Single Cardiac Cycle Multipoint T1 Mapping with Radial Acquisition

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Introduction: Quantitative myocardial perfusion imaging depends on accurate determination of the arterial input function (AIF). Unfortunately, typical doses of contrast agent (CA) cause saturation in the AIF signal intensity at peak contrast concentrations. Methods using dual boluses or dual sequences have been proposed to correct for this effect; however, they require additional data acquisition and complicate the imaging procedure.

By calculating blood and myocardial T1 values during the first pass, CA concentration can be estimated accurately, overcoming the signal saturation problem [1]. This work proposes a method similar to [1] in which T1 relaxation is sampled using a radial acquisition scheme. However, instead of using a lengthy single shot acquisition which may be susceptible to motion artifacts (especially in patients with fast heart rates or arrhythmias), multiple images are acquired after a single saturation recovery (SR) preparation using a multi-shot radial acquisition and reconstruction technique (sequence parameters similar to [2]) with an improved HYPR-based compressed sensing reconstruction. The result is a series of images with different saturation recovery times. These images can then be used to estimate T1 and CA concentration. This method was performed in vivo and compared to the dual sequence method [3].

Methods: T1 relaxation following SR preparation and FLASH acquisition can be theoretically modeled by Eq. 1 (3).

$$S = \rho \left| \left(1 - e^{-TD/T1}\right)(E\cos(\alpha))^{n-1} + (1-E)\frac{1-(E\cos(\alpha))^{n-1}}{1-E\cos(\alpha)} \right| \qquad (1)$$

with ρ = proton density, T_2^* relaxation, and coil sensitivity variations, $E = e^{-TR/T1}$, α = flip angle, n = lines to k-space center, TD = delay time, TR = echo spacing. By acquiring multiple images after a single SR and using the acquisition parameters, pixelwise T1 can be found by solving a simple non-linear data fitting exercise. The T1 can then be converted to Gd concentration using the known relaxivity of Gd [4]. The baseline T1 can be found using pre-contrast images.

$$\frac{1}{T_1} = \frac{1}{T_{1basline}} + \gamma[Gd] \qquad (2)$$

Four healthy volunteers underwent perfusion MRI studies on a Siemens 3T Verio system with IRB approval and written consent. Three first pass perfusion scans were performed at rest using a radial sequence, a long TD Cartesian scan, and a short TD centrically encoded Cartesian scan. Subjects were given doses of Gd-DTPA of 0.04 mmol/kg with 10 min interval between doses to allow residual Gd to wash out. Imaging parameters for the FLASH long TD Cartesian scan were as follow: FOV = 300 mm; bandwidth = 650 Hz/pixel; flip angle = 12°; TR = 2.4 ms; TI = 120 ms; matrix size = 160x100; and TGRAPPA = 2. The short TD scan parameters were similar: TI = 25 ms; centrically encoded; matrix size = 64x48.

The multi-shot radial FLASH scan used the following parameters: FOV = 270 mm; BW = 650 Hz/pixel; flip angle = 10°; TR = 2.75 ms; 4 images per SR with TI = 50, 94, 138, and 182 ms respectively; resolution 1.7x1.7mm^2; 160 readouts x 128 projections, 8 shot interleaved. Four images were collected at the same slice position during diastolic phase. Total acquisition time per cardiac cycle is 199 ms. Reconstruction of multi-shot radial data was performed using a compressed sensing based method with a HYPR based composite reference constraint [5]. The AIF was measured in a manually drawn ROI in the LV blood pool.

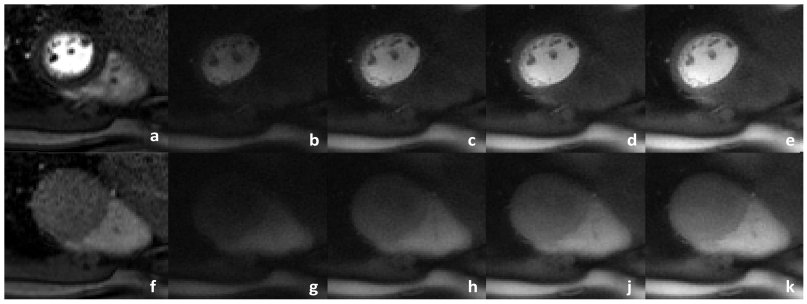

Figure 1: Comparison of Cartesian and radial multi TI sampling. First row shows peak ventricular enhancement. Second row shows myocardial enhancement phase. a/e are Cartesian. Columns 2-5 have TI = 50, 84, 138, 182 ms respectively.

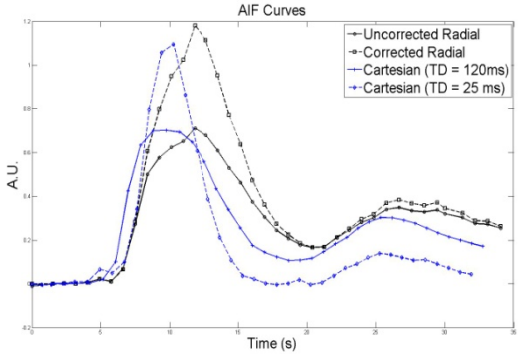

Figure 2: AIF Curves

Results: The long TD Cartesian shows significant truncation due to T1 recovery signal saturation. The short TD Cartesian scan yields a higher peak amplitude because image acquisition starts before signal recovers significantly. Fig. 1 shows T1 relaxation of a single slice during the same cardiac cycle. The images show peak contrast enhancement in the LVBP as well as myocardial enhancement. Fig. 2 shows MPI curves comparing uncorrected radial, corrected radial, and Cartesian long and short TD curves. Similar to the long TD Cartesian scan, the uncorrected radial AIF shows truncation due to signal saturation. Using the proposed T1 mapping technique allows for correction of the radial AIF ('Corrected Radial'), matching the peak amplitude and upslope of the short TD AIF.

Discussion: The described method eliminates the need to acquire two datasets to produce an unsaturated AIF, increasing feasibility for clinical use. Due to the small acquisition window, this method is robust to cardiac motion throughout the cardiac phase. Furthermore, cardiac coverage is not significantly sacrificed. Though the acquisition time for a T1 map is 199 ms, a single image is acquired in only 44 ms. Subsequent images can expand cardiac coverage.

References:

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4) Hanicke, Chien. Med Phys 1990:1004-1010. 5)