High Resolution SENSE coronary MRA using a Robust Coil Sensitivity Calibration

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Introduction

SENSE (SENSitivity Encoding) (1), has been used to increase spatial resolution in a limited imaging time. It requires highly accurate coil sensitivity to reconstruct a full image from a reduced data set. To measure the coil sensitivity, a separate low-resolution image is commonly obtained before or after accelerated acquisition. In breath-hold coronary magnetic resonance angiography (MRA), it does not ensure that coil and breath-hold positions are exactly identical between the sensitivity measurement and the accelerated acquisition. The errors in the coil sensitivity calibration may yield not only residual aliasing artifacts but also amplified noises. In this work, we propose a robust method of incorporating the coil sensitivity calibration with the accelerated acquisition in a single breath-hold for coronary MRA by extending the data acquisition around a diastolic cardiac phase and reordering phase encoding lines.

Theory

To incorporate coil sensitivity calibration and accelerated data acquisition in a single measurement, additional coil sensitivity calibration lines (1st imaging frame) are acquired before the actual image data (2nd imaging frame) (Fig. 1). In the 1st imaging frame, low frequency odd lines in the central region of k-space are acquired. In the 2nd imaging frame, accelerated high-resolution data with even lines are measured. Our hypothesis is that although there may be some cardiac motion in the 1st imaging frame, accurate coil sensitivity will still be obtained, allowing reliable SENSE reconstruction. The reconstruction algorithm consists of the following steps: 1) The low frequency region along the phase encoding direction for each coil is fully generated by combining odd and even lines in the 1st and 2nd imaging frames respectively. 2) The combined k-space is zeropadded in the high frequency region, and then Fourier transformed to yield a low-resolution coil image. 3) Each coil image is normalized by the root sum of squared magnitudes of all the coil images, yielding the coil sensitivity. 4) SENSE reconstruction (1) is applied to the accelerated data in the 2nd imaging frame using the coil sensitivity to generate the final image.

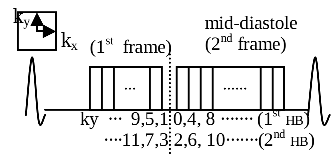

Fig.1. Data acquisition with the reordering of the phase encoding lines in two imaging frames

The 1st imaging frame may not be put on a diastolic cardiac phase, resulting in motion problem in calibrating the coil sensitivity. The errors caused by the motion in the coil sensitivity will be avoided by adjusting the duration of data acquisition in the 1st imaging frame.

For ECG-triggered coronary MRA, data is acquired in a transient state of signal. Signal discontinuities between odd and even lines in the low frequency region of the combined k-space for the coil sensitivity calibration may occur, yielding ghosting artifacts in the final reconstructed image. To minimize this problem, the low frequency region of the combined k-space will be acquired in succession by reordering the phase encoding lines such that the odd lines in the 1st imaging frame are acquired from high (k-space edge) to low frequency (k-space center) while the even lines in the 2nd imaging frame are measured from low to high frequency (Fig. 1).

Methods

An ECG triggered segmented three-dimensional True-FISP (fast imaging with steady state precession) (2) was performed in five volunteers during a single breath-hold at Siemens 1.5T Sonata scanner. An Eight-coil array (4 anterior and 4posterior to heart) was used. The imaging parameters were: TR/TE/flip angle =3.6ms/1.4ms/70^o, FOV=258x360mm^2, number of partitions=6 (interpolated to 12), and thickness=3mm (interpolated to 1.5mm).

(1) A fully sampled data was acquired in each imaging frame (Fig. 1) (acquisition matrix=248x512 for each imaging frame, lines/hearbeat /imaging frame=31). The data was decimated off-line with the proposed reordering of lines. The number of odd lines in the 1st imaging frame used for the combined coil sensitivity was changed to investigate the effect of motion on residual artifacts in the final reconstructed image. Artifact level was calculated by the absolute value of complex difference between SENSE reconstructed images with full and half data in the 2nd imaging frame.

