# Steady-state first-pass perfusion (SSFPP): A 3D "TWIST" in myocardial first-pass perfusion imaging

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**Introduction**: Despite significant technological advances, myocardial perfusion assessment using first-pass contrast-enhanced MRI has not yet become a routine diagnostic tool, primarily because of insufficient image quality, insufficient coverage, and dark rim artifacts (DRA) [1]. Current techniques relying on saturation recovery (SR) preparation for T1 contrast result in poor SNR, low efficiency, and k-space modulation during SR. Further, the analysis of these images is tedious, with a clinical trial reporting ~30 minutes/patient [2]. In this work, we propose an alternative perfusion imaging technique, called Steady-State First Pass Perfusion (SSFPP).

**Objective:** To develop a new 3D first-pass perfusion imaging technique that can potentially address the limitations of current methods and report initial experience in volunteers and one patient.

**Theory:** SSFPP is a 3D SSFP sequence in which the magnetization is maintained in constant steady-state while the data acquisition is gated to diastole. The SNR and CNR are similar to those in SSFP cine imaging, allowing the use of automatic segmentation algorithms. Furthermore, the tissue contrast is dependent on T1/T2; serendipitously, this causes blood signal to remain almost constant, whereas the myocardial signal exhibits a nearly linear correlation with contrast agent concentration (Fig 1); this has the additional benefit of reducing the step in signal intensity between myocardium and blood upon the arrival of bolus, thereby mitigating the effect of Gibbs ringing on DRA [1]. Maintenance of steady-state throughout data acquisition avoids k-space modulation, and the elimination of saturation recovery time increases data acquisition efficiency by reducing dead time.

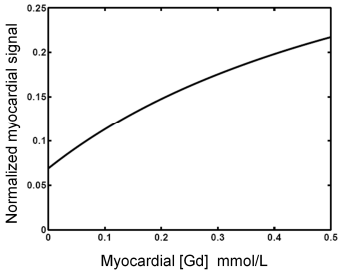


**Figure 1:** (Simulation) Relation between steady-state SSFP signal and [Gd] in myocardium. These simulations consider the relaxivities and recommended dosage of Multihance.

**Materials and Methods:** SSFPP was implemented on a 1.5T scanner (Avanto, Siemens). RF pulse (time-bandwidth product = 10, flip angle ~40°.) was optimized for 3D slab excitation profile. Other parameters: resolution ~2.2x2.8x8mm$^3$, matrix 160x103x6, slab oversampling 33.3%, TR = ~2.7 ms, Multihance (0.1 mmol/kg). Acceleration of 3D k-space was achieved using a combination of partial fourier (7/8 in both PE and slice directions), GRAPPA (rate 3 in PE; 24 intrinsic reference lines) and TWIST [3] acquisition schemes. For TWIST, central 4% of k-space was updated every frame, whereas the peripheral region was undersampled at 33%, leaving a "temporal footprint" of 3 heart beats (Fig 2). Acquisition time per 3D frame was ~300-340 ms. Resting perfusion images were acquired in 7 healthy subjects and one patient with undiagnosed cardiomyopathy during contrast agent injection to evaluate feasibility of this new method.

Non-rigid registration, optimized for dynamically varying contrast [4], was used for three-dimensional motion-correction prior to automated contouring (Argus, Siemens) of endo and epicardial borders. To enhance the visualization of first-pass wash-in and wash-out kinetics, a dynamic series of contrast enhancement ratio (CER) images were computed from the raw images, such that each pixel in nth CER image is given by: $(S_n - S_{baseline})/S_{baseline}$; time intensity curves (TIC) of these CER images were plotted.

