

# Cardiac Imaging using Echo-Planar Steady-State Free Precession

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## Introduction

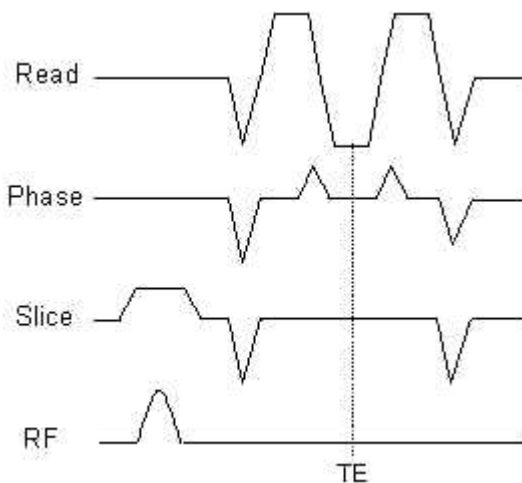
With the greater availability of high-performance scanner hardware, multi-shot echo-planar imaging (EPI) has found widespread use in both clinical and research applications. Consistently high image quality has been observed when the data acquisition window is kept short. This is achieved with the use of short echo-train lengths (ETLs) and high sampling bandwidths. As a result, EPI is often more SNR-limited than other short-TR, low-flip-angle, gradient-echo (GRE) sequences, such as FLASH or GRASS.

The recently renewed attention to ultrashort-TR, steady-state free precession (SSFP) imaging (e.g., TrueFISP, FIESTA) [1] has provided the impetus for increasing the SNR of otherwise low-SNR, fast-imaging sequences. A combined SSFP-EPI technique could offer the increased imaging speed of EPI over conventional GRE imaging while avoiding the limited SNR of standard GRE-EPI [2].

The purpose of this work was to develop a more efficient SSFP imaging sequence for cardiac imaging applications. Design criteria included using an echo-planar readout and maintaining a very short TR, without increasing motion sensitivity.

## Methods

The SSFP-EPI pulse sequence is shown in Figure 1. An ETL of 3 was used to keep the TR short and to preserve the symmetry of the readout gradient about the effective echo time TE, which occurred on the second gradient echo. The symmetry afforded by an odd ETL maintains the nulled first moment (for motion compensation) of the readout gradient at each RF pulse. Furthermore, unlike single-echo SSFP, SSFP-EPI with an odd ETL also provides gradient moment nulling at TE. The first moment of the slice-select gradient and the zeroth moments of all gradients are also nulled within each TR. To minimize the TR, each echo was acquired with 128 points.



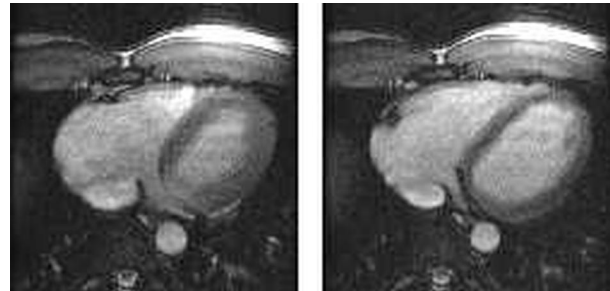
**Fig. 1.** SSFP-EPI pulse sequence timing diagram. The read gradient has zero first moment at each RF pulse as well as at the second gradient echo (i.e., the effective TE).

Initial feasibility studies were made on phantoms to assure comparable image quality of SSFP-EPI with conventional SSFP and GRE-EPI sequences. To assess potential clinical utility, SSFP-EPI cardiac cine scans were performed on healthy adult volunteers under an IRB-approved protocol. Scans were performed in both axial and double-oblique planes. Imaging was carried out on a 1.5 T Signa CV/i scanner

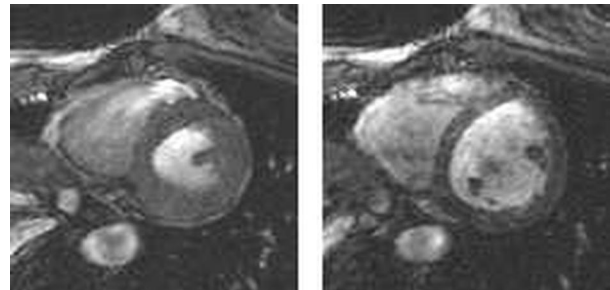
(GE Medical Systems, Milwaukee, WI) with 40 mT/m peak gradients and 150 T/m/s maximum slew rate. The axial scans used the following parameters: TR/TE/flip 4.9/2.1/40°; 39 msec temporal resolution; 40 x 30 cm FOV. The double-oblique scan used: TR/TE/flip 5.6/2.5/90°; 45 msec temporal resolution; 26 x 20 cm FOV. Other parameters included: ETL 3; 128 x 192 matrix (frequency vs. phase); 250 kHz bandwidth; 24 views per segment; 6-heartbeat scan time.

## Results

Figures 2 and 3 show end-systolic and end-diastolic phases of the SSFP-EPI cardiac cine scans in axial and double-oblique planes, respectively. The relatively low resolution of the axial images (Fig. 2) is due primarily to the large FOV and low frequency resolution.



**Fig. 2.** Axial SSFP-EPI cine images at end-systole and end-diastole. (TR/TE/flip 4.9/2.1/40°; 40 cm FOV)



**Fig. 3.** Double-oblique SSFP-EPI cine images at end-systole and end-diastole. (TR/TE/flip 5.6/2.5/90°; 26 cm FOV)

## Discussion

This work has demonstrated the feasibility of an echo-planar SSFP sequence for cardiac cine imaging. With a data acquisition window of less than 3 ms, this sequence can provide SNR similar to single-echo SSFP sequences, but with a shorter effective TR per view (i.e., TR/ETL). This can be exploited by 3D or cine acquisitions, for example, by allowing higher temporal resolution or shorter scan times. Low-resolution cardiac monitoring during stress function exams could particularly benefit from the high SNR and increased frame rate.

Further study is required to optimize the flip angle and, especially, the frequency-encoding resolution. One option that would not substantially increase TR is to use a reduced FOV in the frequency-encoding direction. Additional work is also needed to characterize image contrast and flow sensitivity.

## References

1. Oppelt, A. et al., *Electromedica*, **54**:15 (1986).
2. Heid, O. et al., Proc. 3<sup>rd</sup> ISMRM, 481 (1995).