How to Tackle AIF Clipping for Myocardial Perfusion Modelling with Bayesian P-Splines

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INTRODUCTION

First pass myocardial perfusion MRI with Gd-DTPA is increasingly being used for detecting tissue with low myocardial blood flow (MBF) that may lead to ischemia. To this end, the signal intensity (SI) in the left ventricle (LV) or aortic outflow track is usually used for measuring the arterial input function (AIF). It is well know, however, that SI is only linear to low tracer concentration, as high volume of Gd-DTPA in the LV can lead to full magnetization recovery with a long saturation delay. This can cause *clipping* of the LV blood pool signal, thus causing an underestimation of the AIF [1]. To resolve this problem, a range of new imaging techniques have been proposed, which include the use of dual bolus injection [2] and hybrid sequence design with short saturation-recovery time [3] for the accurate estimation of AIF. In terms of practical clinical use, both techniques require extensive modification of the scanning protocol, which may prohibit their wide-spread application. The purpose of this study is to propose a purely post-processing technique based on Bayesian hierarchical model, where the measured AIF is used as prior information to estimate the true AIF simultaneously with the response function. Both AIF and response function are modelled as smoothed function using the theory of Bayesian P-Splines [5,6].

METHODS

To model the SI time series in the sectors of the heart measured at time $t_1,\ldots,t_n$ points, we follow the ideas of [4] and [5]. The SI time curve $\mathbf{S_t}$ is modelled using a discretized convolution $\mathbf{S_t = Af = ABβ = Dβ}$, where $\mathbf{A}$ is a convolution operator which includes the (unknown) input function $\mathbf{S_p}$ and is defined as $A_{ij} = S_p(t_{n-j+1})\ \Delta t$ if $i<j$ and 0 else. The response function $\mathbf{f}$ is replaced by a B-spline representation $\mathbf{Bβ}$, where $\mathbf{B}$ is the B-spline design matrix.
We assume that the observed input function $\mathbf{Y}$ is the unknown true input function $\mathbf{S_p}$ plus Gaussian noise. The standard error of the noise distribution is assumed to be small where signal intensity is low and higher where $\mathbf{Y}$ is high. That is, clipping is *a priori* handled as additional source of error. The true $\mathbf{S_p}$ is re-constructed as B-Splines, *i.e.* a smooth function is assumed, which is simultaneously estimated from $\mathbf{Y}$ and $\mathbf{S_t}$.
Modelling is done in a hierarchical Bayesian framework, *i.e.* all unknown parameters are estimated simultaneously. Stochastic restrictions are applied on the B-Splines to ensure numerical stability, *i.e.*, a smoothing prior (random walk of first order) is applied on the regression parameters $\mathbf{β}$ following the ideas of Bayesian P-Splines [6].

RESULTS

To evaluate our approach, simulation perfusion curves were generated using the MMID4 model [7] and translated to normalized T_1-weighted signal intensities according to [1]. Data were simulated to represent healthy persons and patients with stenosis, both in rest and under stress. Fig.1 depicts the (true) AIF used in the simulation, the simulated signal intensity in the LV and the reconstructed AIF. Fig.2 shows true and estimated MBF; each group (healthy/stenosis in rest and under stress) was simulated 10 times with 3 different true values. With the proposed technique the mean overestimation of MBF is reduced from 118% to 28%. Fig.3 shows the true and estimated myocardial perfusion reserve (MPR), defined by the ratio of hyperemic and basal MBF. The mean square error of MPR estimation was reduced by 60.6% with the proposed re-construction of the AIF.

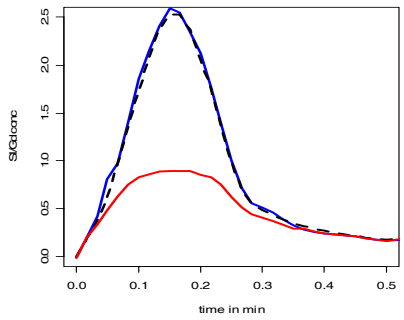

Figure 1: True AIF (dashed line), simulated signal intensity in LV (solid black line) and re-constructed AIF (blue line). Results from healthy person under stress.

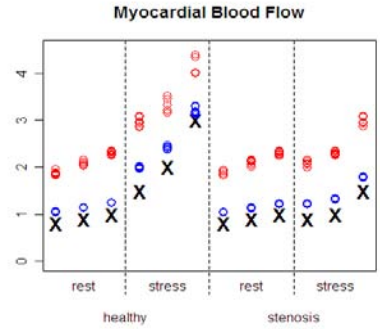

Figure 2: MBF estimates from proposed technique (blue) and with uncorrected AIF (red) compared with true values (black).

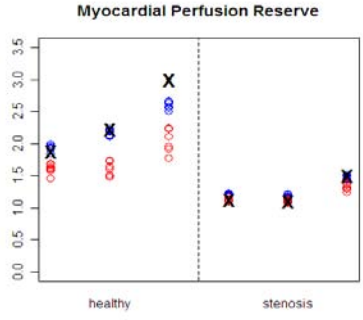

Figure 3: MPR for healthy person (left) and patients with stenosis (right). Black circle true values, blue estimates with corrected AIF, red with uncorrected AIF.

DISCUSSION AND CONCLUSIONS

AIF "Clipping" is a major problem for accurate myocardial perfusion quantification. The proposed technique addresses the re-construction of the AIF using information from the measured AIF – the SI in the LV – and from the intensities in the other sectors of the tissue. For both MBF and MPR, the proposed technique estimates the true values in the simulation study more accurate and the AIF is re-constructed quite precisely, thus forgoing the modification existing sequence design or scanning protocols.

REFERENCES

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