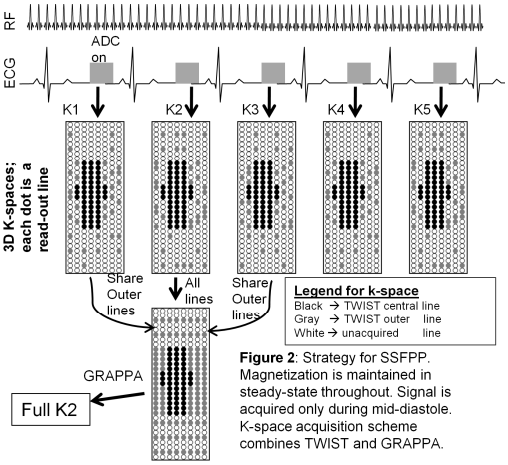


**Figure 2**: Strategy for SSFPP. Magnetization is maintained in steady-state throughout. Signal is acquired only during mid-diastole. K-space acquisition scheme combines TWIST and GRAPPA.

**Results**: Temporal footprint of 3 heart-beats, along with a low value for region A rendered the technique sensitive to respiratory motion, giving non-diagnostic images in 2 volunteers who could not breath-hold sufficiently long to capture first-pass dynamics; in the remaining 5 volunteers, no subendocardial DRA was observed during first-pass wash-in kinetics, and the maximum CER in healthy subjects varied between 120-150%. Fig 3 depicts late gadolinium enhanced (LGE) image from the patient. Raw and CER images from the patient during first-pass dynamics are shown in Fig 4, whereas TIC curves from CER images for the pathologic region (as defined by the bright region in LGE image) and remote regions are shown in Fig 5.

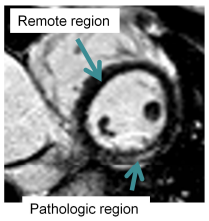


**Figure 3:** Late gadolinium enhancement image showing the pathologic and remote regions

**Summary**: A new approach to myocardial first-pass perfusion imaging was proposed, and its feasibility in detecting regional perfusion defects demonstrated in a patient. This technique provides high SNR and CNR, circumvents some of the suspected causes of DRA, and facilitates image analysis by enabling automatic contouring. Future work will focus on additional acceleration to reduce the temporal footprint, and the feasibility to use phase information of the central region A for motion compensation. Subsequently, studies with a larger patient cohort, and stress vs. rest perfusion imaging are need to evaluate SSFPP.

**References:** [1] Kellman & Arai. JCMR (2007)9:525-537. [2] Nagel et al. Circulation. 2003; 108:432-437. [3] Laub, Kroeker, Magnetom Flash 3 : 93 (2006) [4] Xue et al. MICCAI. 2008; 11(Pt2):35-43

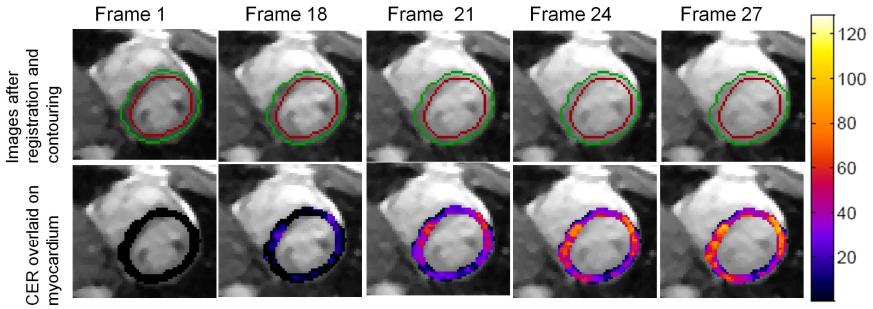


**Figure 4 (Color):** Original images (after registration and contouring) and CER map overlaid on myocardium in select frames. Contours were drawn automatically in Frame 1 and were transferred to other frames.

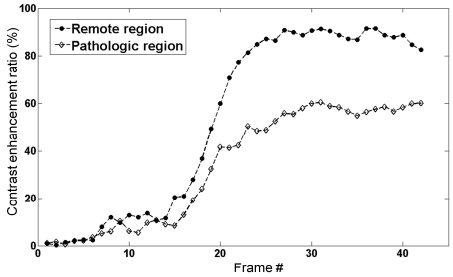


**Figure 5:** Time-Intensity curves of remote and pathologic regions. Pathologic region was defined as the bright region in late gadolinium enhancement (LGE) images.