Inflow Quantification in 3D Cardiac MR: Implications for Whole Heart Coronary Imaging and 3D Cine

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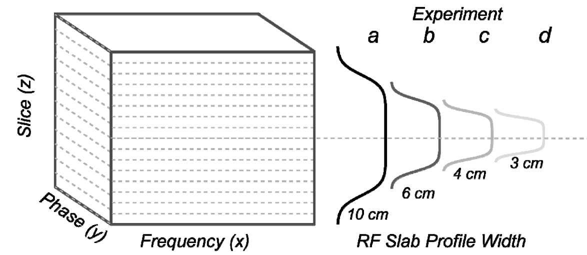

Figure 1: Image acquisition set-up: a large 3D axial 10 cm slab is prescribed to cover the entire heart. In the reference experiment (*a*), the imaging RF pulse excites the entire 10 cm volume. In subsequent experiments, (*b, c,* and *d*), the excitation volume is reduced by changing the magnitude of the RF encoding gradient, reducing the effective slab width to 6.0, 4.0 and 3.0 cm, respectively.

Introduction: Large volume 3D cardiac MR imaging (CMR) is appealing with applications in both 3D cardiac cine and whole heart coronary imaging. The transition from single 2D slices or small 3D slabs (e.g. 2-3 cm) to thicker 3D slabs (10-12 cm), theoretically, could result in increased SNR and better image registration. However, for CMR there is an associated penalty that results from saturation of blood flowing into the imaging volume which can adversley affect blood SNR and blood-myocardium CNR. We sought to investigate inflow enhancement (or lack thereof) in 3D single-phase imaging (for coronary applications) and also cardiac cines (for function evaluation).

Theory: An imaging sequence was developed in which, without modifying image acquisition or phase/slice encoding, we altered the gradient amplitude during RF excitation, effectively changing the width of the slab that is excited by the RF pulses (**Fig. 1**). By encoding the same voxel size regardless of RF slab thickness, the theoretical SNR remained constant between different acquisitions, thereby, permitting direct quantification of inflow effects. Since either balanced steady-state free precession (SSFP) and gradient-recalled echo (GRE) sequences can be used in large 3D acquisitions, both were tested using four slab thicknesses, ranging from 3cm (targeted 3D coronary volume) to 10 cm (whole-heart volume or 3D cine).

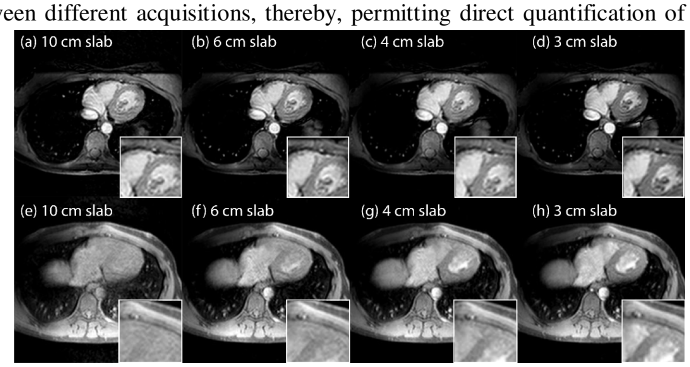

Figure 2: 3D SSFP (top row) and GRE (bottom row) whole heart images acquired with different slab widths: (a) 10 cm, (b) 6.0 cm, (c) 4.0 cm, and (d) 3.0 cm. The images demonstrate the increased contrast found at smaller slab widths, and most appreciated on GRE images.

