# Spiral Steady State Free Precession Imaging with the Diminishing Variance Algorithm for High Resolution Coronary Artery Imaging

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**Synopsis**: A breath-held, cardiac-gated, fat-suppressed, steady state free precession (SSFP) sequence with short spiral readouts can produce high-resolution images of the coronary arteries; however, the resolution and SNR are limited by breath-hold length. The diminishing variance algorithm (DVA) reduces motion artifacts while maintaining SNR and allowing free breathing. It monitors heart position using navigators and iteratively improves a base image by re-acquiring motion-afflicted data. By combining a cardiac-gated, fat-suppressed, spiral SSFP sequence with navigated imaging using DVA we have the ability to produce sub-millimeter resolution coronary artery images in free-breathing subjects with good contrast and high SNR.

**Introduction**: Imaging the coronary arteries is important for diagnosing and treating a variety of coronary artery diseases. To be a viable tool, coronary MR images must have good contrast, high SNR, high resolution and minimal artifacts from cardiac and respiratory motion. A cardiac-gated, steady state free precession (SSFP) sequence with fat-suppression and spiral readouts can achieve 1.2 mm by 1.2 mm resolution over a 14 heartbeat breath-hold with high contrast (1). Spiral imaging gradients are used because they provide efficient k-space coverage and have good flow properties. In this work, we integrated a cardiac-gated, fat-suppressed SSFP sequence with short spiral readouts with the diminishing variance algorithm (DVA) (2) to allow free-breathing while reducing motion artifacts. The longer scan times made available by relaxing the breath-hold constraint allow aggressive sequence design that can yield sub-millimeter resolution with high SNR and good contrast.

**Method**: The pulse sequence in Figure 1 shows the combination of a spiral SSFP sequence with update-mode DVA (described below). The spiral SSFP sequence consists of (A) global fat suppression, (B) a short catalyzation to steady-state, (C) a series of short spiral readouts while in the steady state, (D) a dephasing crusher gradient and (E,F,G) three orthogonal navigators. The (A) fat suppression block is played immediately before the SSFP sequence begins. A 100 degree spectral tip followed by a spoiler gradient saturates the lipid signal (3). To catalyze steady-state, (B) two slice-selective excitations are spaced TR apart with flip angles of 20$^o$ and 40$^o$. The sequence is designed to use ramp catalyzation (4,5) for *N* segments, where the flip angle linearly increases toward the final flip angle over the first *N* non-imaging TRs. The SSFP sequence is achieved by repeating slice-selective excitation pulses (60$^o$ flip angle) with slice-select and imaging gradients fully rewound over a TR of 5.8 ms. Chopping is used to place on-resonance spins in the SSFP signal passband. Next, (C) eight SSFP spiral imaging TRs are played. These eight interleaves are acquired in a 46ms window. Then, a (D) crusher is played on the Z gradient to dephase any remaining signal. Finally, (E,F,G) three non-overlapping orthogonal navigators are acquired (placed in the S/I, A/P and R/L direction over the heart) and used by the DVA to calculate heart position. Each navigator is a 2 cm cylindrical excitation with a 1D readout along the excitation axis. They are acquired immediately after each image data acquisition to avoid image saturation. Each navigator is cross-correlated with a reference navigator to determine relative position to a resolution of 0.4 mm. Unlike the original DVA, each set of navigators now corresponds to eight frames of imaging data. After a complete image set has been acquired, the DVA finds the most common heart position (mode position). The DVA then iteratively re-acquires and replaces the sets of interleaves that were acquired with the heart furthest from this mode position. As the sequence progresses, the mode is updated to adjust for patient movement. Scans were performed on a GE Signa 1.5T CV/i scanner (40 mT/m, 150 mT/m/s, 5” receive coil).

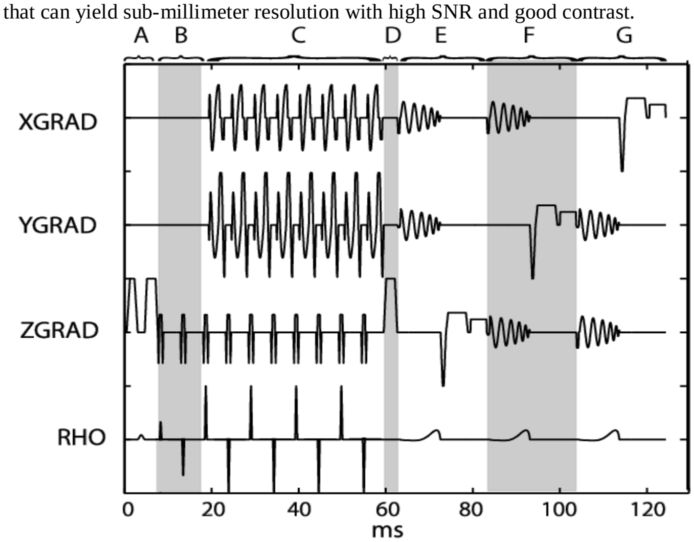


**Figure 1**: Sequence with (A) fat-suppression, (B) catalyzation of steady state, (C) spiral readouts during steady state, (D) dephasing spoiler, (E,F,G) navigators.

**Results**: Figure 2 shows an image (0.8 mm resolution) of the right coronary artery (RCA) before DVA and after convergence. The initial image suffers from severe motion artifacts. After three DVA overscan periods (an overscan period is equal to the amount of time to collect the initial image), the RCA becomes more clear and a cross-section of the left main artery (LM) appears.

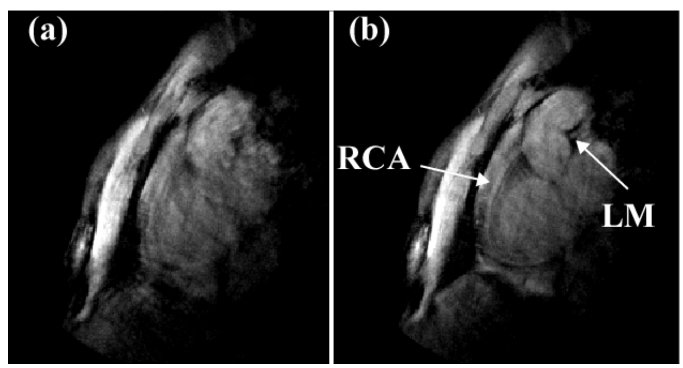


**Figure 2**: Images of the Right Coronary Artery (RCA) using 144-interleaf spiral readout with 0.8 mm resolution with a 24 cm FOV (a) before DVA and (b) after three overscan periods.

**Discussion**: Combining spiral SSFP with DVA requires modifications to the DVA. To keep the S/I navigator accurate, a Z gradient spoiler is used to dephase spins. Because a single set of navigators is used for every eight data acquisitions, the DVA transfers eight sets of imaging data each time the image is updated. The eight interleaves acquired together can be grouped in different ways. Additionally, navigator integrity can be added to improve the navigator accuracy (6). Further research will be done to determine how to best improve fat suppression and collect position information more frequently.

**Conclusion**: This work combines the advantages of two useful methods. Spiral SSFP with DVA allows for an aggressive sequence design that can produce sub-millimeter resolution coronary artery images with high SNR and contrast in free-breathing patients.

**References:**

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