Reducing Saturation Effects in the AIF Determination of Quantitative First-Pass Perfusion Imaging Using a Model-based Reconstruction

Johannes Tran-Gia[1], David Lohr[1], Andreas M. Weng[1], Christian O. Ritter[1,2], Thorsten A. Bley[1], and Herbert Köstler[1]

[1]*Department of Diagnostic and Interventional Radiology, University of Würzburg, Würzburg, Germany,* [2]*Department of Diagnostic and Interventional Radiology, University Medical Center Göttingen, Göttingen, Germany*

Target Audience: Researchers and clinicians working in the field of quantitative myocardial perfusion imaging and cardiac MRI.

Purpose: To determine an unsaturated AIF for quantitative first-pass perfusion imaging using the Model-based Accelerated Parameter mapping (MAP) algorithm and to compare this approach to a standard dual-bolus technique.

Introduction: The quantitative analysis of a myocardial first-pass perfusion image series critically depends on the determination of the arterial input function (AIF), which provides information about the rate, amount, and timing of the delivery of the contrast agent (CA) in the blood. AIF estimation is typically performed by positioning an ROI within the left ventricular (LV) cavity, and monitoring the change in signal intensity due to the CA concentration C over time. For a saturation recovery (SR) prepared FLASH sequence, this can be described by $\Delta S \propto 1 - e^{-T_S \cdot C/T_1}$ (T_1: longitudinal relaxation time, T_S: recovery time after SR pulse) [1]. As the determination of T_1 for each heartbeat is not feasible, a linearity between ΔS and C is typically assumed for an estimation of the AIF. As this assumption is only valid for $T_S C \ll T_1$, the AIF determination is often hampered by saturation effects for typical combinations of C and T_S. This problem can be addressed by an additional CA injection of a lower contrast agent dose [2,3], or by acquiring an additional low-resolved image with a short recovery time [1,4]. In [5], an application of the MAP reconstruction technique [6] was proposed for a model-based AIF determination from a single-bolus acquisition. In this work, the model-based as well as a conventional dual-bolus AIF determination method were applied to 6 healthy volunteers, and saturation effects in the resulting AIFs were compared.

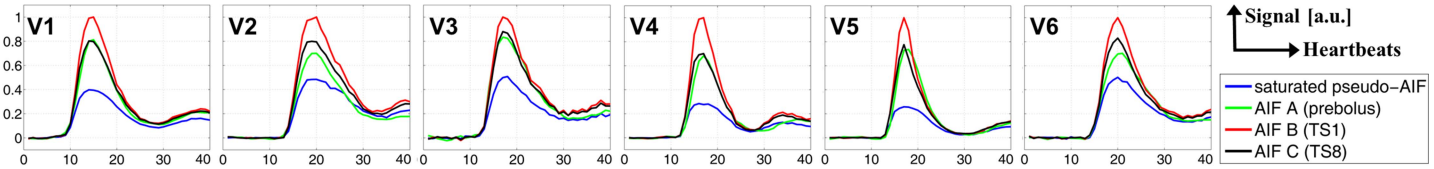

Fig. 1. Saturated pseudo-AIF of the bolus acquisition (blue) and AIFs obtained with methods A-C (A: green, B: red, C: black) for all 6 volunteers.

Methods: The study (approved by our local ethics committee) was performed in 6 healthy volunteers on a 3T whole-body scanner (MAGNETOM Trio, Siemens AG, Sector Healthcare, Germany). After the intravenous injection of the contrast agent (Gadovist®, Bayer HealthCare AG, Germany), an ECG-gated, radial SR FLASH sequence (FOV: 250×250mm^2-270×270mm^2, slice thickness: 8mm-10mm, T_R: 3.49ms-3.60ms, T_E: 1.54ms-1.59ms, α: 12°, projections: 60, readout points: 128, breath-held) was applied for 40 consecutive heartbeats. The dual-bolus approach consisted of a prebolus of 1ml and a bolus of 4ml, injected at flow rates of 4ml/s and followed by a saline flush of 20ml. After data collection, 3 different methods were applied for AIF determination (recovery times varied slightly between the volunteers depending on T_R; values are given for volunteer 1):

A. Average from the prebolus dataset: By gridding the 60 projections of each heartbeat to one k-space, a CA dynamic of 40 images at an average contrast $\overline{T_S} = 106.2$ms was reconstructed. An AIF was determined by positioning a ROI within the LV. This curve was rescaled to the CA concentration C_{bolus} of the bolus acquisition by plotting it $C_{\text{bolus}}/C_{\text{prebolus}} = 4$ times with a distance depending on the injection rate. The sum resulted in the prebolus AIF [3].

