Flow-related Problems in Whole Heart Cine Coronary MR Angiography

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Introduction

The introduction of a new MR scanner generation supporting up to 32 receive channels and corresponding reception coils bears the potential of highly accelerated whole heart coronary MR angiography (CMRA)[1,2]. The employed protocols are mostly based on balanced SSFP (b-SSFP) sequences, which offer superior SNR and CNR. However, despite the high steady state signal of b-SSFP, only a small fraction of the cardiac cycle is typically used for data acquisition in order to freeze cardiac motion. Thus, in principle the scan protocol can be extended to a multi-heart-phase (cine) acquisition providing additional diagnostic information (e.g. ejection fraction, wall motion, cardiac volume) without scan time penalty. On the other hand, the steady-state properties of the sequence may be influenced by the strong blood flow present during the cardiac cycle. It is the purpose of the present study to investigate the performance of a standard high-resolution b-SSFP sequence in a whole heart cine CMRA application.

Methods

All in-vivo experiments were performed on healthy adults (5 male) using a 1.5T whole body scanner (Achieva, Philips Medical Systems) equipped with 32 receive channels. The body coil was used for RF transmission, and a 32-element whole body coil array was used for signal reception. For the whole heart cine scans, an ECG-synchronized, free breathing, b-SSFP sequence (flip angle: 50°, TR/TE: 4.2/2.1 ms, FOV: $270 \times 225 \times 112$ mm³, acquired voxel size: $1.5 \times 1.5 \times 2$ mm³, partial Fourier = 0.625, 12 heart phases) was performed. To reduce eddy-current- and flow-related phase errors caused by the phase encoding gradients [3], linear and reversed-linear view orderings were used for odd and even heart phases, respectively. For scan acceleration, a SENSE factor of 2(AP) × 2(FH) was applied in phase encoding and slice selection direction. A pressure sensor was used for respiratory gating, resulting in a total scan time of about 3 minutes. To study the impact of flow, additional experiments with the same voxel size, but successively reduced slab thickness (56, 28 and 14 mm, respectively) resulting in decreased spatial coverage of the heart were carried out. To make the observed SNR comparable, the scan time was kept constant by reducing the SENSE factor and/or performing signal averaging.

Results and Discussion

In all volunteers a considerable decrease of the relative blood signal from the intraventricular cavity was found with increasing image slab thickness (Fig.1). The signal from the myocardium was approximately constant, resulting in a decreased contrast between blood and myocardium. This effect, which was independent of the heart phase and the spatial position, may be associated with signal enhancement in thin 3D slabs as a result of through-plane flow effects. Depending on the spin replacement rates per TR, significant signal enhancement may be expected [4]. Another potential mechanism is the disturbance of the steady-state due to "in-plane" flow effects. During the long transit time of the blood through a thick 3D-slab considerable accumulative phase errors may evolve due to flow encoding of the phase encoding gradients [3]. In addition, spatial resonance frequency variations (off-resonance) may reduce the steady-state signal of moving spins [5]. In the present study, the signal drop was accompanied by an increased artifact level, whereas both effects were less pronounced for a lower resolution, and hence, shorter TR. These findings indicate an "in-plane" flow effect. Flow-compensated phase encoding gradients may reduce the flow artifacts, but result on the other hand in a longer TR, and hence, increased off-resonance sensitivity. A simple measure to cope with the observed problem is to divide the image slab into several, successively measured partitions. On the other hand, such an approach would decrease the theoretically achievable SNR and hamper parallel imaging in slice-selection direction. Potentially, 3D-radial b-SSFP [6], which is inherently flow-compensated, can be an interesting candidate to reduce flow-related problems.

Conclusion

Flow-related artifacts and signal attenuation represent a serious obstacle for whole heart cine CMRA based on b-SSFP sequences. Further studies are needed to identify the underlying mechanisms and potential solutions to this problem.

References

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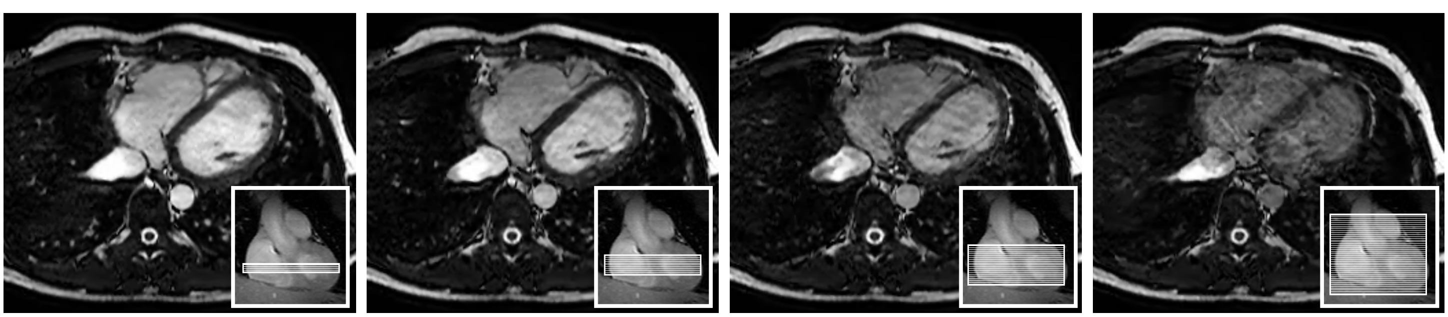

Figure 1: 3D cardiac cine scans acquired with different 3D image slab thickness (from left to right: 14, 28, 56 and 112 mm, see insets). The voxel size was kept constant ($1.5 \times 1.5 \times 2$ mm³) in all cases. The subcutaneous fat signal was taken as a reference to adjust the grayscale window. With increasing slab thickness, the blood signal from the intraventricular cavity decreases. In addition, flow artifacts arise. The diastolic heart phase selected for this example was found to be representative for the whole cardiac cycle.