2D Diaphragm navigation with rapid gradient echo images: validation at 3T and application at 7T

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Target audience: Those interested in free-breathing thoracic imaging or ultra-high field diaphragm navigation.

Purpose: Well established pencil beam diaphragm navigation methods such as 2D excitation pulses (1) or cross paired (CP nav) spin echo acquisitions (2) become challenging above 3T. For 2D excitations, this is because B0 inhomogeneity increases (1, 3) and large B1 gradients become pronounced at ultra-high-field. For CP navigators, this is because they contribute significantly to the power deposition (4) and require extremely high B1+ for a spin echo at 7T. A novel diaphragm navigator has been developed that is robust to B0 inhomogeneity, has low power deposition, low B1+ requirements and is simple an intuitive to setup. The method rapidly acquires a low flip angle spoiled gradient echo image (GRE) in ~70 ms, resolving the diaphragm at a high resolution (1.3mm) in the head-foot (HF) direction and a low resolution anterior-posterior. The navigator is reconstructed online and feeds back the diaphragm position in real time. We validate the method at 3T and demonstrate it at 7T.

Method: A GRE acquisition was inserted into a cardiac triggered sequence as a navigator (GRE nav) with a flip angle of 5°, TR/TE of 3.7/1.6 ms. The GRE sagittal navigator acquires a matrix of 230 x 18, which is zero filled to 230 x 230 in reconstruction, a field of view of 300 x 300 mm^{2}The GRE nav is reconstructed online in real time in approximately 70 ms, edge detection is performed on the central line in HF direction using Siemens product navigator software. The GRE nav is performed online prior to the target imaging block with the feedback used to accept or reject it.

Ethics approval was granted for all scans. Three healthy volunteers were scanned at 3T both with the new GRE nav and the product CP nav. The target scan was set to acquire a short axis cardiac 2D SSFP image with an acquisition matrix of 500 x 500, a FOV of 400 x 400, flip angle of 94°, 20 segments per heartbeat, 4 mm slice thickness, set to be acquired at mid diastole. At 7T three healthy volunteers were scanned with the GRE nav to acquire a target scan of a 2D GRE short axis image with a 240x240 matrix, 300 x 300 mm^2 FOV and approximately 15° flip angle, and 5 mm slice thickness. At 7T a local 8 channel transmit-receive coil was used (3,4). Dynamic B1+ shim adjustment was performed for the diaphragm and heart ROI as in (4), and the flip angle of the GRE nav was approximately 2°.

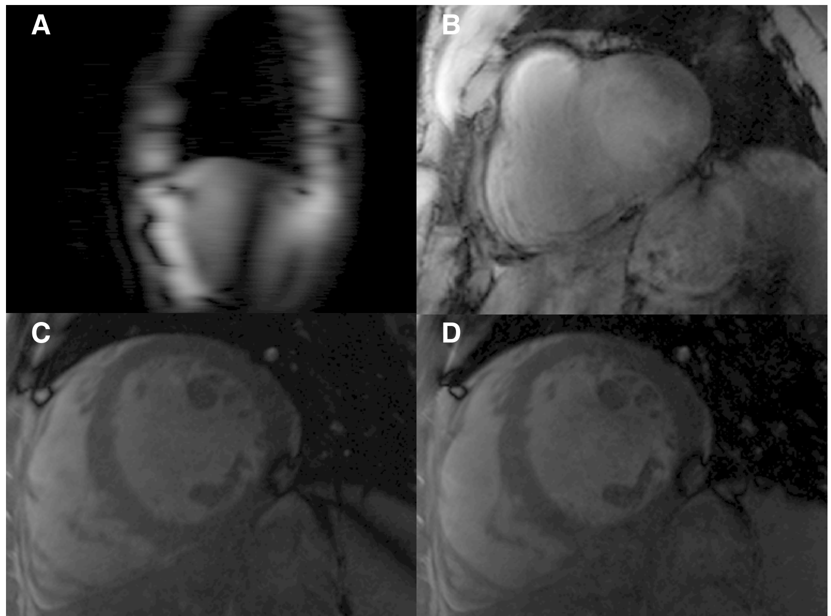

Figure A) Example diaphragm navigator at 7T in right diaphragm. B) Example short axis GRE image at 7T. C) Example high res 2D bSSFP at 3T with CP navigator. D) Example high res 2D bSSFP at 3T with GRE navigator.

For all scans the contrast of the navigators was evaluated as the difference between the average signal in a 40 mm line of the diaphragm and 60 mm line in the lung, while noise was the standard deviation of signal in the lung. Furthermore the edge sharpness of the navigator was calculated as the peak rate of change in contrast per mm at the lung-diaphragm interface.

Results: The figure shows an example 2D GRE nav at 7T, a corresponding target 2D GRE image at 7T, and two 3T bSSFP target images one with each type of navigator. At 3T the average CNR ± SD was 25 ± 9, and 27 ± 13 for the GRE nav and CP nav respectively, and 33 ± 28 for the GRE nav at 7T. At 3T the edge sharpness was 0.27 ± 0.06 and 0.09±0.03 contrast/mm for the GRE nav and CP nav respectively and 0.28 ± 0.05 contrast/mm for the GRE nav at 7T.

Discussion: At 3T The CNR of the 2D GRE nav was similar that of the CP nav while the edge sharpness was significantly greater for the GRE nav (p=0.007). Both contrast and edge sharpness were maintained for the GRE navigator at 7T, however the GRE nav demonstrated a wide range of CNR values. This wide range in 7T CNR is believed to be a result of varying B1 delivered to the diaphragm in different subjects, taking note that the diaphragm is outside of our coil FOV making it extra sensitive to this effect. The navigator has proved to be robust at 7T, intuitive and easy to use with a low contribution to SAR.

Conclusion: A 2D GRE image as a diaphragm navigator provides a robust method for free breathing abdominal imaging that is robust against B1+ and B0 inhomogeneity observed at higher field strengths, and works reliably at 7T.

References: (1) Nehrke K, Bornert P, Groen J et al. On the performance and accuracy of 2D navigator pulses. MRI, 1999;17(8):1173-1181. (2) Taylor A, Keegan J, Jhooti P et al. Differences between normal subjects and patients with coronary angiography respiratory suppression techniques, JRMI 1999;786-793. (3) Tao Y, Hess AT, Keith GA et al. Optimized saturation pulse train for human first-pass myocardial perfusion imaging at 7T. MRM 2014 doi: 10.1002/mrm.25262. (4) Hess AT, Bissell MM, Ntusi NA et al. Aortic 4D flow: Quantification of signal-to-noise ratio as a function of field strength and contrast enhancement for 1.5T, 3T, and 7T. MRM 2014, doi: 10.1002/mrm.25317. **Acknowledgments:** Grant support from the MRC (UK)