Materials and Method: Twelve healthy volunteers were scanned using a 1.5T Achieva (Philips Medical Systems, Best, The Netherlands) and a 5 channel cardiac array (in single phase whole heart study) and a 32 channel cardiac array (in 3D cine). For each volunteer, an axial 3D volume (100mm thick) covering the heart was prescribed. A slice selective 3D acquisition was used with excited RF profile covering the entire imaging volume. The acquisition was repeated 4 times with different RF slab encoding thicknesses (slab selection gradient amplitudes): 3cm, 4cm, 6cm, and 10cm. Typical imaging parameters for the navigator-gated, vector ECG-triggered single phase whole heart acquisitions were: FOV = 270x270x100mm^3, 2x2x1mm^3 voxels, 60° flip angle for SSFP and 30° for GRE. The imaging parameters for a breath-hold cine acquisition were: FOV = 270 x 220 x 100mm^3, 2x2x4mm^3 voxels, 60° flip angle for SSFP and 20° for GRE. SNR and CNR were measured by drawing ROIs in both ventricular blood and myocardium regions. Noise was measured using ROI outside the chest wall. Only relative SNR was measured for cine function because of parallel image acquisition and reconstruction.

Results: **Fig. 2** shows example mid slice images from a whole heart study acquired with different slab thickness. With SSFP, 6.1% and 4.3% of baseline SNR of arterial blood and myocardium, respectively, were lost for each 1 cm increase in slab thickness (R^2=0.99, R^2=0.98, respectively) while with GRE images, 11.2% and 8.4% (R^2=0.98, R^2=0.98) of baseline SNR was lost, up to slabs 6.5 cm thick, after which no further losses were observed (data not shown). **Fig. 3** shows the middle slice mid-systole and end-diastole from a cine acquisition. **Fig. 4** shows normalized CNR measurements for all studies. The results show that there are 60% and 75% reductions in blood-myocardium CNR associated with increasing the acquisition slab thickness from 3cm to 10cm with SSFP and GRE whole heart acquisition, respectively and 50/60% (systole/diastole) and 65/85% (systole/diastole) reduction in cine SSFP and GRE acquisition.

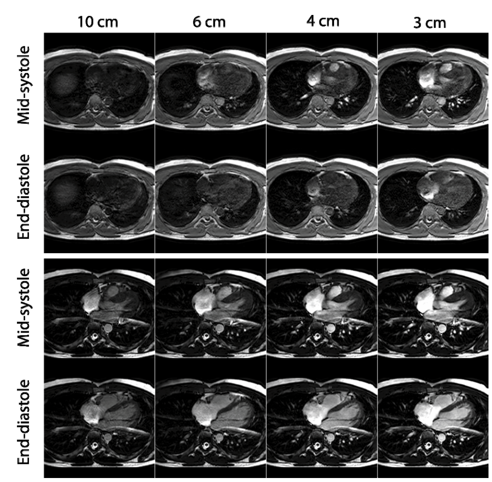

Figure 3: Example mid-slice from a 3D cardiac cine acquisition in systole and diastole for GRE (top two rows) and SSFP (bottoms two rows) as a function of slab thickness.

Discussion and Conclusions: The losses in SNR and CNR due to inflow saturation will reduce the effective SNR gains expected when increasing the number of z-partitions in 3D CMR. New approaches must be tested and found to counteract the loss of contrast due to inflowing spins. These may include the use of contrast agents as well as other volumetric approaches.

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References: [1] Markl M, MRM. 2003. [2] Nehrke K, ISMRM 2006.

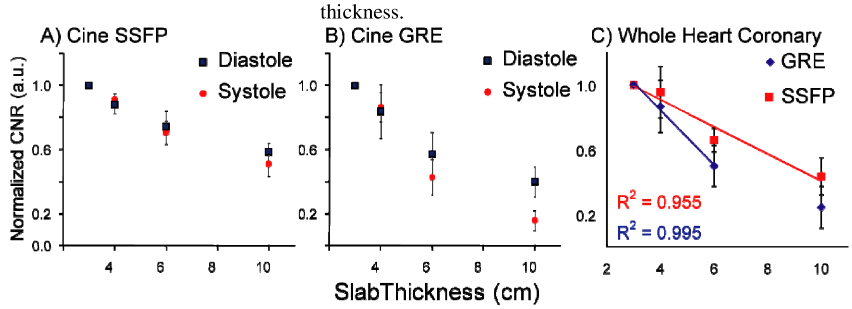

Figure 4: Normalized CNR measures as a function of slab thickness for A) cine SSFP, B) cine GRE and C) whole heart coronary imaging. The results shows CNR decreases associated with a larger slab size.