3D Spiral LGE for reduced enhancement artifacts in PV imaging of pre- and post-ablation scar.

B. R. Knowles[1], W. J. Manning[1], and D. C. Peters[1]
[1]Cardiovascular Research, Havard Medical School, Beth Israel Deconess Medical Center, Boston, Massachusetts, United States

Introduction. Spurious enhancement observed in late gadolinium enhancement (LGE) MR imaging can make the interpretation of LGE images challenging. This is particularly problematic in left atrial (LA) 3D LGE imaging for the detection of the pre-existing arrhythmic substrate [1], and ablation lesions in patients with atrial fibrillation (AF) [2], since enhancement is located along the thin LA wall. Spurious enhancement, due to incomplete fat suppression or artifacts such as edge-enhancement, can confound the interpretation of these images.

LGE artifacts can be caused by modulation of the received MR signal during the 100-200ms acquisition window, after the application of a 180º inversion pulse. T1 regrowth due to the inversion pre-pulse, and the train of α-pulses disturbs the net magnetization of the tissue, varying the received signal as k-space is filled. Furthermore, artifacts from spectrally-selective fat-suppression pre-pulses are possible, due to regrowth of the fat magnetization during the acquisition, or due to imperfect shim. In this study we investigate an LGE stack-of spirals sequence to reduce spurious enhancement.

Methods ***Cartesian Sequence:*** The 3D Cartesian LGE acquisition had a TR/TE/α of 5.2/2.5ms/25º, spectrally-selective fat saturation pre-pulse, 1.4x1.4x4mm^3 spatial resolution, 30 α-pulses per heart-beat, ~150ms acquisition window, using a centric ky-space order.

Spiral Sequence: The 3D stack-of-spirals LGE sequence had a TR/TE/α of 26/4.6ms/45º. Fat suppression was achieved using 1331 spectrally selective binomial composite RF excitation pulses [3] to excite only water protons. A train of 5 TRs per heart-beat were acquired, corresponding to a 130ms acquisition window, with kz - linear acquisition.

Simulations: Bloch equation simulations were performed in MATLAB for the aforementioned Cartesian and spiral LGE sequences. The effect of a Spectral Presaturation with Inversion Recovery (SPIR) pre-pulse, where the fat signal is allowed to re-grow during read-out was also simulated. The simulated MR signal was used to weight the k-space of a numerical phantom, which was subsequently reconstructed.

Phantom Experiments: Gd-DTPA doped water phantoms with T1 values of 335 and 210ms were imaged on a 1.5T Philips Achieva MR scanner. To demonstrate the effect of edge enhancement, images were acquired with the Cartesian LGE sequence using an acquisition window of 25ms, and 150ms. For comparison, images were also acquired from the spiral LGE sequence using a 150ms acquisition window.

Patient and Volunteer Experiments: Volunteer data (n=3, mean age = 20.6±0.6) and AF patient data (n=8, pre ablation = 6, post ablation = 2, mean age = 57±20) were acquired using both the Cartesian and spiral sequences. Spiral LGE images were reconstructed offline using information from a B0 map to deblur images [4]. ROIs were drawn around the brightest areas of apparent enhancement in the LA wall, and measurements of the artifact intensity-to-blood signal was calculated. Artifact measurement was plotted against time after contrast administration

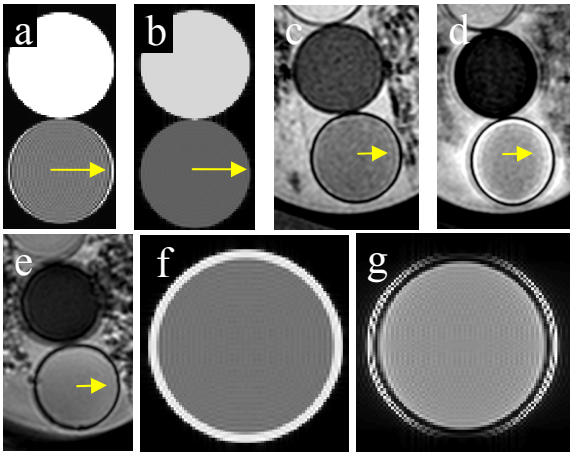

Figure 1. Demonstrations of the edge artifact observed in LGE (yellow arrow). .A-B are Bloch simulations of the Cartesian (A) and spiral LGE sequences for circles with T1 values of 300ms and 200ms (top circle and bottom circle respectively). C-D show phantom images acquired with the Cartesian LGE sequence, where the edge artifact can be observed with greater intensity for increasing acquisition window duration. (25ms and 150ms respectively). E shows the spiral LGE sequence with a 150ms acquisition window. F-G shows the effects of incomplete fat suppression using a SPIR pre-pulse. A phantom surrounded by a thin layer of fat was simulated (F). G shows the simulated artifact. It can be observed that the effect is similar to the edge artifact observed in A.

