Motion, Resolution and Noise Thresholds for the Accurate Classification of Human Coronary Atherosclerotic Plaque by MRI

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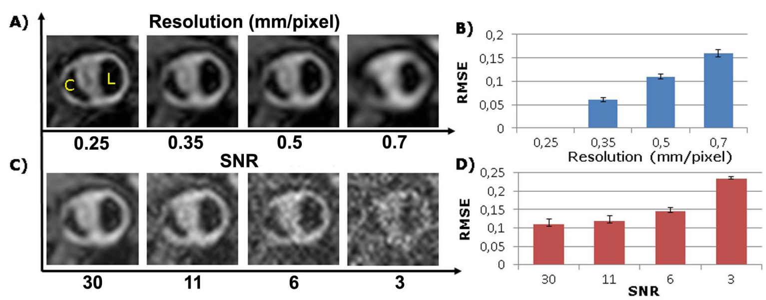
Target Audience: Scientists/clinicians interested in MRI of human coronary atherosclerotic plaque.

Purpose: In a recent study the use of T1, T2 and UTE MRI was shown to accurately classify human coronary atherosclerotic plaque ex vivo (Karolyi M, JACC Imaging)**.** The raw k-space data in this study, acquired at 9.4 T with an isotropic resolution of 250 um, provide valuable “ground truth” data. We aimed here to reconstruct the “ground truth” data under varying conditions of resolution, SNR and motion to determine the requirements for the accurate classification of coronary artery plaque in vivo.

Methods: Seven atherosclerotic plaques from donor hearts with extensive coronary artery disease were studied. Analysis was performed on T1W 3D FLASH images acquired with the following parameters: resolution 0.25mm isotropic, α =45º, TR/TE=30/2.5ms, fat suppression**.** The plaques were imaged in a fluorocarbon medium, eliminating signal from the vessel lumen. Areas of plaque calcification produced marked hypointensity, providing morphologic features for analysis. Zero-padding of outer k-space was performed to reduce spatial resolution and Gaussian noise was added to the k-space data to simulate representative SNR values (Figure 1). The impact of motion was modeled through the use of in vivo motion profiles, acquired by placing 3 respiratory navigators on the left ventricle of a healthy adult subject (Figure 2D). Perfect correction of coronary translation resulted in 0% residual motion. The impact of imperfect correction was modeled as the percent of the translation (% residual motion) remaining after the correction. The root-mean squared error (RMSE) between the plaque in the original and reconstructed image was used to measure image accuracy.



Results: Figure 1: (A, B) Reducing the resolution from 0.25mm to 0.5mm produced an average RMSE of 0.11 and only a slight reduction in subjective image quality. Since a resolution of 0.5mm is far more attainable in vivo than 0.25 mm, the SNR and noise limits were tested at a resolution of 0.5mm. (C, D) A SNR of >10 was needed to maintain image quality and keep the RMSE low. L=lumen. C= calcium.

Translation of the heart was by far the largest in the head-foot direction (red profile, Figure 2D). At a resolution of 0.5mm, however, the translational motion measured at least 1-2 pixels in all directions. Motion correction in the head-foot direction only, even when almost perfect, thus proved inadequate due to the impact of motion in the other 2 directions.

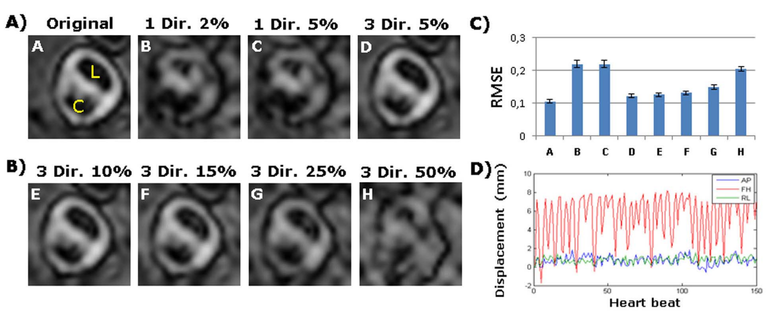


Figure 2: Impact of motion. (AA) No motion. (AB, AC) Motion correction in the head-foot direction only with residual motion of 2% and 5% respectively. Image quality is extremely poor. (AD-BH) Motion correction applied in all 3 directions but with a progressively higher percent of residual motion. Even with residual motion of 25% (BG), image quality is acceptable and RMSE (C) remains low. (D) Translation of the heart in a normal volunteer. At a resolution of 0.5 mm, motion correction in all 3 directions is needed.

Two further strategies to reduce motion artifact were tested. The impact of reducing the navigator acceptance window from 5 to 3mm and of acquiring the central portion of k-space during a breathold were tested (Figure 3). At a resolution of 0.5mm, we estimated that 10-15% of k-space could be acquired in a realistic breathold. Plots of RMSE were created with 0, 5, 10 and 15% of k-space sampled during a motion-free breathold, and the remainder of k-space sampled at varying degrees of residual motion.

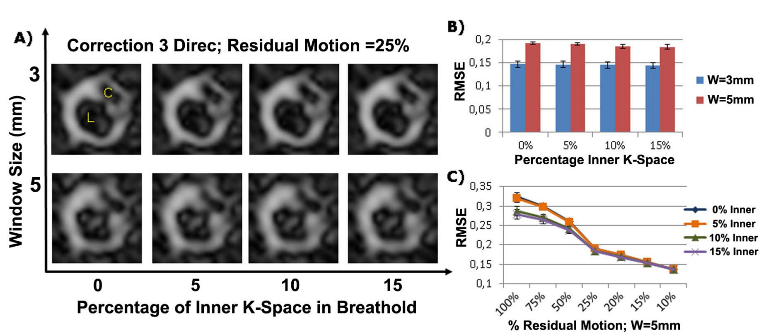


Figure 3: (A, B) Reduction of the navigator acceptance window from 5 to 3mm produces little change in image quality. (C) Plots of RMSE calculated with either 0, 5, 10 or 15% of k-space acquired in a breathold. When residual motion is high, the acquisition of the central part of k-space during a motion-free breathold reduces the RMSE.

Discussion: The accurate classification of human coronary atherosclerotic plaque requires a spatial resolution of 0.5mm, an SNR > 10, and motion correction to be performed in all 3 directions. Acquisition of the central 10-15% of k-space in a breathold can reduce artifact, particularly when large amounts of residual motion are present after correction.

Conclusion: The imaging of plaque in the coronary artery in vivo will require improved motion correction strategies to be developed.