Non-contrast MR Angiography of the heart and great vessels using SSFP with non-selective excitation

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Introduction

Steady-state free precession (SSFP) techniques are gaining widespread acceptance for cardiovascular imaging at 1.5T. Recently, angiographic and morphologic uses of SSFP have been demonstrated for non-contrast MRA of the pulmonary arteries (1), renal arteries (2), carotid arteries (3) and in morphologic assessment of congenital heart disease (4). SSFP has a unique T2/T1 signal weighting that enhances contrast between blood and most background tissues in the body. However, sensitivity to field inhomogeneity is a major limitation of SSFP, which can cause signal losses that mimic pathology. Additionally, flow can lead to signal losses in the blood pool. Furthermore, out of slice contributions (5) may cause image artifacts. Many of these potential drawbacks can be overcome by using non-selective excitation in SSFP. Non-selective excitation permits use of short duration radiofrequency (RF) pulses that reduce TR, and consequently the signal sensitivity to field inhomogeneities. Since each RF pulse excites all tissues within the range of the RF field, even blood flowing outside the region of interest is maintained in steady-state. Moreover, out of slice contributions may be reduced.

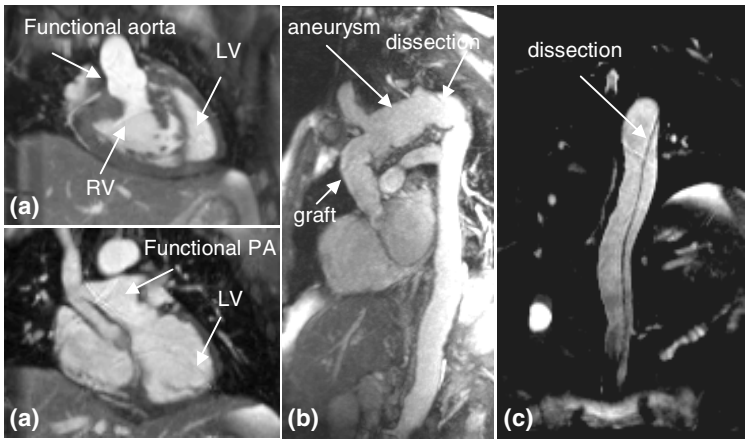
The purpose of this study was to evaluate the feasibility and performance of SSFP with non-selective excitation for evaluation of cardiac morphology and non-contrast MRA of the aortic, pulmonary, and coronary vessels. In patients, SSFP images were compared with contrast MRA using a gradient-echo sequence, the current standard.

Materials and Methods

A 3D free breathing, navigator-gated, fat suppressed, T2-prepared, ECG triggered, segmented sequence with non-selective RF excitation was implemented on a clinical scanner (1.5 T, MAGNETOM Avanto, Siemens Medical Solutions). Six healthy volunteers and 10 patients were examined and the resulting images were evaluated in terms of SNR and image quality. The following imaging parameters were used: TR/TE = 2.3 ms/1.0 ms, flip angle = 90°, readout bandwidth = 980 Hz/pixel, field-of-view (FOV) = 400 mm × 400 mm, matrix size = 320 × 320, slice thickness = 3 mm interpolated to 1.5 mm, number of partitions = 88-128, T2-preparation time = 40ms, parallel acquisition factor = 2, respiratory gating window = 4 mm. The SSFP magnetization preparation was modified from a linear flip angle ramp (6,7) in order to reduce the SSFP signal oscillations in a reduced number of preparation cycles. An adaptive navigator-gating algorithm was used to change the respiratory gating window position to compensate for drifts in the breathing pattern. In patient studies, the results were compared with those from a clinically optimized breath-hold contrast-enhanced MR angiography scan. Image quality was scored by two experienced radiologists (MK and SR) on a scale of 0-5 with 0 representing diagnostic image quality with minimal image artifacts, and 5 with extensive image artifacts. These evaluations were based on image quality in the aorta and pulmonary vessels. Cardiac structures were not included in this analysis because it would have skewed the results in favor of the SSFP sequence, due to the fact that is was ECG-triggered. SNR was measured and compared in the descending aorta in the two sequences.

Results

A reduction in TE and TR is achieved with non-selective excitation. The TR of the SSFP sequence was 2.3 ms, a reduction of 600 μs as compared to that with selective excitation. Non-contrast MRA images acquired in healthy volunteers showed high blood SNR and blood-background contrast. The cardiac and vascular anatomies were very well depicted in each case, with uniform blood signal over the entire FOV. Figure 1 shows three reformatted views of 3D volume datasets in patients with **(a)** transposition of the great vessels, **(b)** Marfan's syndrome with aortic aneurysm, dissection, and graft, and **(c)** aortic dissection. Note that the blood signal is uniformly high, and minimal image artifacts are visible. The acquisition time for these datasets was on the order of 7-15 min. with the navigator acceptance rate ranging from 30 to 60 %. Of the 10 patients that were imaged, there were 2 cases of transposition of the great vessels, 2 aortic dissections, 2 aortic aneurysms, 2 cases with single ventricle, 1 enlarged right atrium, and 1 normal. All the results correlated well with contrast MRA evaluations. The image quality was evaluated as excellent with minimal image artifacts that did not impede the diagnosis in data acquired with both imaging sequences.



Mean±SD	Non-con SSFP	MRA
SNR	95.45±30.2	94.3±28.6
Image quality	0.39±0.41	0.43±0.45

Table 1. Comparison of SNR and image quality in free-breathing non-contrast SSFP and contrast-enhanced MRA. The SNR is similar in both sequences. The image quality was also rated similar in both sequences.

Figure 1. Images acquired with the SSFP sequence in 3 patients with **(a)** transposition of the great vessels. **(b)** Marfan's syndrome with type A dissection, composite graft, evidence of aneurysm, and dissection flap distal to the left subclavian artery, and **(c)** aortic dissection. Note the high blood-myocardial contrast in **(a)**, the uniform blood signal over the entire FOV in **(b),** and a clear depiction of the dissection in **(c)**.

Discussion

Results show that non-contrast MR angiography of the chest vasculature is feasible using an SSFP sequence, and gives very good image quality. Using non-selective excitation in such a sequence can have multiple potential benefits, as listed earlier. Image quality was found to be equivalent with the SSFP sequence and the contrast MRA sequence. However, cardiac morphology and coronary arteries are better described with the SSFP sequence because of cardiac triggering.

The major advantage of non-selective excitation is the reduction in TR of the SSFP sequence, and is evident in the uniform blood signal over the entire FOV 0f 400 mm. One of the potential limitations of non-selective excitation is that a larger number of partitions need to be acquired than with selective excitation. However, this increases the overall imaging time only marginally, because the reduction in TR permits acquisition of a larger number of phase-encoding lines in each heartbeat, thus compensating for the increased number of partitions to be acquired. In general, the acquisition time for the non-contrast SSFP sequence is quite long since it is used as a free breathing approach, as compared to the 20s contrast-enhanced MRA. On the other hand, the SSFP scan offers the advantage of depicting the cardiac morphology and coronary arteries well due to its ECG gated approach as opposed to contrast MRA. In conclusion, SSFP with non-selective excitation is a promising approach for non-contrast MRA.

References **1.** Hui BK, et al. JMRI 2005:831-5. **2.** Katoh M, et al. MRM 2005:1228-33 **3.** Zavodni AE, et al. JMRI 2005:86-90 **4.** Sorensen TS, et al., Circulation 2004:110:163-9 **5.** Markl et al. MRM 2003:945-52. **6.** Nishimura et al. ISMRM 2000:301. **7.** Deshpande VS et al. MRM 2003: 151-7.