

# IMPROVED SIGNAL-TO-NOISE RATIO IN LATE GADOLINIUM ENHANCEMENT IMAGING BY USING RESPIRATORY-NAVIGATOR-REJECTED K-SPACE LINES

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**INTRODUCTION:** Three-dimensional (3D) late gadolinium enhancement (LGE) MRI is acquired in a segmented fashion over multiple heartbeats, which necessitates compensation of respiratory motion. Several respiratory motion compensation approaches have been proposed over the past two decades [1], among which prospective navigator (NAV) is the most commonly used technique for respiratory motion compensation. In this technique, the k-space lines acquired immediately after the NAV signal are used for image reconstruction only if the navigator signal is within a pre-defined gating window, whereas those outside the gating window are rejected and re-acquired, and the rejected lines are not utilized further. Sub-optimal SNR and CNR is another challenge in high-resolution LGE imaging, limiting the spatial resolution or leading to lengthy acquisition times. In this study, we sought to develop and evaluate a technique that utilizes the NAV-rejected k-space lines for improved SNR in high-resolution 3D LGE.

**THEORY:** Consider a k-space line along the read-out ( $k_x$ ) direction at k-space location ( $K_y^1, K_z^1$ ), and denote this noise-free line by the vector  $\mathbf{s}$ . If the NAV detects object movement during imaging, this line will be rejected. For the  $p^{\text{th}}$  NAV-rejection of this line, we use  $(x_p, y_p, z_p)$  to denote the translational movement [2,3] of the object. Then the NAV-rejected line is given by  $\mathbf{s}^{\text{rej},p} = e^{-i2\pi k_x x_p - i2\pi k_y y_p - i2\pi k_z z_p} \circ \mathbf{s} + \mathbf{n}_p$ , where  $\mathbf{n}_p$  is measurement noise,  $\mathbf{k}_x$  is the vector of values for the extent of the k-space in the read-out direction, and  $\circ$  denotes element-wise multiplication. Since  $\mathbf{s}$  only contains measurements along the  $k_x$  direction for a fixed k-space location, the motion in y-z direction cannot be determined individually, hence  $\mathbf{s}^{\text{rej},p} = e^{-i2\pi k_x x_p - i\theta_p} \circ \mathbf{s} + \mathbf{n}_p$  for  $p$  from 1 to  $n_{\text{rej}}$ . The accepted line is given by  $\mathbf{s}^{\text{acc}} = \mathbf{s} + \mathbf{n}_{\text{acc}}$ . We propose to simultaneously recover  $\mathbf{s}$  and the motion parameters  $\{x_p, \theta_p\}$  under an independent identically distributed Gaussian noise assumption using maximum-likelihood (ML) estimation:

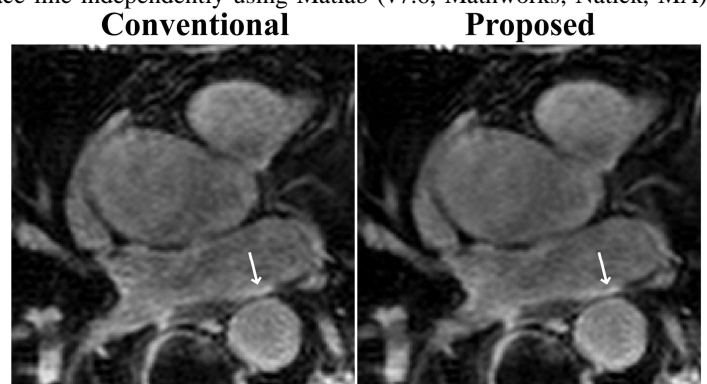
$$\left( \mathbf{s}^{\text{ML}}, \{x_p^{\text{ML}}, \theta_p^{\text{ML}}\}_{p=1}^{n_{\text{rej}}} \right) = \arg \min_{\mathbf{s}, \{x_p, \theta_p\}_{p=1}^{n_{\text{rej}}}} \left\| \mathbf{s} - \mathbf{s}^{\text{acc}} \right\|_2^2 + \sum_{p=1}^{n_{\text{rej}}} \left\| \mathbf{s}^{\text{rej},p} - e^{-i2\pi k_x x_p - i\theta_p} \circ \mathbf{s} \right\|_2^2.$$

