 \sim 0.1$). Overall, image reconstruction from highly asymmetric readout showed only very minor image degradations, as compared to the fully symmetric scans (Fig. 1b).

Lung imaging is generally complicated by the large numbers of air-tissue interfaces inducing strong susceptibility gradients which lead to exceptional short T2* relaxation times. As a result, either turbo spin-echo techniques (TSE) or ultra-short echo time (UTE) sequences were proposed to address the transverse relaxation problem (3,4), but promising results were recently also demonstrated for 2D balanced SSFP with a TR ~ 2.2 – 2.6ms and a slice thickness of 6 – 8mm (5). Using ultra-fast balanced SSFP, 3D isotropic images of the lung can be obtained with high spatial resolution and within a single breath-hold (Fig. 2). Due to the ultra-short TR, balanced SSFP images are free of off-resonance related image artifacts and degradations, such as banding artifacts.

Discussion & Conclusion. Ultra-fast SSFP was successfully applied for structural in-vivo 1H lung imaging using balanced gradient moments, but can be equally well applied to a non-balanced protocol, such as spoiled gradient echo (SPGR), commonly used for contrast-enhanced MR angiography. As a result, ultra-fast SSFP protocols might represent a promising new powerful approach for SSFP-based imaging in clinical and scientific applications.

References. (1) Bieri O et al. MRM 2005;54:129. (2) Haacke EM et al., J. Magn. Reson. 2001;92:126. (3) Kiefer B et al. J. Magn. Reson Imaging 1994;4:86 (4) Alsop DC et al. MRM 1995;33:678 (5) Failo R et al, MRM 2009;61:299.

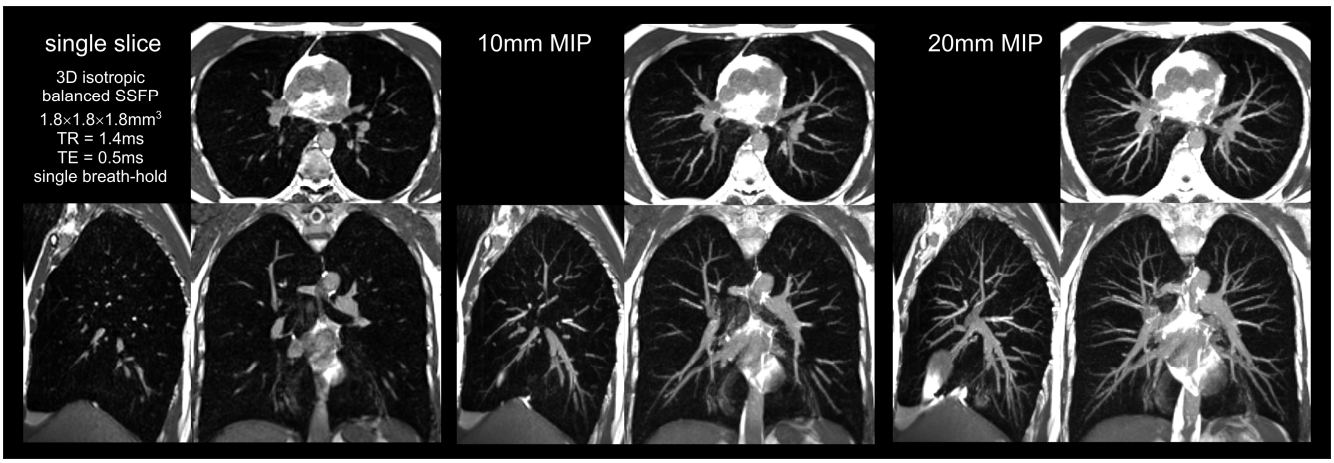

Fig. 2: 1H imaging of the human lung at 1.5T using ultra-fast balanced SSFP (TR = 1.4ms, TE = 0.5ms, α = 20°, BW = 1849Hz/Pixel, 208×186×112 imaging matrix yielding 1.8mm isotropic resolution). A 3D volume scan of the lung was acquired within a single breath-hold (~20 sec). Sample images in transversal, coronal and sagittal orientation of a single slice are shown on the left. Maximum intensity projection (MIP) images are also given (middle: 10mm; right: 20mm).