Factors Affecting the Arterial Input Function in Myocardial Perfusion CMR

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Introduction

For quantitative myocardial perfusion cardiovascular magnetic resonance (CMR) using deconvolution, the optimal characteristics of the arterial input function (AIF) include sharpness and high peak gadolinium concentration provided that this does not exceed image T1 response. Factors that influence AIF are unclear and no systematic study has been completed. Potential influences upon the AIF are injection dose and rate, site of injection, cardiac function, breath hold, volume of normal saline flush and type of gadolinium, etc. Although the duration and peak gadolinium concentration of the AIF entering the right heart would obviously be influenced by injection rate, it has not been clarified whether further bolus spreading during pulmonary circulation and left heart transit is dominant over the effects of injection parameters. Quantitative analysis methods (such as deconvolution and normalized upslope analysis) aim to remove AIF variability from perfusion assessments, but may not succeed entirely. This work therefore aims to assist the analysis by 1) finding how to reduce variability in AIF between injections and patients, 2) achieving most compact high-concentration AIF. For this purpose, it is designed to determine the effects of injection rate, cardiac function and breath-hold upon the AIF. A low resolution 50 ms FLASH sequence was optimised for dynamic blood T1 measurement during first-pass of gadolinium. This sequence utilizes multipoint saturation recovery (SR) technique for better T1 measurements. Sequence parameters were optimised to minimize inflow effects and to avoid full-recovery during peak gadolinium concentration.

Methods

A 1.5T scanner (Siemens Sonata) with 4-channel body array coil and gradient performance up to 40mT/m and 200T/m/s was used. 30 Patients undergoing a CE-CMR study for late enhancement assessment had gadolinium (Magnevist) injected at 3, 5 or 7 ml/s (10 patients at each) using a Medrad power injector in the right antecubital fossa (0.1 mmol/kg followed by 10 ml normal saline flush) during end expiratory breath-hold. 5 other patients were injected at 5ml/s during inspiratory breath-hold for comparative breath-hold study. In each cardiac cycle during the first-pass, a series of SR FLASH low-resolution images (TE 0.35 ms, TR 1.06 ms, matrix 64 x 48) with exponentially increasing saturation recovery delay times were acquired starting immediately after the R-wave. The sequence used a 5º flip angle and a non-selective saturation to avoid fresh inflow effects. The short 50ms FLASH sequence and a centric-out phase-encoding order enabled acquisition with short saturation-recovery delays. A transversal plane through the ascending aorta (AA) was selected to minimize cardiac motion effects, and images were acquired for 45 cardiac cycles during the injection. All the patients were asked to hold their breath as long as possible during the 45 cycles, aiming to include the first-pass in this.

Signal intensity measurements used a region-of-interest (ROI) placed in the AA in all the SR images. The calculation of short T1s during peak gadolinium concentration was performed by fitting the mean ROI magnitude against saturation recovery delay times, where a Levenberg-Marquardt fitting algorithm was adopted for a better exponential recovery fitting. The duration of the AIF was also determined from the series of T1 measurements during these cycles.

Results

The T1 at the peak concentration of the bolus in the ascending aorta shortened as the injection rate increased from 3 ml/s to 5ml/s (p=0.0035, n=20) and 7 ml/s (p=0.001, n=20). See Fig. 1. The duration of the AIF shortened as the injection rate increased from 3 ml/s to 5ml/s (p=0.045, n=20) and 7 ml/s (p=0.029, n=20), as is shown in Fig.2. The T1 shortened as cardiac output increased (p=0.043, n=16, incomplete analysis in progress), shown in Fig. 3

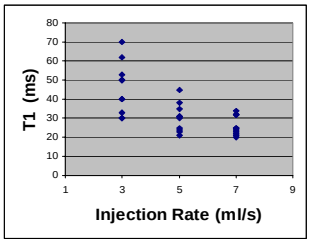

Fig. 1. Injection rate vs lowest T1 in ascending aorta

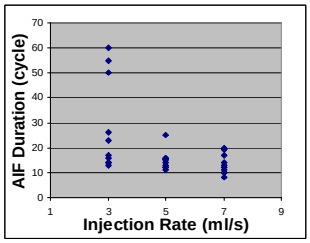

Fig. 2. Injection rate vs AIF duration

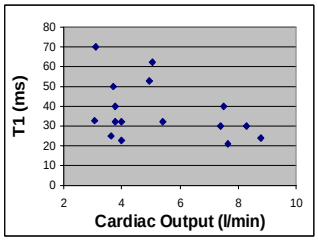

Fig. 3. Cardiac output vs lowest T1 in ascending aorta

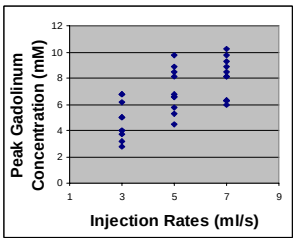

Fig. 4. Injection rate vs highest gadolinium concentration

The variability of T1 and AIF duration between different patients were also found to be much reduced at 7 ml/s. Nevertheless, no clear conclusion could be drawn from the breath-hold study possibly due to the small number of patients. Furthermore, no significant relationship between T1 values and LV function, RV function or heart rate was found in this initial study.

Discussion and conclusion

This study shows that injection rate has a profound effect on the AIF. An injection rate of 7 ml/s gives a consistently sharper AIF with higher peak concentration compared with the AIF found at 3 ml/s. On conversion from T1 to gadolinium concentration [Gd], it was found that the variability in [Gd] is decreasing with injection rate increasing. (Fig.4. 3ml/s:4.7 $\pm$ 1.4 mM, 5ml/s: 7.1 $\pm$ 1.7mM, 7ml/s: 8 $\pm$ 1.6mM). It shows that cardiac output also affects the AIF, for low cardiac output allowed increased spreading and dilution of Gd bolus. Further studies in progress will evaluate whether breath-hold could affect bolus dilution during pulmonary transit.

These results suggest improved consistent delivery of sharp and short AIF, hence the reproducibility and accuracy of quantitative perfusion will be improved. This technique for measuring short T1 values will be used to investigate other potential influences upon the AIF, including site of injection, volume of normal saline flush and type of gadolinium.