Significant improvement in reproducibility of DCE-MRI achieved using cardiac-output based constraint of arterial input function

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Introduction

Dynamic contrast enhanced (DCE) MRI has become an important non-invasive tool for tissue functional assessment (1). Clinic applications include renal function and tumor angiogenesis. For quantitative analysis, tissue parameters can be obtained by deconvolving concentration vs. time curves from the tissue and from an input artery (or arterial input function, AIF). However, as multiple artifacts such as inflow and partial volume effects contaminate AIF, its reliable measurement can be challenging.

One way to overcome the problem is to constrain the area under the first pass of AIF (AUC_{FP}) based on indicator dilution principle (dose = CO×AUC_{FP}) (2, 3). CO can be readily measured in the same MRI session using phase-contrast MRI. In a preliminary validation of this idea the same CO was assumed for two scans repeated on the same day and reproducibility of renal function measurement dramatically improved (2). However, individual subject CO was not measured.

This study examines more directly the utility of the CO constraint in greater detail for measuring renal function. We performed repeated DCE-MRI exams in the same individual, each with individual CO measurement. We hypothesized that the AIF-correction method would improve the reproducibility of renal function estimates.

Methods and Materials

Five human subjects were enrolled in this study, each examined twice at a 1.5 T system (Avanto, Siemens). In four subjects the second scan took place the day after the first exam, and in one subject the second visit was 19 days later. Both exams were acquired at approximately the same time of the day (within 0.5 hour). Before each scan, we obtained written informed consent from the subject.

For MR renography, two sequences were used. On one day, coronal 3D FLASH (TR/TE/flip angle=2.84ms/1.05ms/12°, FOV 425×425 mm^2, voxel 1.7×1.7×2.5 mm^3, acquisition time 3s) of the abdominal aorta and kidneys was acquired 5 times in a single breath hold before tracer injection. A 4 ml bolus of Gd-DTPA was injected, followed by 20 ml saline flush both at 2 ml/s. Eight seconds following the start of Gd-DTPA injection, 10 3D acquisitions were repeated continuously for 30 s, during which the subject suspended respiration. After a break of 18 sec, 12 additional volumes were acquired during separate 3 s breath-holds spaced over 5 min. For renography on the other day a non-selective saturation-recovery prepared 2D FLASH (TR/TE/TI/flip angle=526ms/1.21ms/300ms/16°, FOV 381×419 mm^2, voxel 1.2×1.2×8.4 mm^3, acquisition time 0.5s). The coronal imaging slice covered abdominal aorta. The same procedure for tracer injection as in the 3D scan was used. Images were acquired continuously for 5 min at time intervals of 2 sec, during which the subject breathed freely. On both days, before tracer injection, a phase contrast MR with ECG gating was performed to measure CO by imaging perpendicular to the root of ascending aorta. At the end of the entire exam, an operator computed CO from the acquired phase-contrast images on the Siemens workstation (4).

For both the 3D and 2D renography images, regions of interest (ROI) were chosen in the abdominal aorta at the level of renal artery. The signal vs time curve from aortic ROI was converted to concentration vs time curve, i.e. AIF, by direct conversion (5) and by conversion with CO-based constraint (2). The blood T_1 value was assumed to be 1200 ms. For each AIF, the area under the curve was computed (AUC).

To more closely examine inflow effects in 3D images, we also sampled aortic blood signal at 3 different levels (upper, middle, lower) of abdominal aorta. Each AIF was used to estimate key functional kidney parameters: glomerular filtration rate (GFR), renal plasma flow (RPF) and mean transit time (MTT). For each parameter and each method of AIF conversion (either direct or CO-based), we computed the coefficient of variation (CV) across the estimates corresponding to different aortic levels.

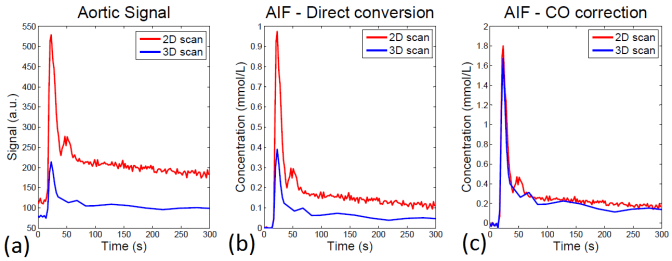

Fig. 1 Comparison of aortic signals (a), AIFs without (b) and with correction (c) for 2D and 3D scans.

Results and discussion

CO values for the 3D scan ranged 4.2-7.5 L/min, and for the 2D scan 4.6-6.8 L/min. Within subject CO difference was 0.6±0.4 L/min or 10.7%±6.3%, indicating lack of significant change (paired t-test, P = 0.61). With direct conversion, the AIF AUC (0-300 sec) difference between the two exams was 31.9±12.2 s·mmol/L. CO-based constraint significantly decreased the AUC difference by about half to 17.2±8.2 s·mmol/L (P = 0.003). A representative example of 2D vs. 3D comparison is shown in Fig. 1. After compensating for the CO variation in each case, the AUC for the 3D AIF was still lower than the 2D AIF, by a difference in AUC of 11.1±10.6 s·mmol/L (P = 0.04). The lower AUC for 3D AIF is probably due to the missing of the recirculation peak during the breath-hold break.

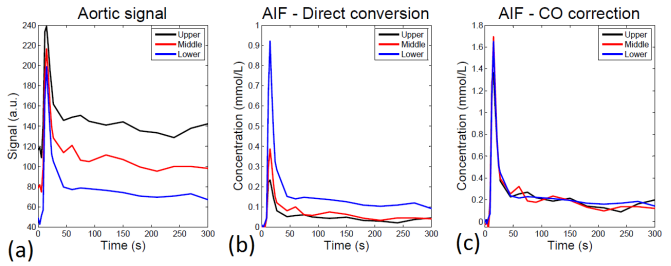

Fig. 2 Comparison of aortic signals (a), AIFs without (b) and with correction (c) from different levels of aorta.

Fig. 2 compares AIFs from 3 different aortic ROIs for a representative case. CV of the kidney parameter estimates are shown in Fig. 3. The use of CO-based constraint decreased CV of GFR from 48.7%±21.1% to 11.8%±6.2% (paired t test, P = 0.0003), for RPF from 60.3%±12.7% to 20.1%±12.2% (P = 0.00004). The decrease in CV of MTT (from 21.9%±19.7% to 12.8%±7.8%) was not significant (P = 0.083).

In conclusion, the CO-based approach for AIF correction effectively reduced the intra-scan variability in AIF due to inflow effect and thus improved the precision of GFR and RPF. As the method deals with tracer concentration, it is capable of handling data from different imaging sequences (2D and 3D FLASH in this study), and is expected to work well on other sequence such as dynamic susceptibility contrast (DSC) T2*-weighted imaging.

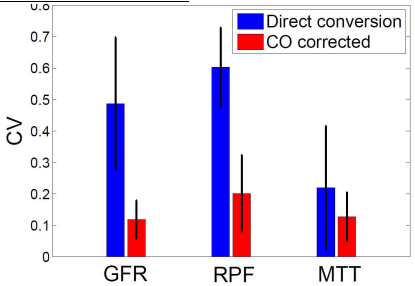

Fig 3. Coefficient of variation (CV) for kidney parameters estimated with direct-converted AIF and CO-corrected AIF.

Reference

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