(2) Two images were generated in each volunteer under the same imaging time by: a) the root sum of squares reconstruction with conventional full acquisition in a single imaging frame (acquisition matrix=124x512, lines/hearbeat=31) and b) SENSE reconstruction with accelerated acquisition with the proposed reordering of lines in two imaging frames (acquisition matrix=40x512 (1st imaging frame, 10 odd lines/hearbeat), 124x512 (2nd imaging frame, 31 even lines/heartbeat)). These two images were presented to two of the authors for visual grading. Scoring is on a 4-point scale: 1) poor (markedly blurred), 2) fair (moderately blurred), 3) good (mildly blurred), 4) excellent (sharply defined). Signal-to-noise ratio (SNR) and sharpness of vessel were measured (3). A two-tailed t-test was used to evaluate the statistical difference between the two images reconstructed with and without SENSE (P = 0.05).

Results

Artifact level in SENSE reconstruction decreases when more odd lines in the 1st imaging frame are combined with even lines in the 2nd imaging frame for the coil sensitivity calibration as far as motion is not severe (Fig. 2). SENSE reconstruction (Fig 3b) with the proposed way of obtaining the coil sensitivity improves the delineation of the vessels with no significant artifacts compared with the conventional reconstruction (Fig. 3a) under the same imaging time. The images reconstructed by the proposed scheme yield higher visual rating, 25 % increase of vessel sharpness and 19 % decrease of SNR (Table 1).

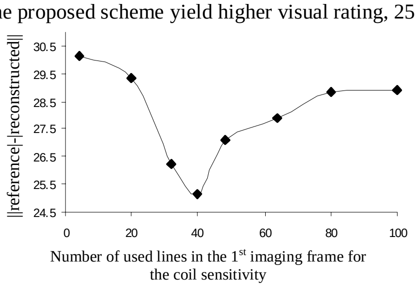

Fig. 2. Artifact level versus the number of used lines in the 1st imaging frame for the coil sensitivity calibration. Note the increase of artifacts due to motion after 40 lines.

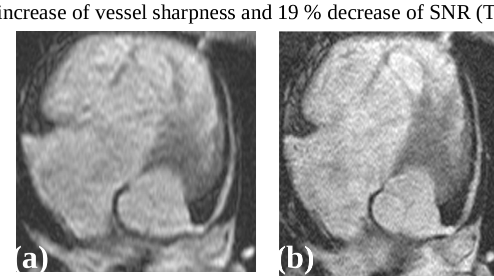

Fig. 3. Images reconstructed under the same imaging time by: (a) conventional reconstruction and (b) SENSE reconstruction with the proposed reordering of lines (acceleration factor=2). Note the increase of vessel sharpness.

Table 1. Qualitative and quantitative comparisons of the two images generated by conventional reconstruction and SENSE reconstruction with the proposed way of the coil

	No SENSE	SENSE
Visual Rating	2.9 ± 0.5	3.8 ± 0.4*
SNR	11.3 ± 0.9	9.2 ± 0.7*
Sharpness	0.8 ± 0.04	1.0 ± 0.1*

(*P < 0.05, indicating significant differences)

Discussion & Conclusions

The miscalibration of the coil sensitivity often occurs when it is measured separately from the accelerated data. In this work, the coil sensitivity scan is incorporated with the accelerated data acquisition in a single measurement. For robust coil calibration, the accelerated imaging data is included in the coil sensitivity minimizing the calibration errors. The possible ghosting artifacts resulting from simply combining the data in the 1st and 2nd imaging frame are minimized by reordering the phase encoding lines and adjusting the duration of data acquisition in the 1st imaging frame. SENSE reconstruction with the proposed scheme successfully delineates the coronary arteries with no significant artifacts and noises. Higher acceleration will be feasible at 3T under the same imaging time due to significant signal gain.

Reference

(1) Pruessmann KP,et al. MRM 42: 952-962 (1999). (2) Deshpande et. al. MRM 46: 494-502 (2001). (3) Steven et. al, JMRI 13:301-307 (2001)