Signal-to-Noise Ratio Enhancement in Coronary MRA Using Parallel Imaging

J. Yu[1], M. Schär[2], E-J. P. Vonken[2], S. Kelle[2], and M. Stuber[2]

[1]Biomedical Engineering, Johns Hopkins University, Baltimore, MD, United States, [2]Johns Hopkins University, Baltimore, MD, United States

Introduction: In coronary magnetic resonance angiography (MRA), image data are typically collected in a short acquisition (ACQ) window during a period of minimal myocardial motion. This requirement limits the number of radiofrequency (RF) excitations per ACQ window and leads to prolonged scanning time. Keeping the ACQ window constant, the scanning time could be abbreviated by shortening the repetition time (TR) while simultaneously increasing the number of RF excitations. Unfortunately, to shorten TR, stronger readout gradients are necessary and the subsequent increase in readout-bandwidth results in a signal-to-noise ratio (SNR) loss. As an alternative to shorter TR, scanning time can be shortened through the use of parallel imaging. Using SENSE, weaker readout gradients and lower readout bandwidths can be employed which, to a certain degree, supports an improved SNR.

Purpose: To investigate whether the use of SENSE can be exploited to improve relative SNR in coronary MRA.

Theory: When reducing the number of RF excitations by a certain factor while keeping the ACQ window constant, the TR is prolonged. With a prolonged TR, weaker readout gradients can be employed which increases the SNR at the expense of scanning time. This extra scanning time can be compensated for with SENSE [1]. The SNR gain secondary to the reduced readout bandwidth is expected to be offset by the SNR loss associated with SENSE. However, by removing RF excitations, extra time during the ACQ window is made available that can be used for signal sampling rather than for RF transmission (Fig 1). In theory, this can be exploited to gain additional SNR in coronary MRA.

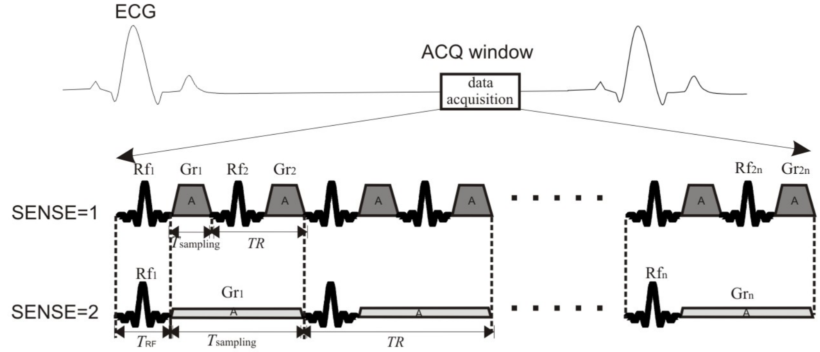

Figure 1. Schematic of a baseline (SENSE=1) and a SENSE accelerated (SENSE=2) coronary MRA pulse sequence. In the case of SENSE=2, the number of RF excitations is reduced by 50%, TR is doubled, the readout gradient is reduced, and the readout bandwidth is smaller. Note that the sampling time (Tsampling) increases more than twice. Gr=readout gradient, Trf=duration of RF transmission, Tsampling=duration of the signal sampling period.

Methods: A numerical simulation of the Bloch equations was implemented in Matlab to compute the SNR as a function of the SENSE factor, the ACQ window, and T1. Phantom experiments were then performed on a 3T MR system (Philips Achieva) using a 6-element cardiac coil. Images of a cylindrical phantom (T1=240ms) were acquired using 3D imaging (FOV 360x360mm^2, matrix=516x362, RF excitation angle=20°, slices=10, slice thickness=3mm, T2Prep [2]). For SNR quantification on SENSE images, an additional 3D noise scan (duration=20sec) without RF excitations and gradients was implemented. These *in vitro* measurements were performed with five different ACQ windows ranging from 36ms to 70ms, and three SENSE factors of 1.0, 1.5 and 2.0. For the *in vivo* study, 10 healthy adult subjects (28±8 years) underwent navigator-gated and corrected free-breathing 3D coronary MRA of the right coronary artery (RCA) with the same pulse sequence as in the phantom study. Four coronary MRA data sets were collected in each subject with different SENSE factors and ACQ windows (Table 1; TFE factor = number of RF excitations per ACQ window). On the resultant images, the signal intensity (S_{Image}) was measured in a region of interest (ROI) in the phantom or ascending aorta. This ROI was then copied to the corresponding 3D location of the noise scan for noise quantification (SD_{Noise}). SNR for the different scans was computed (S_{Image}/SD_{Noise}) and a one-sided t-test was used for statistical comparison.

