Bound Pool Fraction and $T_{1,free}$ Quantification by Non-linear Parameter Identification of Composite Echoes

B. Neumayer[1], and R. Stollberger[1]
[1]Institute of Medical Engineering, Graz University of Technology, Graz, Steiermark, Austria

Introduction

Magnetization transfer (MT) is commonly characterized by a two-pool model [1] consisting of a bound and a free proton pool. It has been shown recently in [2], that the pool size ratio, respectively the bound pool fraction (BPF), being the key parameter of the model, can be determined exploiting the dependence of a stimulated echo on the mixing time T_M. It was shown in [3] that the longitudinal relaxation time T_1 can be determined acquiring the phase of a composite echo (PACE) consisting of a stimulated and a spin echo and using a lookup table. Using non-linear parameter identification and therefore gaining information on the separate echoes should allow for the additional quantification of BPF. The aim of this study was to determine if the stimulated echo information can be separated from the composite signal and be used for the quantification of BPF exploiting the full information of the acquired signal.

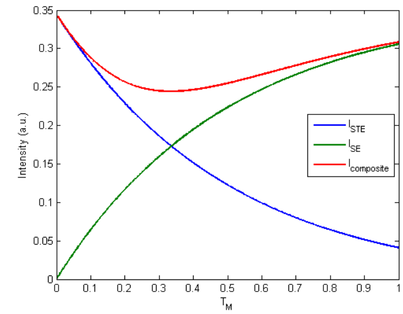

Fig. 1: Signals of a PACE sequence as a function of the mixing time T_M and in absence of magnetization transfer.

Theory

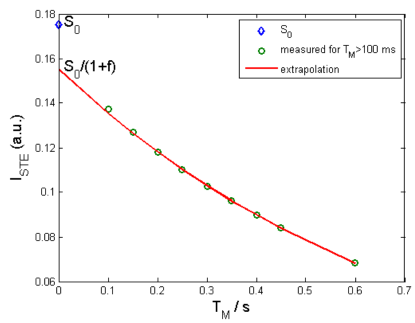

Fig. 2: S_0 and extrapolation of the mono-exponential decay.

A PACE sequence consists of 4 RF pulses producing a stimulated echo and a phase shifted spin echo at the same time. These two components exhibit a T_1-modulated phase shift which is defined by:

$$\Phi_{T1} = \arctan\left(\frac{I_{STE}\sin\varphi}{I_{STE}\cos\varphi + I_{SE}}\right), \qquad (1)$$

where φ is the initial phase offset, and I_{STE} and I_{SE} are the stimulated and the spin echo, respectively. Using a lookup table only the phase information of the composite echo can be used to determine T_1, however, fitting equation (1) to the measurement results additionally provides relative values of both echoes, as can be seen in **Fig. 1**: the magnitude image provides a composite intensity according to the red curve but knowing all measurement parameters allows to split this signal up into its components (shown for absence of MT) by fitting T_1.
With a value of the stimulated echo for T_M=0 (S_0) and relative changes for measurements with values of T_M above 100ms it is possible to acquire the mono-exponential decay of the stimulated echo necessary to determine $S_0/(1+f)$ by extrapolation (**see Fig. 2**), with f being the pool size ratio and BPF=f/(f+1) ([2],[4]).

Materials and Methods

The PACE sequence was implemented on a clinical 3T scanner with a gradient strength of 38mT/m. Parameters for all scans were: FOV=100, Matrix=64, T_R=2000ms, T_E=8ms, φ=90°, α_3=45° and various values for T_M (see **Fig. 2**). The method was validated in six phantoms with BSA concentrations ranging from 10 to 30% of BSA to water per weight.
While parameter identification provides relative changes of I_{STE}, the proportionality constant between these results and the actual signal strength can easily be calculated using the magnitude images (see **Fig. 1**). This is important for the comparison of S_0 acquired with minimum possible T_M (1.5ms) for which the resulting magnitude image directly provides I_{STE} (I_{SE} is zero for T_M=0). Additionally, inversion recovery (IR) measurements have been performed to validate the T_1 results of the measurements.

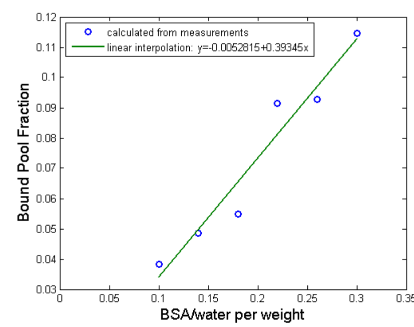

Fig. 3: Calculated BPF for phantom measurements.

Results

The graph in **Fig. 3** displays the calculated BPF values for the BSA phantoms. The values feature a linear behaviour and the extrapolation to zero concentration yields a negligible small negative offset of 0.005. As expected, T_1 results of the PACE measurements were in good agreement with the IR results (not shown). Additionally, the usage of a lookup table and the parameter identification yielded the same results for T_1.

Discussion

The results show that a separation of a PACE signal into its components is possible using parameter identification, wherefore all available information of the acquired signal can be exploited. Furthermore, the stimulated echo can be used for quantification of the BPF. Due to the monotonically rising nature of equation (1) no stability problems are to be expected for the parameter identification which is underlined by identical results using a lookup table.
The calculated values for BPF are in good agreement with the values published in [2] where phantoms with identical concentrations of BSA were used and linear extrapolation yielded almost exactly the same parameters. This serves as a basis to use this approach for a comprehensive characterization of two-pool models determining T_1 of both pools and BPF.

Acknowledgements

This work is supported by SFB F3209-N18.

References

[1] Henkelman et al MRM, 29:759–766 (1993) , [2] Soellinger et al, Proc. Intl. Soc. Mag. Reson. Med. 18: 5148 (2010), [3] Ropele et al, Magn Reson Med 1999;41:386–391, [4] Ropele et al MRM 49(5):864-71 (2003)