B. MAP of the bolus dataset: 100 MAP iterations with a signal model as described in [1] were applied for reconstruction. The result was a set of 60 images of contrasts $T_{S,j}$ for each of the 40 heartbeats. The image series of the shortest available recovery time $T_{S,1}$ was used to estimate an unsaturated AIF. Rescaling was performed based on the ratio between the average recovery time $\overline{T_S}$ of the bolus reconstruction (106.2ms) and the recovery time $T_{S,j}$ of the model-based reconstruction ($\rightarrow T_{S,1} = 3.2$ms).

C. MAP of the bolus dataset: As the product $C \cdot T_S$ differed for methods A and B, a third AIF was determined as described in B. To mimic the saturation of the prebolus (method A), the AIF was estimated using the contrast $T_{S,j}$ closest to $C_{\text{prebolus}}/C_{\text{bolus}} \cdot \overline{T_S} \approx 26.6$ms ($\rightarrow T_{S,8} = 27.7$ms).

Absolute perfusion values (ml/g/min) were quantified with a customized software tool based on [7] (including rigid motion correction, segmentation of 6 sectors, partial volume and baseline correction [8]) using a Fermi function model for constrained deconvolution as described in [9].

Results & Discussion: Fig. 1 depicts pseudo-AIFs of the bolus acquisition (blue) as well as the AIFs obtained using determination methods A-C. For all volunteers, the saturation effects of the pseudo-AIF (blue) can be clearly recognized during the passage of the CA through the LV. Over the same period, the model-based curves B (red) are least saturated and exceed all other curves. As expected, the AIFs of methods A (green) and C (black) have very similar signal courses and lie between pseudo-AIF and method B. The average perfusion values over all 6 sectors as well as the means (μ), standard deviations (σ) and relative errors (σ/μ) are listed in Table 1. While the difference in μ between methods A and C is only 5.3 %, the difference to the proposed method B is 21.3 %. In combination with the similar relative error of all methods (about 10%), this indicates a systematic deviation between methods A and C (saturated AIFs) and method B (less saturated AIF).

	V1	V2	V3	V4	V5	V6	μ ± σ	σ/μ (%)
A	0.69	0.86	0.71	0.78	0.64	0.83	0.75 ± 0.09	11.3
B	0.56	0.61	0.67	0.54	0.52	0.62	0.59 ± 0.06	9.9
C	0.63	0.69	0.77	0.82	0.63	0.7	0.71 ± 0.08	10.7

Table 1. Average perfusion values (ml/g/min) as well as means (μ)*, standard deviations* (σ) *and relative errors* (σ/μ) *for all volunteers.*

Conclusion: The MAP reconstruction enables recovery times of ~3ms in myocardial first-pass perfusion imaging, which significantly reduces saturation effects for typical relaxation times T_1 and contrast agent concentrations C and therefore enhances the quality of the AIF estimation in comparison to current standard methods (dual bolus and two recovery time methods). Additionally, only one acquisition has to be performed.

Acknowledgements: Johannes Tran-Gia was supported by a grant of the German Excellence Initiative to the GSLS, University of Würzburg.

References: [1] Kholmovski et al., Magn Reson Med 57:821-827 (2007), [2] Christian et al., Radiology 232:677-684 (2004), [3] Köstler et al., Magn Reson Med 52:296-299 (2004), [4] Gatehouse et al., J Magn Reson Imag 20:39-45 (2004), [5] Stäb et al., ISMRM 19:4974 (2011), [6] Tran-Gia et al., Magn Recon Med 70:1524-1534 (2013), [7] Pack et al., Comput Cardiol 36:269-72 (2009), [8] Köstler et al., Magn Reson Med, 51:848-52 (2004), [9] Jerosch-Herold et al., Med Phys 25:73-84 (1998).