High-Resolution 3D Breath-hold Coronary Artery Imaging at 3T using Wideband SSFP

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Introduction The challenge for breath-hold coronary artery imaging is to acquire adequate SNR, blood-myocardium contrast and spatial resolution within limited scan time. The application of SSFP sequences at 1.5T has shown excellent results [1] with increased SNR and CNR compared to GRE. SSFP at 3T has also been used to generate coronary artery images [2] with substantially higher SNR and blood-myocardium CNR compared to 1.5T. Because of the increased B_0 inhomogeneity, SSFP image quality at 3T is unstable. The need for a short TR [3] limits the usable readout duration, and makes it difficult to achieve sub-millimeter spatial resolution, which is needed for diagnostic quality coronary artery imaging.

Wideband SSFP (wbSSFP) uses two alternating repetition times to remove the 1/BW TR limitation, and allows a flexible trade-off of the high SNR of 3T SSFP for an increased bandwidth [4]. It has been shown that wbSSFP can suppress off-resonance related artifacts in SSFP cardiac imaging for a given spatial resolution [5]. This work describes the application of wbSSFP technique to 3D breath-hold coronary artery imaging at 3T and compares the results to conventional SSFP and GRE sequences.

Method Coronary artery scans were performed, after informed consent, in volunteers on a GE Signa Excite 3T scanner with an 8-channel cardiac phased-array coil (GE Healthcare Technologies, Waukesha, WI). The gradient system has a maximum amplitude of 40 mT/m and a maximum slew rate 150 mT/m/ms. Slab-selective three-dimensional SSFP/wbSSFP/GRE sequences were used to image the left main coronary artery (LMCA) in mid-diastole. The sequences used a spectrally-selective fat saturation pulse and 64 phase-encoding steps for GRE and conventional SSFP, and 42 steps for wbSSFP per R-R interval. Two sets of images with different spatial resolution were acquired using GRE, SSFP and wbSSFP. Imaging parameters for the low-resolution scans were: FOV = 26 × 19.5 cm, in-plane resolution = 1.0 × 1.5 mm (256 × 128 acquisition matrix), through-plane resolution = 3 mm, flip angle = 40°, TR = 3.3ms for SSFP and TR/TRs = 3.3/2.2 ms for wbSSFP (where TRs is the alternate short repetition time). Imaging parameters for the high-resolution scans were: FOV = 26 × 19.5 cm, in-plane resolution = 0.5 × 1.5 mm (512 × 128 acquisition matrix), through-plane resolution = 3 mm, TR = 4.2 ms for SSFP and TR/TRs = 4.2/2.2 ms for wbSSFP. The synthesizer frequency was manually adjusted for proton excitation. Plethysmograph gating was used for a total breath-hold time of 24 R-R intervals for wbSSFP and 16 R-R intervals for conventional SSFP and GRE.

Results and Discussion Figure 1 shows LMCA images with 1.0 × 1.5 mm in-plane resolution. With imaging TR = 3.3ms, conventional SSFP (Fig.1b) has sufficient bandwidth to cover the off-resonance across the ROI and shows higher SNR and CNR compared to GRE (Fig.1a). The wbSSFP image (Fig.1c) also has a clear ROI and lower SNR than conventional SSFP.

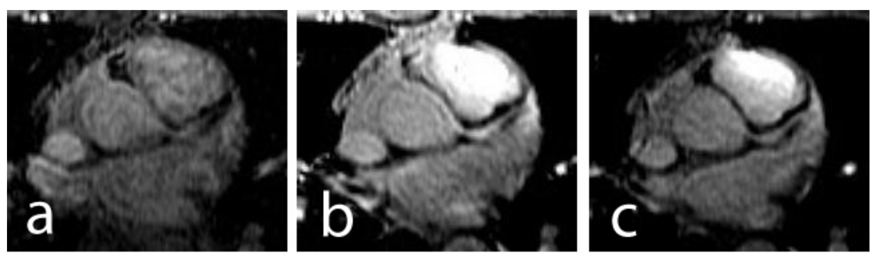

Figure 1. LMCA images at mid-diastole. The in-plane resolution is 1.0×1.5mm. a: GRE (TR=4.2ms, SNR~18); b: SSFP (TR=4.2ms, SNR~27); c: wbSSFP (TR/TRs = 4.2/2.2 ms, SNR~23).

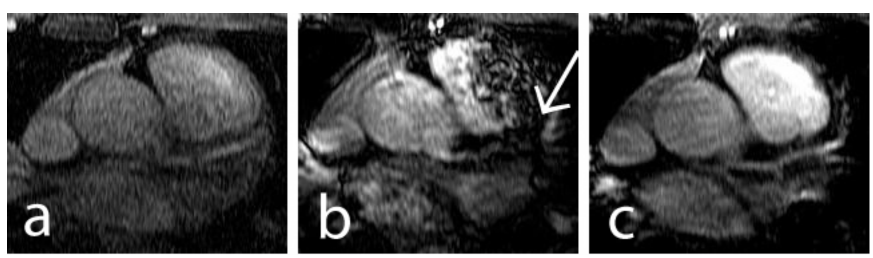

Figure 2. High-resolution LMCA images at mid-diastole. The in-plane resolution is 0.5×1.5mm. a: GRE (TR=4.2ms, SNR~15); b: SSFP (TR=4.2ms, SNR~23); c: wbSSFP (TR/TRs = 4.2/2.2 ms, SNR~19). White arrow indicates severe off-resonance artifact inside the ROI.

Figure 2 shows LMCA images with 0.5 ×1.5 mm in-plane resolution. As the TR was increased to 4.2ms, banding artifacts obstruct the ROI in conventional SSFP (Fig.2b). wbSSFP with TR/TRs = 4.2/2.2 ms is expected to have a 30% wider null-to-null spacing (~310Hz) compared to SSFP with the same TR. This increased bandwidth successfully removes the off-resonance artifacts from the ROI (Fig.2c). The GRE image (Fig.2a) is free from off-resonance artifacts but has much lower SNR. In the wbSSFP scans partial-α-half-TR followed by 10 dummy cycles was played after fat saturation pulse to reduce the transient magnetization fluctuation. Both the magnetization transient behavior and fat suppression can be improved by using a catalyzation method optimized for wbSSFP, such as modified TIDE [6,7]. Resolution in the phase-encoding direction was kept low in these scans in order to complete the acquisition in a single breath-hold, and can be increased by incorporating parallel imaging techniques [8,9].

Conclusion We have demonstrated coronary artery imaging at 3T using a three-dimensional wbSSFP sequence. An in-plane resolution of 0.5 mm was obtained along the frequency-encoding direction in one breath-hold. Our preliminary results demonstrate the ability of this technique to utilize the high SNR of SSFP-based sequences at 3 Tesla to achieve high spatial resolution in coronary artery imaging with desired contrast. To establish its clinical efficacy, further improvements such as effective magnetization preparation schemes are necessary and are currently being investigated.

References [1] Deshpande et al., MRM, 46:494-502(2001) [2] Stuber et al., MRM, 48:425-429(2002) [3] Schär et al., MRM, 51:799-806(2004) [4] Nayak et al., ISMRM 2005 p.2387 [5] Lee et al., ISMRM 2006 p.143 [6] Huang et al., ISMRM 2006 p.663 [7] Paul et al., ISMRM 2006 p.2445 [8] Park et al., MRM 52:7-13 (2004) [9] Niendorf et al., MRM 53:885-894 (2005)