Scan	ACQ window (ms)	TFE factor	SENSE Factor	TR (ms)	TE (ms)	BW (Hz/ pix)	Scanning Time (min)
a. Scan 1	40	12	1	3.3	1.2	724.1	~10
b. Scan 2	40	6	2	6.6	1.8	149.3	~10
c. Scan 3	70	12	1	5.7	1.6	188.9	~10
d. Scan 4	70	6	2	11.4	2.7	69.7	~10

Table 1. Some imaging parameters for SENSE=1 and SENSE=2 scans.

Results: The numerical simulation predicts that SENSE in conjunction with a reduced signal readout bandwidth can be exploited to improve relative SNR in coronary MRA. This predicted SNR gain is greatest for the shortest ACQ window investigated. For a tissue with a T1 of 240ms, the SNR improvement is expected to be 53% (SENSE factor 2 vs. 1) and 46% (SENSE factor 1.5 vs. 1) for an ACQ window of 36ms. For T1=1550ms, the predicted SNR increase is 52% for a 40ms ACQ window and 11% for a 70ms ACQ window (SENSE factor 2 vs. 1). Phantom experiments with a 36ms ACQ window yield a relative SNR gain of 53±6% (200.4±17.6 vs. 131.2±12.9, ($p<0.0001$)) for a SENSE factor of 2 vs. 1, and 40±7% (182.7±15.0 vs. 131.2±12.9, ($p<0.0001$)) for a SENSE factor of 1.5 vs. 1. However, the relative gain in SNR drops when the ACQ window is prolonged. The results obtained from the numerical simulation and those from the *in vitro* study are compared in Fig 2. *In vivo,* a 55±10% relative increase in blood SNR was obtained for an ACQ window of 40ms (85.2±23.9 vs. 54.8±14.3 ($p<0.0001$)) by using a SENSE factor of 2 vs. 1. For the prolonged acquisition window (70ms), the 11±10% SNR gain for a SENSE factor of 2 versus 1 (114.0±29.2 vs.101.7±21.0 ($p<0.005$)) was also significant and consistent with the theory. *In vivo* data also show that with a SENSE factor of 2, the SNR obtained using a short ACQ window (40ms) is 74±6% of that from a longer (70ms) ACQ window (85.2±23.9 vs. 114.0±29.2; $p<0.0001$). However, without the use of SENSE and while keeping the scanning time constant, the SNR from the short ACQ window (40ms) was reduced to 53±5% relative to that measured from the 70ms ACQ window (54.8±14.3 vs. 101.7±21.0; $p<0.0001$). Representative images of the RCA are shown in Fig 3.

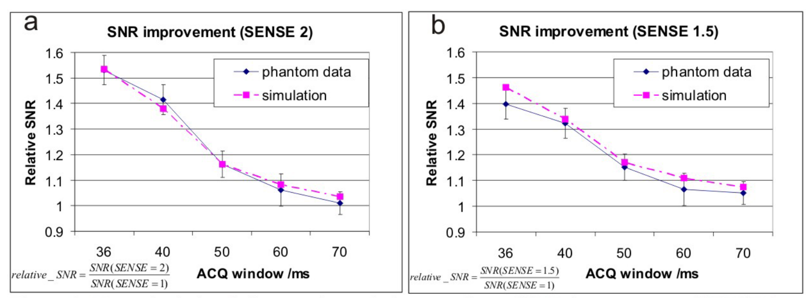

Figure 2. Numerical simulation results and phantom data of SNR improvement (SENSE 2 vs. 1(a) and SENSE 1.5 vs. 1(b)) at different ACQ window length. Phantom measurements agree with numerical simulation.

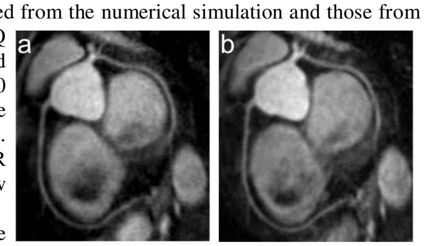

Figure 3. 3D MRA of the RCA of one volunteer reformatted with the "Soap Bubble" software. ACQ window 40ms baseline (a) and SENSE=2 image (b). SENSE=2 image has enhanced SNR.

Conclusions: A reduced number of RF excitations in combination with parallel imaging can be exploited to improve the relative SNR in coronary MRA with short ACQ windows while the scanning time remains unchanged. For ACQ windows of 70ms and longer, this SNR benefit is small. However, for shorter acquisition windows, the gain is considerable (~50% for an ACQ window of 40ms). While these values were predicted using numerical simulations, they were in good agreement with both the *in vitro* and *in vivo* findings. This method may have important implications for further improved motion suppression through the use of shorter ACQ windows in coronary MRA [3].

References: 1). Weiger, MRM 2005; 53:177-185. 2). Nezafat, MRM 2006; 55: 858-864. 3). Johnson, JCMR 2004; 6(3): 663-673.