Results and Discussions. Images from the simulations and phantom experiments can be seen in Figure 1. It can be seen that the artifact observed in the simulated image (Fig 1A) closely resembles the artifact in the phantom image (Fig. 1D). Spiral LGE does not create edge artifacts (Fig 1B,E). By shortening the number of TRs per RR interval, the edge artifact becomes reduced, as can be observed when comparing Figures 1C and 1D. Incomplete fat suppression may also cause an edge-artifact, as can be seen in Figure 1G. Figure 2 shows an example of Cartesian and spiral LGE images acquired in post-ablation patient. The incomplete fat-suppression in the Cartesian LGE image is evident. Edge enhancement is also reduced in the spiral LGE images, however some areas in the images still exhibit enhancement although this is more likely to reflect fibrosis. Figure 3 shows the graph of artifact measurement in the LA with imaging time after contrast administration. While, there was no correlation between artifact and imaging time after contrast administration (correlation coefficient p-values: p=0.8 for Cartesian and p= 0.4 for spiral), the mean artifact intensity was found to be higher in the Cartesian LGE images compared to spiral LGE, with mean values of 10±4, and 6±3 respectively (p<0.005 from paired t-test), which may indicate increased artifactual edge enhancement for Cartesian LGE.

Conclusions. This study identifies an important source of artifacts (fat re-growth and edge-enhancement) in LA LGE imaging, and demonstrates the ability of spiral LGE to reduce artifacts. Water-selective pulses, possible due to spiral's increased scan efficiency, allows for more effective fat suppression. Kz-ordering eliminates the in-plane artifacts arising from signal variations in k-space. Spiral LGE provides improved imaging for LA scar.

References.
[1] Peters D.C. Radiology. 2007;243(3):690-5. [2] Oakes R.S. Circulation. 2009 7;119(13):1758-67. [3] Hore P.J. J Magn Reson 1983;54:539-542. [4] Chen W MRM 2008;60(5):1104-1111.

Acknowledgements: This work is supported by grants from the NIH: NHLBI HL098573-01 and NIBIB K01EB004434-01A1.

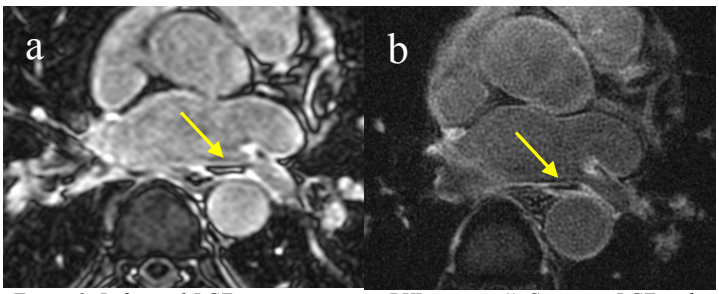

Figure 2. Left atrial LGE images in a post PVI patient. A) Cartesian LGE with a ky-centric order, B) Spiral LGE using a Kz-centric stack-of-spirals trajectory. Images were acquired 18 and 31 mins post- contrast administration respectively. Yellow arrow indicates a region of incomplete fat suppression in the Cartesian LGE image.

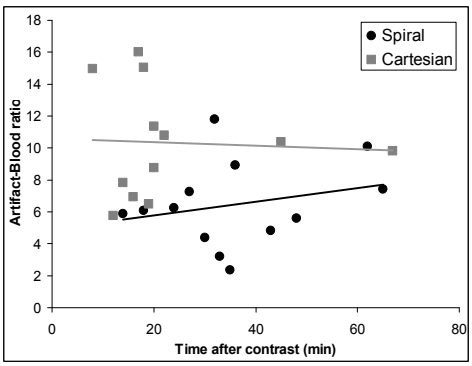

Figure 3. Graph o f aortic wall CNR vs. time after contrast administration. Aortic CNR measured on Cartesian LGE was significantly higher, compared with spiral LGE, indicating edge enhancement.