Self-navigated 3D late gadolinium enhancement imaging of the left atrium

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Introduction: Late Gadolinium Enhancement imaging is evolving as a valuable tool for treatment management of atrial fibrillation using radio-frequency ablation [1, 2]. Enhancement in images post-ablation correlates with regions of ablation [1, 2] that can be used to track treatment progress and identify gaps in the ablated regions. In pre-ablation images, enhancement corresponds to fibrosis which could be a useful tool in predicting the success of the ablation procedure [3]. The current standard for obtaining LGE images is to use a respiratory navigated 3D Cartesian acquisition with parallel imaging [1, 2]. Segments of 3D k-space are acquired each heartbeat in the diastolic phase of the heart with ECG gating and those within a navigator window of motion of the diaphragm are kept while others are discarded [2, 3]. While good quality images can be obtained using this approach, it has been reported that ~20-40% of the scans are non usable due to poor quality [3, 4]. Motion in the images can play a significant role in determining the image quality and depends on the breathing pattern of the patient. The acquisition time can also be long. Here we propose an alternative self-navigated hybrid radial scheme that can overcome some of these limitations. We exploit the self-navigation property of a radial acquisition along with its robustness to undersampling to obtain good quality images efficiently. In addition, we use a total variation based compressed sensing reconstruction to improve the image quality from undersampled data.

Methods: A kz-first hybrid radial scheme in which spokes in 3D k-space are acquired first along the kz-dimension after the inversion pulse [5] was implemented on a Siemens 3T scanner. Computer simulation experiments in [5] showed that this scheme gave good image quality compared to a kx-ky-first scheme where spokes in-plane are acquired first. Angle spacing of 111.25^o (based on golden ratio) between spokes in-plane was used in order to gain flexibility in terms of uniformly covering kx-ky plane from arbitrary number of views [6]. Each kx-ky plane was also rotated by 111.25^o with respect to adjacent kz-encodes to help the reconstruction exploit sparsity along the z-dimension. Scan parameters for the patient acquisitions were TR=3.8 ms, TE=2.1 ms, TI=300-350 ms, flip angle=14^o, FOV=300x300 mm^2, slice thickness=2.5 mm, acquisition matrix=320x252x36. Also every heartbeat we acquired an additional anterior-posterior projection with kz=0 to identify motion across different segments of k-space for self-navigation.

Figure 1a shows such a projection image from a patient three months post-ablation. Projections from individual coil images were combined in a sum of squares fashion. The horizontal axis in the image represents different heart beats and each vertical line represents summation of signal along rows of the axial volume. We can see respiratory motion of the heart and chest wall in the top region in the image. Here we assume there is minimal motion within each segment. Inconsistent projections are automatically identified by first computing gradient of the projection image in y-direction (Figure 1b) and then using k-means clustering to separate the segments into two respiratory phases, end inspiration and end expiration as shown in Figure 1c.

The arrow in the image shows separation between the two clusters. Corresponding sorted projection image is also shown in Figure 1d. Tracking edges in 1D projection images can identify motion and the edges are robust to signal variations across different projections caused by factors such as eddy currents, gradient delays and changing heart rates. Self-navigated reconstructions are obtained by discarding inconsistent projections and using only the consistent ones. In order to improve the image quality using fewer rays we use a compressed sensing reconstruction [7,8] with a 3D total variation constraint.

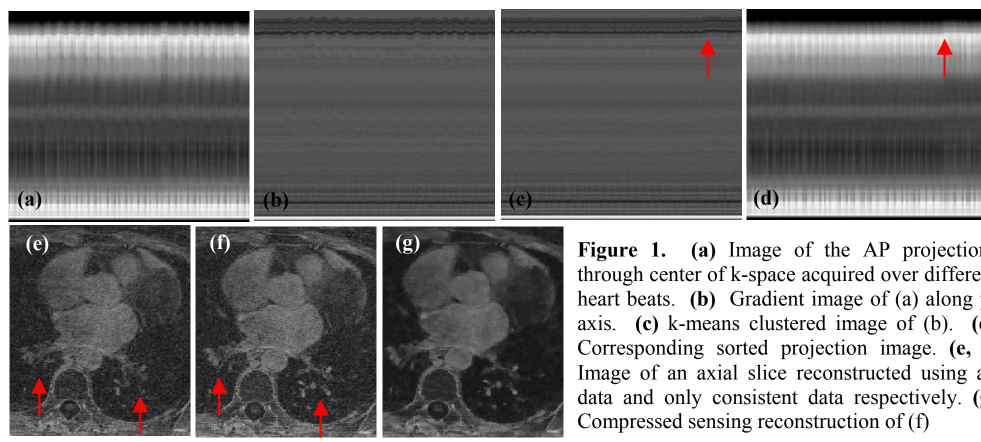

Figure 1. **(a)** Image of the AP projections through center of k-space acquired over different heart beats. **(b)** Gradient image of (a) along y-axis. **(c)** k-means clustered image of (b). **(d)** Corresponding sorted projection image. **(e, f)** Image of an axial slice reconstructed using all data and only consistent data respectively. **(g)** Compressed sensing reconstruction of (f)

Results: Images reconstructed using all of the acquired data and by throwing away the inconsistent projections are shown in Figures 1e and 1f respectively. Although the SNR is lower due to fewer rays, we can see fine structures in the lung better and the image looks less blurry than Fig 1e. Figure 1g shows the compressed sensing reconstructed image after self-navigation. Compared to Figure 1e this image looks sharper and also has 76% higher SNR. Figure 1 was from a post-ablation patient. Results from a pre-ablation patient are shown in Figure 2. Images after self navigation and compressed sensing look sharper with more fine features in the lung and better delineation of the border between the atrial blood pool and left ventricular myocardium. SNR in the image is 80% higher than Figure 2a.

Discussion: The additional projection through the center of k-space offers a more direct measurement of motion of the heart than a diaphragm based navigator. While a fixed angle projection takes an additional 3.8ms it removes variations that depend on view angle. Total acquisition time was under four minutes for the acquisitions which is on the order of half the average time with the standard Cartesian acquisition with navigator based off a diaphragm [2, 3]. Here we throw away inconsistent data with motion and use compressed sensing reconstruction to recover the image from undersampled data. Alternatively motion can be estimated from each of the projections and all of the data can be incorporated into the reconstruction with registration techniques [9].

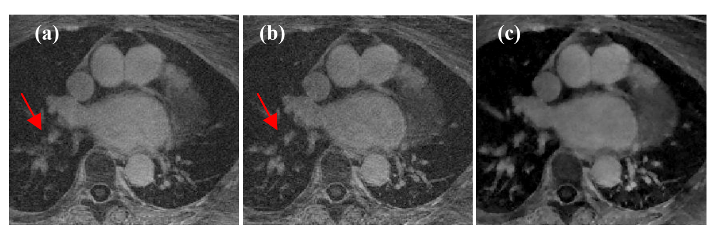

Figure 2. **(a)** Image reconstructed using all acquired data. **(b,c)** Self-navigated image for respiratory motion with standard gridding and compressed sensing reconstruction respectively

Conclusion: Self-navigated hybrid radial scheme can offer good quality LGE images of the LA efficiently. Golden angle spacing in kz helps exploit sparsity in z-dimension as well and in kx-ky offers flexibility in terms of reconstructing images from arbitrary number of rays from arbitrary heart beats.

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