Importance of k-Space Trajectory for Accurate Quantification of AIF and High CNR of Myocardial Wall Enhancement in First-Pass Myocardial Perfusion MRI

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Introduction: The accuracy of myocardial perfusion measurements derived from T_1-weighted first-pass contrast-enhanced MR images depends on several factors, including: accuracy of the arterial input function (AIF) [1,2,3] and contrast-to-noise (CNR) of the myocardial enhancement [2,3]. A combination of long saturation-recovery time delay (TD) and high dose of contrast agent (Gd-DTPA) is optimal for high CNR of myocardial enhancement, but this condition typically leads to underestimation of the AIF due to near complete recovery of the magnetization at peak blood enhancement. In contrast, a combination of low dose of Gd-DTPA and short TD is optimal for accurate quantification of AIF, but this condition typically causes low CNR of wall enhancement. One approach to modifying the T_1-weighted signal strength (i.e., the effective recovery time of magnetization at the origin of k-space), without changing the dosage of Gd-DTPA and TD, is to vary the k-space trajectory. The purpose of this study, therefore, was to compare the relative T_1-weighted first-pass contrast-enhanced signal produced by the bottom-up, center-out, and center-in k-space trajectories, for accurate quantification of AIF and high CNR of myocardial wall enhancement.

Methods: A saturation-recovery TurboFLASH pulse sequence was modified and implemented on a 3T whole-body MR scanner (Tim Trio, Siemens), in order to compare the three types of k-space trajectories: bottom-up, center-out, and center-in. Imaging parameters include: field of view = 300 x 300 mm, acquisition matrix = 128 x 128, in-plane resolution = 2.3 x 2.3 mm, slice thickness = 8 mm, TE/TR = 1/2 ms, flip angle = 10°, TurboFLASH image acquisition time = 147 ms, GRAPPA [4] parallel acceleration factor = 2, additional reference lines = 8, TD = 25 ms, and bandwidth = 750 Hz/pixel. The pulse-train saturation pulse was used to achieve uniform saturation of magnetization [5]. The total image acquisition time, including TD (25 ms) and saturation pulse duration (7.5 ms), was 180 ms. In addition to the saturation images, for signal normalization, baseline proton-density weighted (PDW) images were acquired with 3° flip angle and no saturation pulse. The T_1-weighted images were divided by the corresponding PDW images a pixel-by-pixel basis, and the resulting normalized images were multiplied by the factor sin(3°)/sin(10°) to account for the difference in the two flip angle values. The image normalization corrects for signal variations due to surface coil effects and equilibrium magnetization. In vitro imaging experiment was performed using phantoms containing 16 different dilutions of Gd-DTPA (0 - 44 mM), in order to derive an empirical look-up table for converting the normalized T_1-weighted signal into concentration of Gd-DTPA ([Gd-DTPA]). The experimental data curves were interpolated using least-squares fitting of a function signal = a + b(1-exp(-[Gd-DTPA]/c), as previously described [6]. One healthy volunteer and one patient with left ventricular hypertrophy were imaged in a basal short-axis view of the heart, where the three different k-space acquisitions were performed sequentially per heart beat, in order to permit signal strength comparisons using the same contrast injection. Human imaging was performed in accordance with protocols approved by the Human Investigation Committee at our institution; all subjects gave written informed consent. A single dose (0.1 mmol/kg) of Gd-DTPA (Magnevist, Schering) was injected at a flow rate of 5 ml/s by a power injector (Medrad), followed by a 20 ml flush of saline. For quantification of AIF, a region-of-interest (ROI) was set centrally in the left ventricular cavity, and the resulting mean normalized T_1-weighted signal-time curves were converted to [Gd-DTPA]-time curves. For the myocardial wall analysis, an ROI covering the whole left ventricular wall was manually drawn, and the resulting mean normalized T_1-weighted signal-time curves were converted to [Gd-DTPA]-time curves.

