## Gated and Real-time Wideband SSFP Cardiac Imaging at 3T

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**Introduction:** SSFP cardiac imaging provides excellent blood-myocardium contrast and has become a standard procedure at 1.5T. At 3T, MR imaging benefits from doubled SNR [1] but the susceptibility-induced off-resonance is also doubled. In clinical scans conventional SSFP requires a TR of 3 ms or less to avoid banding artifact [2], which limits readout duration to about 1.5 to 2 ms. This short readout duration effectively limits spatial resolution and prevents the use of time-efficient readout schemes such as EPI or spirals, which have been successfully combined with cardiac SSFP at 1.5T [3,4] but not 3T.

Wideband SSFP (wbSSFP) uses two alternating TRs to establish a steady state with two different echoes; both of them have a passband width of about 2/(TR+TRs) [5]. Thus for the long-TR echo readout duration is no longer limited by 1/BW. wbSSFP provides an efficient scheme for acquiring SSFP cardiac images at 3T with long readouts, which will allow the high SNR of 3T SSFP to be translated into higher spatial resolution and temporal resolution. In this work we implemented wbSSFP for both gated and real-time cardiac imaging at 3T and compared it to conventional SSFP.

**Method:** Volunteer cardiac scans were performed on a GE Signa Excite 3T scanner with an 8-channel cardiac phased-array coil. 2DFT readout was used for gated imaging with parameters: FOV = 30 cm, in-plane resolution = 1.2 × 1.2 mm (256 × 256 acquisition matrix), slice thickness = 8 mm, flip angle = 30°, TR = 4.8 ms for SSFP and TR/TRs = 4.8/2.4 ms for wbSSFP. TE was set to TR/2 in all scans. Simulation suggests that with these parameters the null-to-null spacing should be 287Hz for wbSSFP and 208Hz for SSFP. Plethysmograph gating was used for a total breath-hold time of 16 R-R intervals. The temporal resolution was 115.2 ms for wbSSFP and 76.8 ms for conventional SSFP.

Real-time gradient echo (GRE), SSFP and wbSSFP scans were performed using the same three-echo EPI readout of 3.2 ms duration. All sequences were implemented within a custom real-time imaging system [6]. 29 interleaves were used to achieve an 87 × 87 matrix and approximately 2 mm in-plane resolution. Imaging TR was set to minimum for GRE and SSFP sequences. GRE sequence has TR = 5.8 ms (temporal resolution 169 ms) and flip angle = 30°, conventional SSFP has TR = 5.5 ms (temporal resolution 159 ms) and flip angle = 30°, wbSSFP has TR/TRs = 5.1/2.4 ms (temporal resolution 217.5 ms) and flip angle = 45°. Localized linear shimming and center frequency determination were used.

**Results and Discussion:** Figure 1 contains two sets of short-axis images obtained with wbSSFP and SSFP. Both sequences showed high contrast between blood and myocardium. In Fig.1b banding artifact appears inside the heart because of the insufficient bandwidth to cover the off-resonance across the whole heart. For wbSSFP with TR/TRs = 4.8/2.4 ms, the central pass band is about 1.33 times wider than SSFP with TR = 4.8 ms. This increased bandwidth effectively shifted the dark band out of the heart (Fig.1a). In Fig.1d there is a severe through-plane flow transient artifact near the left ventricle area that obstructs the cardiac assessment. This kind of artifact arises when signal void occurs at a location where through-plane flow has a variable velocity [2,7]. It will not be present if there is no dark band within the blood pool, as in Fig.1c.

Figure 2 shows sample frames from short-axis real-time EPI scans. GRE images (Fig.2a) do not experience "banding" artifact but the blood-myocardium contrast depends on inflow and varies throughout the cardiac cycle. Banding and transient flow artifacts were observed in conventional SSFP images (Fig.2b). With the same readout duration wbSSFP successfully avoided off-resonance banding in left ventricle (LV) while exhibiting a consistent contrast (Fig.2c).

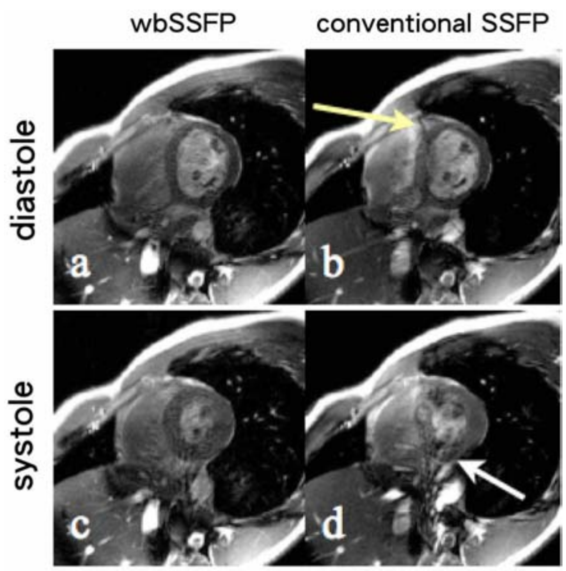


**Figure 1** Short-axis images at end-diastole (a & b) and end-systole (c & d). a and c were obtained with wbSSFP (TR/TRs = 4.8/2.4 ms); b and d were obtained with SSFP (TR = 4.8 ms). White arrows indicate banding artifacts and transient artifacts caused by flow through spectral bands. Wideband SSFP is less sensitive to off-resonance, with a 33% wider bandwidth in this case.

**Conclusion:** We have demonstrated gated and real-time cardiac imaging at 3T using wideband SSFP. wbSSFP sequence yielded high blood-myocardium contrast which is comparable to SSFP. Off-resonance banding artifact was suppressed in wbSSFP given the same readout duration and spatial resolution as conventional SSFP. The improved readout duration made it possible to implement time-efficient acquisition schemes, which can be used to shorten the length of breath-hold or to do free-breathing real-time imaging. Our preliminary EPI-wbSSFP results show the feasibility of implementing SSFP-based sequences for real-time cardiac imaging at 3T, and suggest potential clinical applications.

**References:** [1] Wen et al., JMR 125:65-71(1997) [2] Schär et al., MRM 51:799-806(2004) [3] Herzka et al., MRM 47:655-664(2002) [4] Nayak et al., MRM 53:1468-1473(2005) [5] Nayak et al., ISMRM 2005 p.2387 [6] Santos et al., IEEE EMBC 2004 p.1048-1051 [7] Markl et al., MRM 50:892-903(2003)

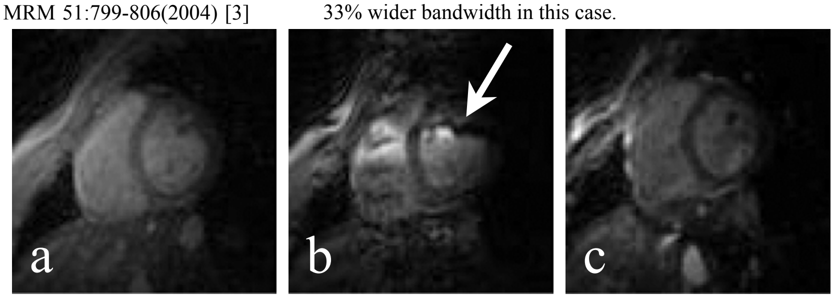


**Figure 2** Real-time multishot EPI short-axis images at end-diastole. a: GRE (TR=5.8ms); b: SSFP (TR=5.5ms); c: wbSSFP (TR/TRs = 5.1/2.4 ms). White arrow indicates severe banding artifact inside the LV area.