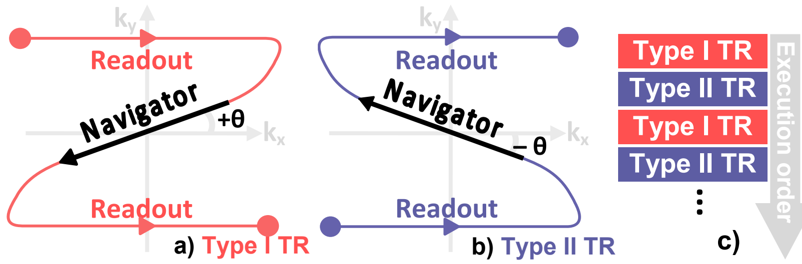
Dual-Projection Cardiac and Respiratory Self-Navigated Cine Imaging Using SSFP

L. Guo[1], E. R. McVeigh[1], R. J. Lederman[2], J. A. Derbyshire[2], and D. A. Herzka[1]

[1]Biomedical Engineering, Johns Hopkins University, Baltimore, MD, United States, [2]Translational Medicine Branch, National Heart, Lung, and Blood Institute, National Institute of Health, Bethesda, MD, United States

Introduction – Cardiac cine imaging is highly sensitive to the heart's intrinsic and respiratory motion, and often requires the use of patient breath hold or respiratory navigator to maintain image quality. When such measures are impractical due to patient ability or time constraint, self-navigated cardiac imaging offers a potential alternative [1-7]. Here we present a dual-projection self-navigated sequence that acquires a high-resolution navigation projection during every TR at alternating projection angles. Preliminary free-breathing images (automatically reconstructed) are also presented.

Theory – Starting with a "fly-back" dual-echo SSFP imaging sequence [e.g. 8], a navigation projection is inserted between the two imaging readouts. The gradient waveforms are designed such that the navigator projections cross the center of k-space at the same angle (θ) every TR, regardless of phase encoding step. However, TRs whose first readouts acquire a positive PE use the positive projection angle +θ (Type I TRs, Fig. 1a), and those that have a negative first PE use the complementary alternate k-space trajectory with the negative projection angle, –θ (Type II TRs, Fig. 1b). Overall, the two types of TRs (I & II) are alternated such that each of the two navigator projections is acquired with a temporal resolution of 2TR (Fig. 1c). Corresponding readouts from TR I and TR II are reconstructed separately and are combined in the image domain. The alternation of TRs projects cardiac and respiratory motion onto two different axes, enabling 2D motion tracking. Note that TR is the same for both types and is minimized (taking into account both projection angle and nav resolution) to avoid SSFP artifacts at long TRs.



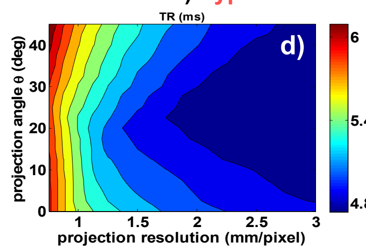


Figure 1. a) Type I TR (first readout in $+k_y$, +θ projection). b) Type II TR (first readout in $–k_y$, –θ projection. c) Interleaved execution order of Type I and II TRs. d) TR as a function of projection angle and projection resolution for a 256x192px 360x270mm scan with a constant 270mm nav FOV. Note that a finer projection resolution results in a larger extend of the projection's k-space trajectory and therefore longer gradient transition time to and from readouts.

Methods – **Pulse Sequence**: To minimize TR, HOT (Hardware Optimized Trapezoid) gradient waveforms design [9,10] is used. Because TR significantly depends on θ, the optimal ±θ for minimum TR is automatically chosen by the sequence. **Simulation**: the HOT gradient waveform design was directly ported from the MR to MATLAB (The MathWorks, Natick, MA) to guarantee an exact match between simulations-scanner behaviors. **Image acquisition**: 6 normal volunteers were imaged using a 1.5T Avanto or Espree system (Siemens Medical Solutions, Erlangen, Germany) with a 32-channel cardiac phased array (Rapid Biomedical, Rimpar, Germany), with informed consent and local IRB approval. Both short- and long-axis views were acquired, with sampling matrices ranging from 256x224 to 196x162. The max gradient and slew rate ranged 30~40mT/m and 110~140mT/m/ms respectively. The optimized positive θ ranged 15~45° and the projections contained 128~256 samples. Minimized TRs ranged from 4.4ms to 5.5ms. For reference, standard breath-hold cine images were acquired using the same imaging parameters. **Motion Detection**: the temporal Fourier transform of the navigator projections was used to automatically identify pixels with high power in either cardiac or respiratory frequencies. A linear combination of the signal intensities of those pixels were used to generate separate indicators for cardiac and respiratory.

