Revisiting the determination of myocardial perfusion by T_1 based ASL methods applying Look-Locker readout

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Introduction

Myocardial perfusion is an important parameter of the micro circulation and the assessment of absolute perfusion values is of great interest for diagnosis and monitoring in medical applications. Arterial spin labeling (ASL) techniques have been developed to quantify perfusion. The ASL method considered in this work exploits the measurement of the longitudinal relaxation times in tissue after slice selective and a global inversion [1, 2, 3]. To save measurement time these inversion recovery experiments are often performed with Look-Locker readout scheme. The application of Look-Locker readout pulses leads to an apparent reduction of the longitudinal relaxation time which is normally corrected according to Deichmann et al. [4].

However, Bauer et al. [5] pointed out that the strong perfusion in myocardial tissue hampers the application of this correction. Therefore, an equation considering the effect of the Look-Locker readout should be used.

Furthermore, only completely relaxed spins are assumed to enter the imaging slice via perfusion after the slice selective inversion. The application of the slice selective inversion pulse in myocardial perfusion measurement, however, results in a partial inversion of the blood inside the left ventricle (see Fig. 1) and therefore also partially inverted spins will reach the imaging slice influencing the determined perfusion. This work theoretically evaluates these issues in myocardial ASL perfusion measurements using Look-Locker read out techniques.

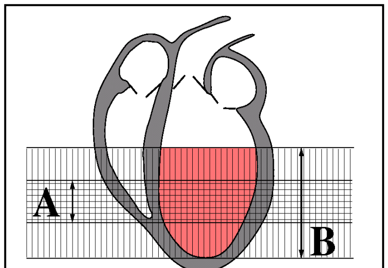

Fig 1: Visualization of the slice selective inversion issue (A: imaging slice, B: inversion slice). The red area marks the fraction of blood inside the left ventricle that is inverted.

Materials and Methods

In the work of Bauer et al. [5] the myocardial tissue is described by a two compartment model (see Fig. 2). It was used to derive an equation for the temporal evolution of the MR signal in a global inversion recovery experiment applying the Look-Locker readout scheme. Starting from these results an equation for the perfusion is obtained which directly accounts for the Look-Locker readout. This result is compared to the standard equation usually used to calculate perfusion. Additionally, the effect of the partial inversion of the blood in the left ventricle during the slice selective inversion is considered by calculating an apparent longitudinal relaxation time of the blood which arises from the incomplete blood exchange during the heart cycle (ejection fraction < 1) and the relaxation of the partially inverted blood.

Furthermore, a comparison of the two compartment model in the fast exchange limit with a one compartment model is performed.

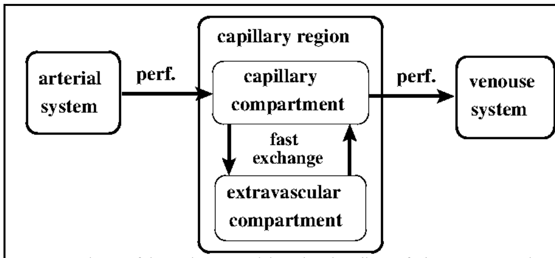

Fig. 2: Scheme of the exchange model used to describe perfusion. It assumes that the capillary region consists of the capillary compartment and the extra vascular compartment which are in fast exchange with each other. It should be noted that only the capillary system is connected to the arterial and the venous system. The first acts as source of the perfusate while the second can be viewed as drain.

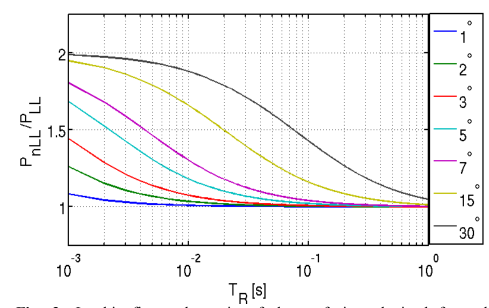

Fig. 3: In this figure the ratio of the perfusion obtained from the uncorrected equation (P_{nLL}) to the perfusion obtained from the equation corrected for the Look-Locker readout scheme (P_{LL}) is shown for different flip angles. Especially for short repetition times (T_R) and large flip angle a significant overestimation of the perfusion by the uncorrected equation can be seen.

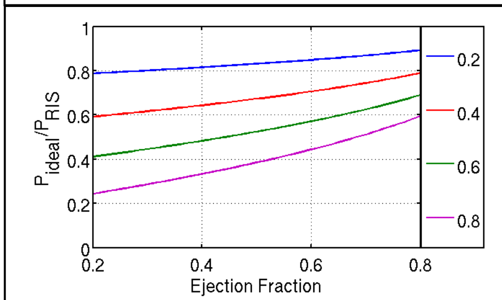

Fig. 4: In this figure the ratio of the perfusion value obtained from the equations for the ideal slice selective measurement (P_{ideal}) is compared to the perfusion value obtained from equation that considers a slice selective measurement where the blood in the left ventricle is assumed to be partially inverted (P_{RIS}) is shown for different inversion fractions of the left ventricular blood (read area in Fig. 1). Especially for low ejection fractions the perfusion value is underestimated significantly when using the equation for the ideal measurement (typical values for mouse are Ejection fraction: 0.6-0.7 and inversion fraction of left ventricular blood: 0.4-0.8).

Results

Applying the equation without correcting for the influence of the Look-Locker readout pulses leads to an overestimation of the perfusion value compared to the perfusion values obtained from the corrected equations (see Fig. 3). Especially for short repetition times and large flip angles this deviation is significant.

Furthermore, the partial inversion of the left ventricular blood results in an underestimation of the perfusion if this effect is neglected (see Fig. 4). This deviation increases with decreasing ejection fraction of the heart and increasing fraction of inverted left ventricular blood.

Comparing the results of the two compartment model with fast exchange to the one compartment model shows that only the blood tissue partition coefficient which is used to correct for the different water fractions [2] retains information on the existence of the two compartments. Both results coincide if a single correction factor neglecting the dependence on the regional blood volume is.

Discussion and Conclusion

In this work the implications of performing Look-Locker ASL measurements to obtain myocardial perfusion is investigated and it could be shown that using the standard equation should lead to significant overestimation of the calculated perfusion. However, the special properties of blood flow and the use of a slice selective inversion which partially inverts the blood in the left ventricle counterbalances this effect. Additionally it is found that if fast exchange conditions are valid a single compartment theory is sufficient to obtain correct perfusion values.

References

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