High Resolution Inner Volume Imaging of Human Coronary Atherosclerotic Plaque: Impact and Limits of Parallel Acquisition

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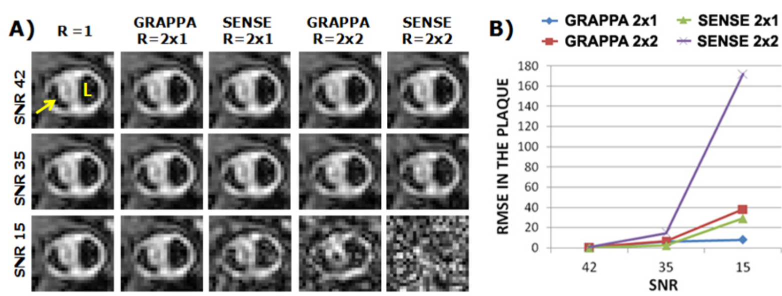
Target Audience: Scientists and clinicians interested in MRI of human coronary atherosclerotic plaque.

Purpose: Multi-contrast MRI shows promise in the accurate characterization of human coronary atherosclerotic plaque[1]. Recent data suggest that a true resolution of 500μm, an SNR > 11 and motion correction with an accuracy of 75–85% will be needed to accurately image coronary artery plaque in vivo[2]. This resolution can theoretically be achieved but would involve unacceptably long scan duration without reduced field-of-view (FOV) imaging. Scanners with parallel transmission capabilities, supporting inner volume imaging, are now available and provide an excellent alternative. The aim of this study was to determine the impact of parallel acquisition on the imaging of coronary plaque under conditions of physiological motion and reduced FOV (64×48×24mm^3).

Methods: Seven atherosclerotic plaques from donor hearts with extensive coronary artery disease were imaged at 9.4T. The raw k-space data were saved and used to simulate the effects of motion, SNR and accelerated acquisitions through undersampling and parallel imaging. Analysis was performed on T1W 3D FLASH images with an isotropic true resolution of 0.5mm interpolated to 0.25mm. The impact of motion on the image was modeled through the use of in vivo motion profiles, acquired by placing 3 orthogonal navigators on the left ventricle of 11 adult subjects. Assuming that a perfect correction of coronary translation is not feasible, several percentages of residual motion in the dataset were simulated. An acquisition scheme was simulated such that the inner part of the k-space is acquired in one breathold (equivalent to a maximum of 30% of the non-zero phase encoding lines in each direction) and the outer part in free breathing regimen using a 5mm gating window. The use of a multi-channel receive coil array dataset was simulated by using coil sensitivity maps acquired on a commercial 3T scanner (Skyra, Siemens Medical) with a 34-element thoracic array. Varying levels of Gaussian noise were added to the simulated images to evaluate the performance of GRAPPA[3] and SENSE[4] over a range of acceleration factors. The normalized RMSE in coronary plaques with complex features was evaluated as a quality measurement.



Results: Coil sensitivity profiles over the reduced FOV were similar in 28/34 elements and limited the performance of both SENSE and GRAPPA. The high degree of co-variance in many of the profiles rendered them very sensitive to noise. **Figure 1**. (A) Impact of parallel acquisition and increasing noise on plaque morphology in the absence of coronary motion. The hypointense area on the left (yellow arrow) is an area of plaque calcification. The vessel lumen is the larger hypointense area on the right (L). With SNR≥35, 2×2 acceleration with GRAPPA and SENSE is possible with minimal reduction in image quality. However, at a SNR of 15 only 2×1 GRAPPA produces acceptable image quality. (B) SENSE is more sensitive to low SNR than GRAPPA, particularly at higher acceleration rates. The impact of motion was modeled as previously described[2]. The center of k-space was acquired during a simulated motion free breathold. This corresponded to 30% of k-space without acceleration and 39% with 2×2 acceleration. The remainder of k-space was sampled in the presence of partially corrected motion. Image quality in the presence of motion was actually improved by parallel acquisition since a greater portion of central k-space could be acquired during the breathold portion of the acquisition.

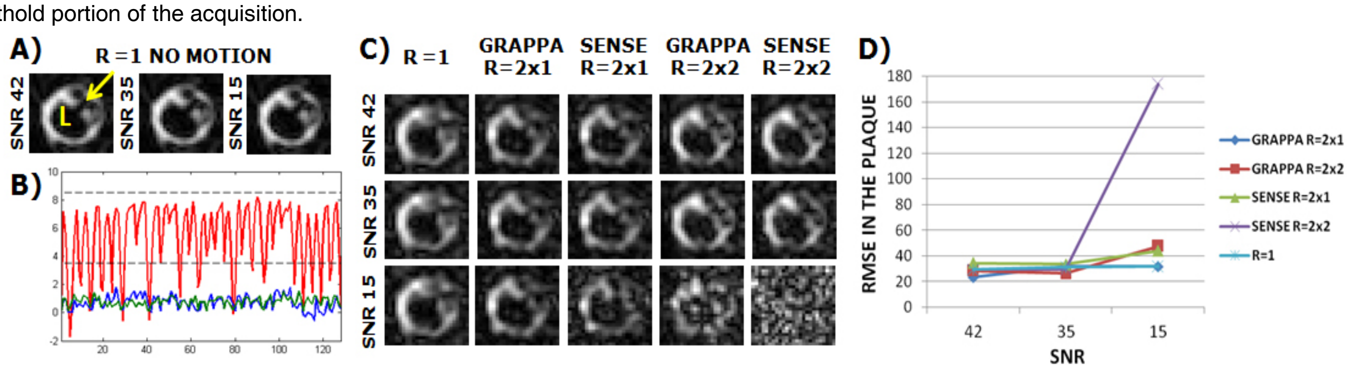


Figure 2. (A) Plaque morphology without motion or parallel acquisition. A complex calcified plaque is present in the upper right quadrant portion of the vessel (yellow arrow); L=lumen. (B) Motion profile from an adult volunteer incorporated to the dataset. Residual motion of 25% after the application of a correction algorithm was modeled. Motion in the head-foot direction is in red. (C) The visualization of plaque morphology is improved by parallel acquisition (compare columns in C to the first one). When SNR falls below 15, however, this effect is lost completely for SENSE and for GRAPPA above rates of 2x1. (D) In presence of motion, the increment in RMSE due to the addition of noise is lower than in absence of motion. The effect of motion dominates the effect of noise for the bigger SNR values.

Discussion: Parallel acquisition can improve the resolution of coronary plaque morphology due to a reduction in motion sensitivity. However, image quality with high-resolution inner volume imaging of coronary plaque is limited by SNR and the high degree of overlap among coil element profiles in commercial arrays when the region of interest is focused on the coronary arteries.

Conclusion: This work motivates the design and construction of dedicated cardiac receive arrays for coronary artery imaging, where design criteria included optimized SNR and coil profiles over the coronary arteries. Such arrays could significantly enhance the impact of parallel acquisition on coronary artery plaque imaging.

[1] Karolyi M, JACC Imaging. 2013. [2] Montesinos P. ISMRM 2012. [3] Griswold M, MRM. 2002. [4] Pruessman KP. MRM 1999.