Results: Figure 1 shows the experimental plots of normalized T_1-weighted signal as a function of [Gd-DTPA]. Compared to the bottom-up trajectory, the center-out trajectory is comparatively less sensitive to [Gd-DTPA], whereas the center-in trajectory is comparatively more sensitive to [Gd-DTPA], due to the different effective recovery time of magnetization at the origin of k-space. Figure 2 shows the T_1-weighted and normalized images produced by the three k-space trajectories at peak blood enhancement and wall enhancement. Compared to the bottom-up trajectory, the center-out trajectory produced comparatively lower signal, whereas the center-in trajectory produced comparatively higher signal throughout the repeated measurements. Figure 3 shows the mean normalized T_1-weighted signal-time curves and the corresponding [Gd-DTPA]-time curves for the blood and myocardial wall. Compared to the conventional bottom-up trajectory, the center-out trajectory produced 42% higher AIF (5.0 ± 1.5 mM vs. 7.1 ± 1.7 mM, respectively), whereas the center-in trajectory produced 35% higher normalized T_1-weighted signal (0.20 ± 0.0 vs. 0.27 ± 0.01, respectively) of myocardial wall enhancement for calculating the concentration of Gd-DTPA.

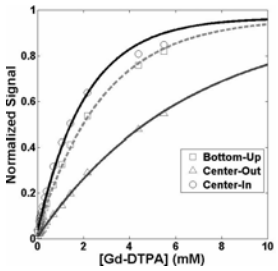

Fig. 1. Plots of normalized T_1-weighted signal as a function of [Gd-DTPA] for the bottom-up, center-out, and center-in k-space trajectories at TD = 25 ms.

Discussion: This study has compared the relative T_1-weighted first-pass contrast-enhanced signal produced by the bottom-up, center-out, and center-in k-space trajectories. Using the aforementioned imaging parameters and assuming a heart rate < 84 beats per minute (e.g., acquisition window = 720 ms), three cardiac views can be acquired using the center-in k-space trajectory to achieve high CNR of wall enhancement and one additional cardiac view can be acquired using the center-out k-space trajectory to achieve accurate quantification of AIF.

References

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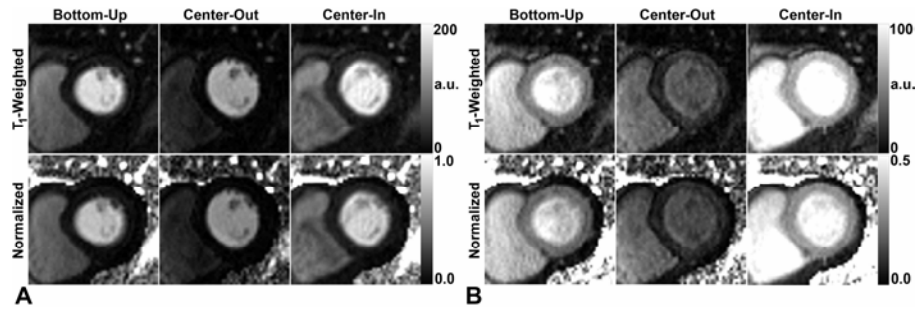

Fig. 2. (Top row) T_1-weighted and (bottom row) normalized images at (A) peak blood enhancement and at (B) myocardial wall enhancement : (left) bottom-up, (middle) center-out, and (right) center-in k-space trajectories. The T_1-weighted and normalized images are displayed using identical gray scales as indicated.

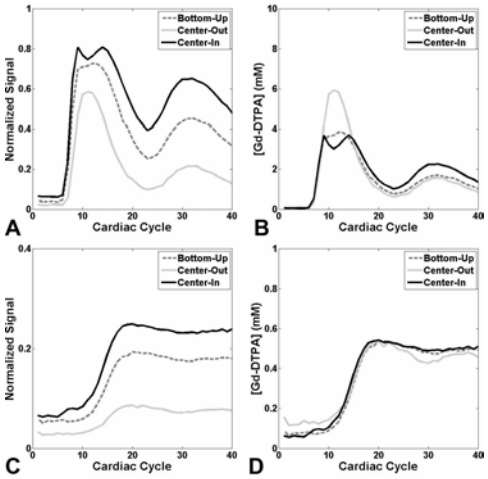

Fig. 3. (A) Normalized blood and (C) myocardial T_1-weighted signal-time curves and their corresponding (B, D) [Gd-DTPA]-time curves.