Theory-based single-point T_1 mapping for quantitative analysis of first-pass cardiac perfusion MRI: a validation study

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Introduction: Quantitative analysis of first-pass contrast-enhanced cardiac perfusion MRI requires a conversion of the T_1-weighted signal-time curve to contrast agent (Gd-DTPA) concentration-time curve. For this purpose, a theory-based single-point T_1 measurement method has been proposed and validated in phantoms at 1.5T [1-2]. The specific choice of the k-space ordering of the TurboFLASH readout can modulate the effect of B_1 variation, particularly at 3T, on the accuracy of the T_1 measurement [3]. In this work, we i) investigated the sensitivity to B_1 variation of the single-point T_1 mapping method, depending on its k-space acquisition order (linear or centric) and ii) validated *in vivo* the single-point T_1 mapping method in the left ventricle (LV) of the cavity and myocardium during contrast enhancement.

Methods: A saturation-recovery TurboFLASH sequence was implemented on a 3T whole-body MR scanner (Siemens; Tim Trio). Images were acquired with the following parameters: FOV = 320mm × 262mm, slice thickness = 8mm, matrix = 144 × 94, TE/TR = 1.24/2.4 ms, flip angle = 10º, TSENSE with acceleration factor 2, and effective saturation pulse [4]. The saturation-recovery time delay (TD) was 10/50 ms and total image acquisition time = 136/176 ms for the linear and centric k-space trajectories, respectively. The effective longitudinal magnetization at the center of k-space was calculated as a function of T_1, using the Bloch equation, as previously described [1]. A proton density-weighted image was acquired in the first heartbeat, with flip angle = 5º and without the saturation pulse, in order to normalize the image signal. A theoretical relationship was thus obtained between the normalized signal and T_1. TDs were chosen so that linear and centric sequences had a similar signal-T_1 theoretical relationship. Note that for the pulse sequence parameters used in this study, the normalized signal for T_1>1000ms is less than 5% of equilibrium magnetization, indicating that the signal-to-noise ratio (SNR) at pre-contrast is inadequate for the single-point T_1 method. Therefore, pre-contrast T_1 measurements were performed using a multi-point T_1 mapping sequence to ensure accurate T_1 measurement. Reference T_1 measurements were performed at nominal B_1 calibration with a multi-point saturation recovery TurboFLASH sequence with variable TD and a centric k-space trajectory. A least square linear regression was used to fit the 10 points on the saturation recovery curve. First, to investigate the effect of B_1 variation, 6 dilutions of Gd-DTPA (Magnevist) in water (T_1 [48–1100] ms) were imaged for each k-space trajectory (linear or centric) with the excitation flip angle ranging from 40 to 120 % of nominal 10°. Second, the accuracy of the single-point T_1 measurements using the optimal centric k-space trajectory, as determined by the phantom experiment, was assessed *in vivo* in 4 healthy volunteers (35±12 years old). A basal short-axis plane of the heart was imaged at 9 time points with the single-point and reference multi-point acquisitions: pre-contrast, 5, 10, 15, and 20 min post first injection (0.1mmol/kg) of Gd-DTPA, and 5, 10, 15, and 20 min post a second injection of Gd-DTPA. Reference T_1s were fitted from 7 data points: no saturation and TDs from 100-600 ms (100ms steps). Contours for the myocardium and left ventricular (LV) cavity were drawn manually (Fig.2.A). Measured T_1s were converted to Gd-DTPA-concentrations ([Gd]) with the following equation: $[Gd] = (1/T_1 - 1/T_1^{baseline}) / k_{Gd}$, assuming fast water exchange condition [5] and T_1 relaxivity (k_{Gd}) of 3.8L/mmol/s [6-7], and $T_1^{baseline}$ measurement with the multi-point fit to ensure its accuracy.

Results: Compared with a linear k-space trajectory, a centric k-space trajectory was found to be less sensitive to clinically relevant B_1 variation at 3T in phantoms (Fig.1). Consequently, the centric k-space trajectory was validated *in vivo*. A good linear correlation was found between the reference and single-point T_1 measurements in the LV cavity and wall (Fig.2.B, R=0.97, p<0.001), as well as between the corresponding Gd-DTPA concentrations ([Gd]) (Fig.2.C, R=0.98, p<0.001). Bland-Altman analyses showed an increasing error in the single-point measurements for longer T_1 values, likely due to the correspondingly lower SNR. The underestimation observed for long T_1 is also likely related to apparent signal increase due to Rician noise bias.

