QUANTIFICATION OF MYOCARDIAL BLOOD FLOW IN THE PRESENCE OF REMAINING CONTRAST AGENT - A SIMULATION STUDY

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INTRODUCTION

Quantification of myocardial blood flow (MBF) using first-pass dynamic contrast enhanced (DCE) MRI is based on the relationship between signal intensity (SI) and concentration of administered contrast agent (CA). In general, in measurements of MBF this relationship is assumed to be linear, but in reality it is more complex. Therefore, residual CA from previous injections remaining in the blood also influences the relationship between SI and concentration of CA by increasing the baseline of the current DCE-MRI measurement. The concentration of residual CA depends, among other factors, on the renal clearance time of CA, which is normally much longer [1] than the interval between two perfusion measurements. These two factors, the nonlinearity of relationship and its dependency on the residual CA, lead to errors in evaluated signal time-courses and in consequence to a faulty quantification of MBF.

The aim of this simulation study was to investigate the error of quantified MBF caused by the nonlinearity of the relationship between SI and concentration of CA and to analyse the error induced by residual CA.

METHODS

A lognormal function was used as input to the simulation, obtained by fitting to an arterial input function (AIF) measured in vivo. The corresponding myocardial function was generated using a 2-compartment model (MMID4) of XSIM [2] using default parameters for MBF=1.0 mL/g/min [3]. The resulting concentration time-courses were derived from this initial pair of signal time-courses using:

$$c_{CA}(t) = \frac{1}{-TR \cdot r_1} \ln\left[\frac{(S(t) - S_0)}{E_1 \cdot (S(t) \cdot \cos\alpha - S_0)}\right]$$

where S(t) is the steady state SI during the perfusion measurement, S_0 is the spin density and α=18°, r_1=4.26 and E_1=exp(-TR/T_1) ($T_{1,AIF}$=(1267+/-72)ms[4], $T_{1,Myocard}$=(834+/-47)ms[5]). During this transformation of the signal time-courses into the related concentration time-courses the parameters T_1+/-dT_1 and S(t)+/-S_{PreCA} were varied (Fig.1), where S_{PreCA} is the error of S(t) before the arrival of CA. In this simulation S_{PreCA} was the average of the measured S_{PreCA} in 17 DCE-MRI measurements performed in 4 pigs with administration of 0.02 mmol/kg CA per measurement. Then the MBF was quantified from these concentration time-courses using XSIM [2]. To simulate the dependency on residual CA the concentration time courses were transformed back to signal time-courses with an additional amount of residual CA, which was derived from the same animal study mentioned above. For residual CA an averaged signal enhancement of 7.2% and a maximum of 21% were used in the simulation with a factor accounting for repeated administration of CA. Then the MBFs were quantified based on the varied signal time-courses. To show the influence of faulty concentration time-courses on MBF quantification, the simulation was repeated with the signal time-courses depending on residual CA as the initial pairs of signal time-courses (cf., Fig. 1). Then concentration time-courses with recalculated transformation parameters were derived from these curves and the MBFs were quantified.

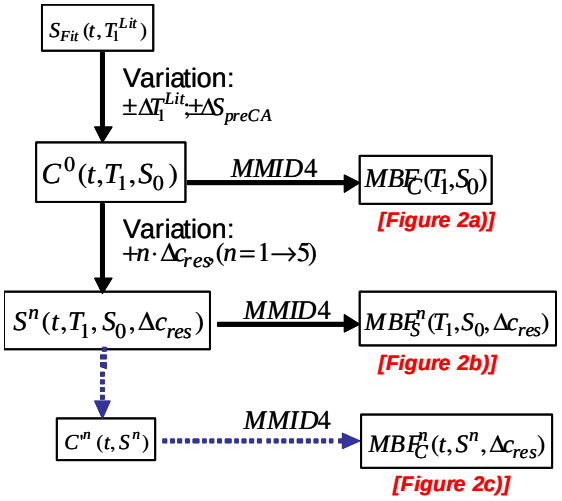

Figure 1: Flowchart for variation of parameter of simulation study.

RESULTS AND DISCUSSION

Quantitative MBF based on signal time-courses is significantly underestimated with more than 10% error (cf., Fig. 2a), because of the nonlinear relationship between SI and concentration of CA. Therefore, residual CA also influences the MBF notably depending on its concentration, if its calculation is based on signal time-courses (cf., Fig. 2b). In the related concentration time-courses residual CA is an additional value, which can be removed by normalization to the concentration before bolus arrival of CA. To minimize the error produced by transformation into concentration time courses, T_1, S_{PreCA} (cf., Fig. 2a) and the spin density (cf., Fig 2c) have to be measured very carefully before any injection of CA.

CONCLUSION

Quantification of MBF based on concentration time courses produces more reliable values than that based on signal time-courses. In the latter case, the MBF is significantly underestimated and also notably influenced by residual CA.

ACKKNOWLEDGEMENT

German Research Foundation (DFG) Grant # SCHR 687/1, MAIFOR Mainz (Germany), Robert-Müller-Stiftung Wiesbaden (Germany)

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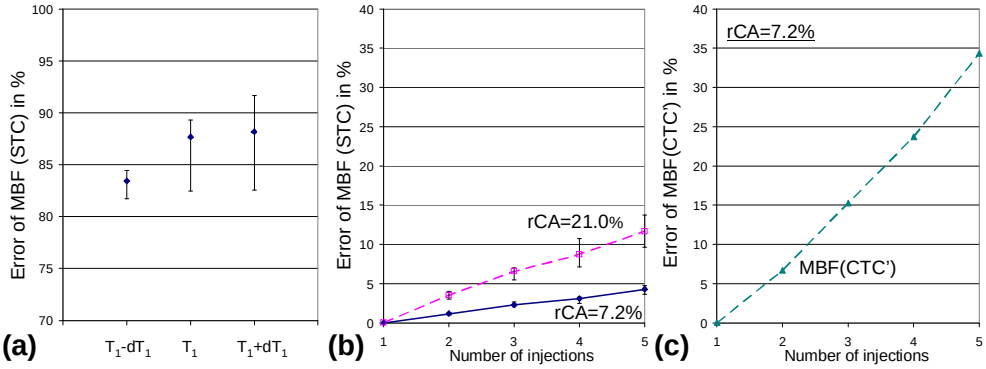

Figure 2: Error of calculated MBF

(a) Caused by the nonlinear relationship between SI and concentration of CA. MBF calculated from signal time-courses (STC) is notably underestimated depending on T_1 within its variation dT_1 and on S_{PreCA} (Error bars).

b) Based on the STCs with residual CA dependency (Error bars depend on dT_1 and S_{PreCA}). Referenced to the quantification without residual CA the error increases faster for higher concentrations of residual CA remaining from previous injections.

(c) Based on concentration time-courses derived from STCs with residual CA dependency. To minimize the error during transformation in concentration time-courses only the initial STCs without residual CA dependency are valid for calculation of the transformation parameters.