# Assessment of Non-Linearities in Cardiac Perfusion Measurements using Low-TI AIF Images

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**Target Audience:** Clinicians, Radiologists, Physicists, Cardiologists

**Purpose:** Quantification of myocardial perfusion is of paramount importance in clinical routine. In general, semi-quantitative analyses are performed, investigating descriptive parameters such as the up-slope. Among others, an actual quantification faces the obstacle of nonlinearities in MR signal with respect to the contrast agent dose. This leads to the predicament that low contrast doses are required for a correct determination of the arterial input function (AIF), but high doses are required for the tissue curves to be well determined. A solution that has been proposed is to acquire additional low-resolution images with low inversion times (and low T1 sensitivity) for AIF determination[1]. It is the purpose of this study to investigate quantitatively the implications of this method in order to assess whether it can be used to reduce the effect of nonlinearities in perfusion quantification.

**Methods:** 10 patients were given a standard dose (0.1 mmol/kg body weight) of Gadobutrol (Bayer Schering, Berlin, Germany) and underwent an MR scan on a clinical 3-Tesla scanner (Magnetom Verio, Siemens Healthcare, Erlangen, Germany) using a linearly ordered saturation-recovery (-SR)-TurboFLASH protocol (matrix=190×160, FoV=360×300 mm², TD=10ms, BW=1002 Hz/px, $\alpha$=15°, TR/TE=2.4ms/0.99 ms). During the acquisition of every such high-resolution (HR) protocol, an additional mid-ventricular low-resolution (LR) image was acquired with a short SR time (SR-TurboFLASH with centric k-space reordering, TD=5 ms, matrix=66×64, FoV=371×360 mm², BW=1302 Hz/px, $\alpha$=8°, TR/TE=1.12/0.65 ms).

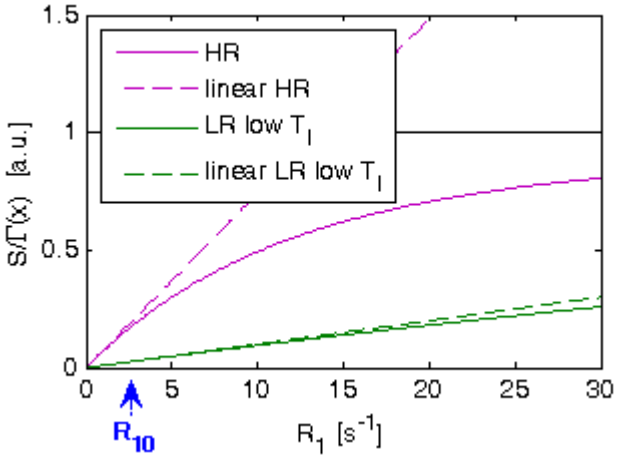


**Fig 1.** Signal curves for both SR-TurboFLASH protocols considered in the text: the LR centric-reordered, low-TI protocol can be well approximated by a linear curve, while the HR linearly ordered higher-TI protocol cannot.

Protocols were acquired under Adenosine stress and in rest. Note, that while TD (the delay before the TurboFLASH readout) was low even in the HR protocol, due to the linear k-space read-out, the effective recovery time ($TI_{eff}$) up to the central k-space line is relatively large ($TI_{eff}$=TD+TR*$N_p$=10ms+90ms=100ms). Arterial concentrations were calculated from ROIs placed within the lumen using the relative signal enhancement. Due to the lower SNR of the LR protocol, baseline values for LR stress protocols were of the order of the background noise or lower and tended to be overestimated, leading to an underestimation of the RSE. This was corrected for by scaling the respective baselines according to $S_{0,LR}^{str} = S_{0,LR}^{rest} \times S_{0,HR}^{str} / S_{0,HR}^{rest}$.

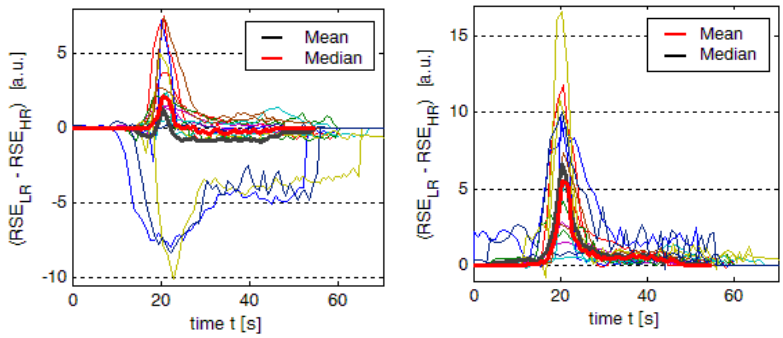


**Fig. 2** Difference in RSE between low- and high-resolution protocols for all patients before (left) and after (right) baseline correction, as well as mean and median values.

**Results:** Signal simulation of both HR and LR protocols are shown in Figure 1. These demonstrate that the signal of the centric-reordered low-TI sequence is indeed highly linear for a large range of R1 values. Fig. 2 shows the difference of RSE of both rest and stress curves for all patients as well as the mean and median values, with baseline correction (right) and without (left). Mean RSE (±standard deviation) peak values of the HR and LR protocols are $mean_{HR}$=7.4±6.1 and $mean_{LR}$=14.1±10.1, denoting a significant difference ($p<10^{-4}$) of the HR and LR protocols. Finally, Fig. 3 shows two exemplary patient curves, demonstrating the R1 values obtained in the patient measurements as well as the corresponding nonlinearities.

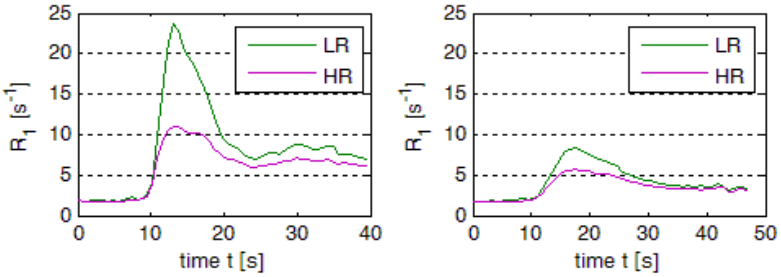


**Fig. 3** Representative R1 curves showing the highest (lest) and lowest (right) peak R1 values obtained in the analysis. These curves also show that nonlinearities are more pronounced the higher the peak signal is.

**Discussion:** Figs. 1 and 3 demonstrate that the centric-reordered low-TI protocol can be well approximated by a linear curve for all R1 values relevant to this analysis. In addition, the results show that the AIF is significantly underestimated when calculated from the HR protocol. This would result in an overestimation of perfusion parameters. Nonlinearities are largest at peak bolus values, which are the most important one for the determination of perfusion quantities. A more precise investigation should include an additional T1 determination (e.g. using a MOLLI sequence). Such a T1 value would even enable a complete analytic calculation of the AIF.

**Conclusion:** The results presented here allow several insights: First, we found a significant underestimation of the arterial input function when calculated from the clinical standard HR protocol, which can be corrected by using a low-TI LR protocol with centric k-space reordering. However, this protocol suffers from low SNR particularly in the baseline and tends to overestimate the baseline signal for stress measurements. The residual contrast agent present in the rest measurements raises the corresponding values and thus allows for this effect to be corrected.

**References:** [1] Gatehouse, et al, J Magn Reson Imaging. 2004 Jul;20(1):39-45.