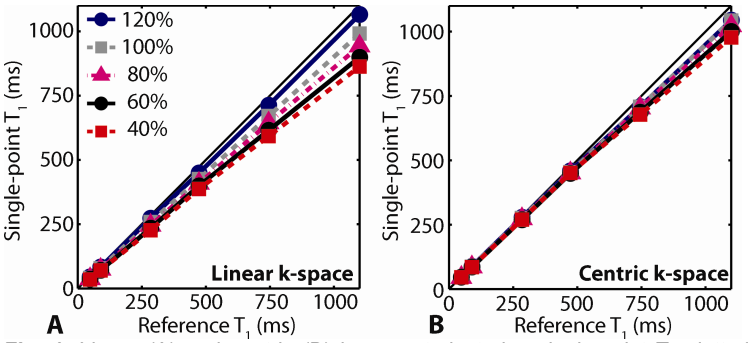

Fig. 1: Linear (A) and centric (B) k-space trajectories single-point T_1 plotted against reference T_1 measured in phantoms for B_1 variation range 60-120%.

Conclusion: We have validated the single-point T_1 mapping sequence against the multi-point T_1 mapping sequence *in vivo*. Compared with a linear k-space trajectory, disadvantages of a centric k-space trajectory are that it requires a longer TD to achieve adequate SNR, and it yields slight edge enhancement, due to high-pass filtering effects in the k-space. Comparative advantages of the centric k-space trajectory are that it is relatively insensitive to B_1 inhomogeneities, inflow effects, and refocusing of residual transversal magnetization from imperfect radio-frequency spoiling. Therefore, the modeling of the signal is simpler for the centric k-space ordering than for the linear k-space ordering. The single-point T_1 mapping pulse sequence with centric k-space trajectory is thus promising for quantitative analysis of first-pass cardiac perfusion MRI.

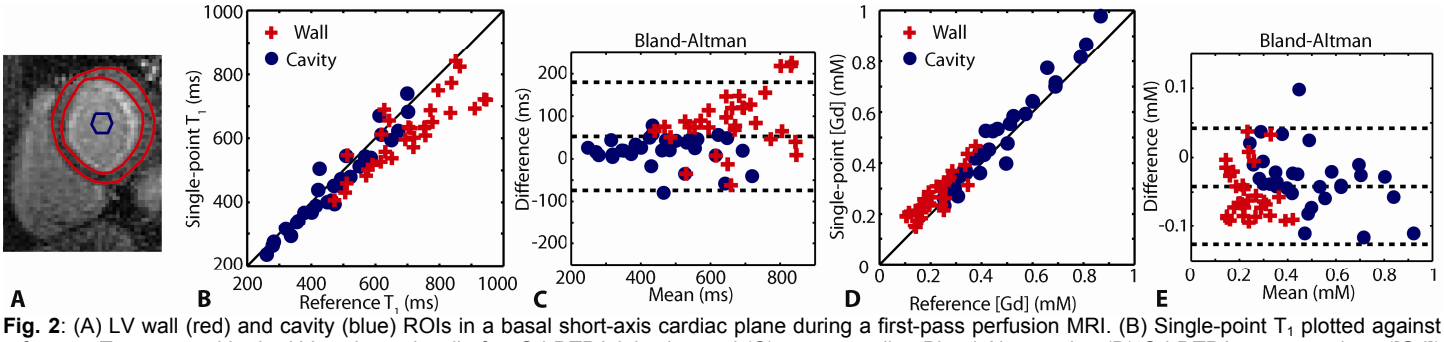

Fig. 2: (A) LV wall (red) and cavity (blue) ROIs in a basal short-axis cardiac plane during a first-pass perfusion MRI. (B) Single-point T_1 plotted against reference T_1 measured in the LV cavity and wall after Gd-DTPA injection and (C) corresponding Bland-Altman plot. (D) Gd-DTPA concentrations ([Gd]) calculated from single-point and reference T_1 and (E) corresponding Bland-Altman plot.

References: [1] Cernicanu A. et al., Acad. Radiol. 2006; [2] Hsu L-Y. et al., JMRI 2008; [3] Kim D. et al., MRM 2008; [4] Kim D. et al., MRM (in press); [5] Donahue K.M. et al., JMRI 1997; [6] Pintaske J. at al., Invest. Radiol. 2006; [7] Rohrer M. et al., Invest. Radiol. 2005

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