# Rapid Imaging using a 3D Cones Trajectory and Balanced SSFP

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## Introduction

Radial imaging trajectories offer many benefits including isotropic resolution, insensitivity to flow and motion and the ability to trade off scan time against the structured noise-like artifacts resulting from undersampling. Examples include 3DPR[1] and the hour-glass (or 3D Cones) trajectory [2,3]. It is desirable to use the 3D Cones trajectory with balanced SSFP to provide rapid acquisition of high-SNR 3D images. The properties of balanced SSFP must be carefully considered in the design of an appropriate 3D Cones trajectory.

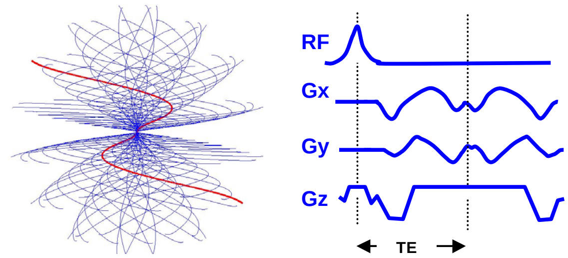


**Figure 1** *k-space trajectory and gradient waveforms for SSFP 3D Cones. The origin is sampled at TE = TR/2.*

## Theory

In order to take full advantage of the benefits of balanced SSFP, the following properties must be considered. First, the $0^{th}$ and $1^{st}$ moments should be fully rewound over the course of a TR in order to maintain a steady state even in the presence of flow. Ideally, the origin of k-space should be sampled at TE = TR/2 where the spins are fully refocused. Finally, in order to reduce the characteristic banding artifacts of SSFP, the TR should be kept small (1/TR should be greater than the maximum range of expected frequency inhomogeneities.)

## Methods

The 3D Cones trajectory optimized for SSFP is made up of a spiral-in/spiral-out trajectory in the $k_x$-$k_y$ plane, and a PR spoke in the $k_z$-axis (see Fig.1). The symmetry of this trajectory results in fully rewound $0^{th}$ and $1^{st}$ moments and also ensures that the origin is sampled at TR/2. The selection of the TR is a tradeoff. Very short TRs do not allow enough time for twist in the spirals and the 3D Cones effectively become 3DPR. A longer TR allows more twist in the spiral and consequently less required interleaves relative to PR (as shown in Fig.2 for gradients with a maximum slew-rate of 150T/m/s) but can cause banding in SSFP. The TR was chosen to be 6 ms which allows for inhomogeneities up to +/-50 Hz at 1.5 T and also places fat and water in opposite phase bands for SSFP phase-based fat-water separation [4].

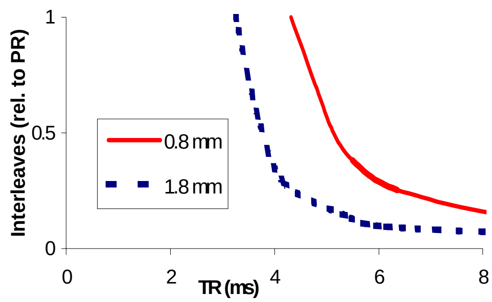


**Figure 2** *Reduction in interleaves of the spiral as a function of increased TR*

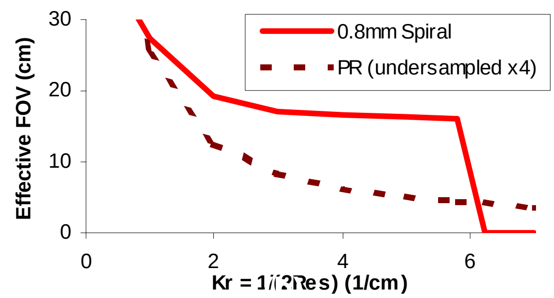


**Figure 3** *Comparison of the effective FOV for spiral and PR (for equal number of interleaves)*

## Results

To compare undersampled SSFP 3D Cones to undersampled SSFP 3DPR, the entire 20x20x32 cm volume of a resolution phantom was imaged at 1.5 T with 0.8 mm resolution using both 3DPR and 3D Cones. As shown in Fig. 2, with TR = 6ms, 3D Cones require about 25% of the interleaves of fully sampled 3DPR for 0.8 mm resolution. For the same number of interleaves, 3DPR must be undersampled 4 times less adequately. As shown in Fig. 3, this will result in a lower effective FOV at higher values of k-space causing noticeably more high-frequency structured (aliased) noise to appear in the image (see Fig. 4).

Moving to a lower resolution (1.8 mm) gives 3D Cones a more dramatic reduction in required interleaves for a TR = 6 ms. In this case, only 10% of the interleaves are required for 3D Cones relative to PR. This allowed a full volume encompassing the heart to be obtained in 500 heartbeats, as shown in Figure 5. No breathing compensation/correction was performed. For 3D Cones (as with 3DPR), this results in blurring and not the introduction of ghosting artifacts. The image will be significantly improved once respiratory gating is performed.

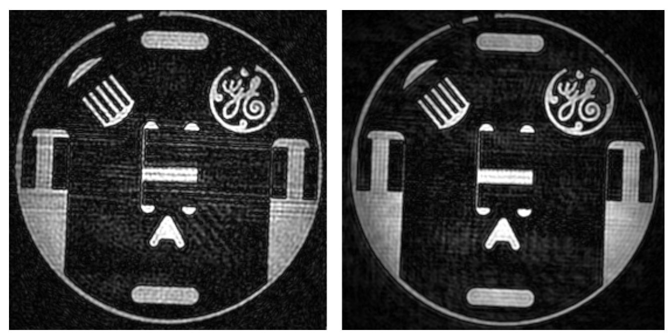

**Figure 4:** *Slices from a 20x20x32 $cm^3$ 3D dataset (0.8mm resolution) for (a) 3DPR (undersampled by 16) and (b) 3D Cones (undersampled by 4). 16000 interleaves each (96 s)*

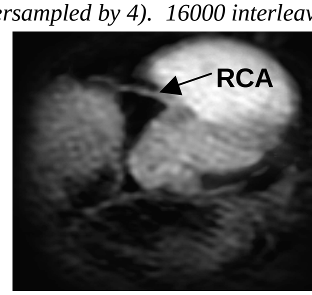


**Figure 5:** *Curved-Planar Reformat of a 24x24x16 $cm^3$ dataset showing the coronary arteries. (Cardiac gated, 500 heartbeats, 1.8 mm resolution using SSFP 3D Cones, TR=6 ms, flip=55$^o$) No breathing compensation (causes blurring).*

## Conclusions

3D Cones is a well-suited imaging trajectory for balanced SSFP imaging, which can be used to lower the required number of interleaves vs. 3DPR while still providing the same desirable properties (such as insensitivity to flow and motion). Dramatic decreases in required number of interleaves can be achieved, especially for less aggressive TRs and moderate resolutions.

## References

[1] Vigen *et al.*, MRM 2000 43:170-176.
[2] Irarrazabal *et al.*, MRM 1995 33:656-62.
[3] Thedens, #1002, ISMRM Toronto 2003.
[4] Hargreaves *et al.*, MRM 2003 50:210-213.