Results – Fig. 2a,b) show the nav projections of a free-breathing scan using θ=±30° projection angles (TR=4.6ms), with automatically extracted cardiac and respiratory motion indicators superimposed. Fig. 2c~f) show breath-hold and free-breathing images from the same volunteer.

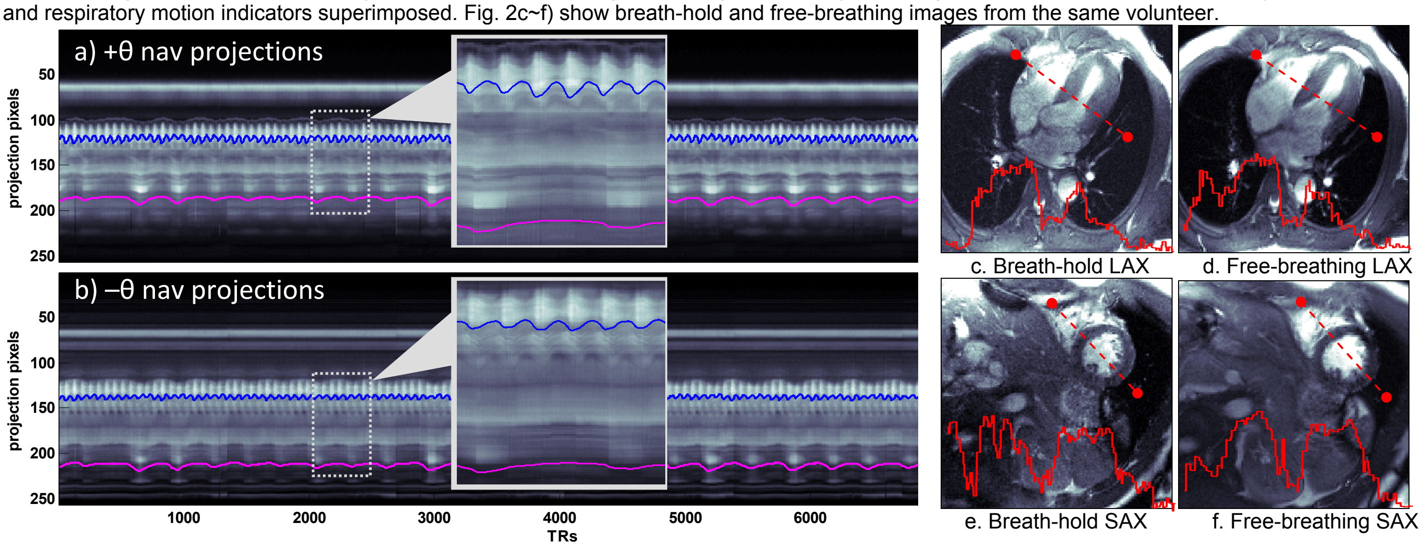


Figure 2 a~b). Navigation projections acquired during a single free breathing scan at projection angles of ±θ. Blue and purple traces are automatically extracted metrics indicating cardiac and respiratory motion. Zoomed portions show 6 cardiac cycle and one respiratory cycle. Standard breath-hold LAX & SAX images (**c**,**e**) are compared with equivalent self-navigated (**e**,**f**) examples (TR=4.66ms).

Conclusion and Discussion – The dual-projection sequence presented here provides cardiac and respiratory motion metrics as viewed from two orientations, potentially providing more robust self-navigation than existing sequences. Preliminary processing has been able to automatically reconstruct comparable free-breathing images; the quality of the cardiac-motion trace suggests that it is possible to also eliminate ECG gating.

References – [1]: Larson et al. MRM 51 2004; [2] Larson et al. MRM 53 2005; [3] Larson et al. MRM 46 2001; [4] Lai et al. MRM 59 2008; [5] Buehrer MRM 60 2008; [7] Uribe et al. 57 MRM 2007; [8] Herzka MRM 47 2002;[9] Atalar MRM 13 1994; [10] Derbyshire 2416 ISMRM 2006;