

# Feasibility of Using Linear Combination SSFP for Lung MRI at 3 T

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## Introduction

Magnetic resonance imaging of the lungs is challenging because of the low proton density in the lungs and because of the large number of air-tissue interfaces which create susceptibility gradients. Although the signal to noise ratio (SNR) can be improved by increasing  $B_0$ , susceptibility artifacts become worse at higher field strengths. For this reason, there have only been a limited number of lung studies at field strengths larger than 1.5 T. The HASTE (half-Fourier acquired single-shot turbo spin echo) sequence has been used along with parallel imaging at 1.5 T to acquire images rapidly (within a second) in order to minimize the blurring that results with single-shot imaging sequences [1]. Recently, HASTE with parallel imaging was applied at 3 T [2] and it was shown that HASTE MRI of the lung is feasible at this field strength. The balanced steady state free precession (bSSFP) imaging sequence has the advantages of offering a higher SNR per unit time [3] and of yielding images that do not suffer from the blurring that occurs with fast spin echo single-shot sequences. However, the major disadvantage of bSSFP is the banding artifact that results from the presence of field inhomogeneities which can scale with  $B_0$ . Linear combination SSFP (LCSSFP) combines data from individual bSSFP images each acquired with a different RF excitation phase cycling scheme in an optimum way designed to minimize the banding artifact [4]. In this work we investigated the feasibility of employing LCSSFP for lung imaging at 3 T.

## Methods

Experiments were conducted on a 3 T Philips Intera whole-body scanner with a 6 element torso phased array RF coil. Coronal 256×256 lung images of a healthy volunteer (slice thickness = 20 mm and FOV = 450×450 mm) were obtained using both the HASTE and the LCSSFP sequences under breath-hold conditions. The HASTE sequence employed a half scan factor of 0.5625 and was applied with SENSE parallel imaging using an acceleration factor of 2. The effective echo time was 42.5 ms and the total acquisition time for the image was about 3.3 s. For the bSSFP sequence, a flip angle of 25°, an echo time of 1.64 ms and a repetition time of 3.3 ms were employed. Four different bSSFP images were acquired with excitation phase cycles as follows:  $\{0^\circ, 0^\circ, 0^\circ, 0^\circ\}$ ,  $\{0^\circ, 90^\circ, 180^\circ, 270^\circ\}$ ,  $\{0^\circ, 180^\circ, 0^\circ, 180^\circ\}$ , and  $\{0^\circ, 270^\circ, 180^\circ, 90^\circ\}$ . Each image was reconstructed and squared. The square root of the sum of the squares was taken to yield the LCSSFP image. The acquisition time for the four images was approximately 3.4 s. In general if  $N$  images are acquired the phase increment from one excitation pulse to the next for a given scan is given by  $360^\circ n/N$ , where  $n$  is the scan number and ranges between 1 and  $N$  [4].

## Results

Figure 1 displays the HASTE image acquired with SENSE parallel imaging while Figure 2 shows the LCSSFP image acquired from four bSSFP scans each acquired with a different RF excitation phase cycling scheme. It is evident that the lung structure is much clearer and far less blurry in the LCSSFP image. Although some banding is still present in the peripheral regions, it can be eliminated by increasing the number of averages ( $N$ ) as demonstrated in Figure 3 which shows an LCSSFP image acquired in 20 averages. The phases of the pulses vary according to the equation given in the methods section ( $N = 20$ ). Respiratory gating can be used in order to remove the breath hold condition allowing more averages to be acquired if desired.

## Conclusion

We have demonstrated the feasibility of employing the Linear Combination SSFP sequence for MRI of the lung at 3 T. Lung images acquired by this method were clearer and suffered less blurring than the images acquired with the HASTE method. Increasing the number of averages removes residual banding present in LCSSFP images.

## References

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## Figures

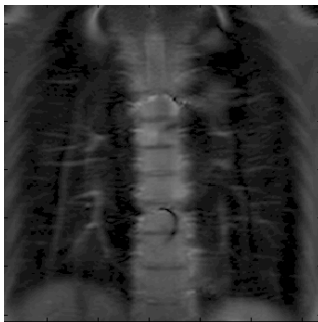


Figure 1: Lung image acquired with the HASTE sequence and SENSE parallel imaging with an acceleration factor of 2.



Figure 2: LCSSFP image of the same slice shown in Figure 1. The image was acquired in 4 averages with RF excitation phase cycles as described in the methods section (acquisition time was about 3.4 s).

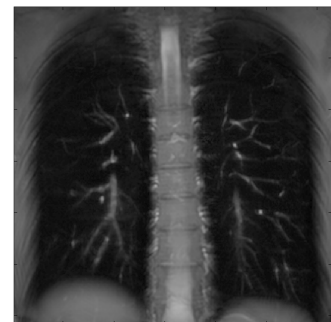


Figure 3: LCSSFP image acquired in 20 averages (acquisition time of about 17 s).