For all datasets, the proposed technique was performed for each k-space line independently using Matlab (v7.6, Mathworks, Natick, MA). Comparison images were generated via the conventional technique of using only the NAV-accepted data. Final images were generated via root-sum-squares of individual coil images.

**METHODS:** Images were acquired on a 1.5T Philips Achieva magnet with a 32-channel cardiac coil. Left atrium (LA) LGE images were acquired axially (with right-left phase encoding) in 21 patients (8 females,  $60.8 \pm 8.6$  years). A free breathing ECG-triggered inversion-recovery GRE sequence was utilized (TE/TR/ $\alpha$ =5.2/2.6/25°, spatial resolution=1.4×1.4×4.0 mm<sup>3</sup>). A navigator placed on the dome of the right hemidiaphragm was used for respiratory motion compensation, utilizing an end-expiration adaptive gating window strategy [4] with a target efficiency varying between 40 and 50%, corresponding to an average gating window of  $8.2 \pm 3.6$  mm.

SNR measurements were performed for both reconstructions. SNR gains were calculated as the SNR of the proposed technique over that of the conventional one. This was compared to the maximum theoretical SNR gain, defined as the theoretical SNR if a given k-space line was acquired  $n_{\text{rej}} + 1$  times without undergoing any motion. Images were scored qualitatively by a blinded reader in terms of overall quality and freedom from motion artifacts.

**RESULTS:** Fig. 1 depicts an example axial slice of LA LGE, reconstructed with the conventional and proposed methods. The reconstructed images are similar, although the proposed technique has 32-39% higher SNR. Table 1 depicts SNR measurements and image scores for these



**Fig. 1:** An example axial slice from a patient who underwent pulmonary vein isolation for treatment of atrial fibrillation, reconstructed using NAV-accepted data only (conventional) and the proposed technique. Enhancement of the LA wall is visualized similarly in both cases. However, the images using proposed technique have 32% higher SNR in the LA blood pool, and 39% higher SNR in the RA blood pool compared to the conventional method.

|              | Quantitative Measures |             |             |             | Qualitative Measures |                     |                 |
|--------------|-----------------------|-------------|-------------|-------------|----------------------|---------------------|-----------------|
|              | SNR (LA)              | SNR gain    | SNR (RA)    | SNR gain    | image score          | freedom from motion | presence of LGE |
| conventional | 22.7 ± 11.1           | 1.00 ± 0.00 | 25.7 ± 13.2 | 1.00 ± 0.00 | 3.00 ± 0.71          | 3.57 ± 0.60         | 6/21            |
| proposed     | 27.9 ± 14.2           | 1.21 ± 0.09 | 31.4 ± 16.1 | 1.22 ± 0.09 | 3.00 ± 0.71          | 3.57 ± 0.60         | 6/21            |
| P-value      | <0.001                | <0.001      | <0.001      | <0.001      | 1.00                 | 1.00                | 1.00            |

**Table 1:** Comparison of the techniques in terms of SNR, SNR gain and image scores. SNR is significantly improved with the proposed technique. Furthermore, there is no difference between two techniques in terms of qualitative image scores and freedom from motion artifacts.

**CONCLUSIONS:** We have demonstrated a technique that utilizes NAV-rejected k-space lines, which are conventionally discarded, for improved SNR without resulting in a longer acquisition or imaging artifacts.

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**REFERENCES:** [1] Scott, Radiology, 2009; [2] Keegan, JMRI, 2007; [3] Bhat, MRM, 2011; [4] Moghari, MRM, 2012.