The Impact of Imperfect Saturation and Inflow on Perfusion Input Function

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Introduction: The estimation of perfusion from signals measured with a T_1 -weighted saturation-recovery turbo-flash (TF) sequence[1] relies on the measurement of an arterial input function[2]. The T_1 values calculated in the input voxel depends on the flow velocity during imaging, and on the effectiveness of the saturation. The saturation pulse is rarely 90 degrees but more commonly several degrees off due to imperfect power optimization, pulse profile, and B_1 inhomogeneities. To assess the effects of inflow and imperfect saturation, computer simulations were performed. These were verified in a flow phantom study, and demonstrated in a human volunteer.

Methods: A mathematical expression was derived for the longitudinal steady state magnetization, at time T_s after saturation when the center of k-space is sampled, $M_z(T_s)$. The expression omits inflow but takes into account a non-selective but imperfect saturation pulse, p_{90}, the T_R between successive saturation pulses, the post TF delay, the number of imaged slices, the TF flip angle, α, and the relaxation time T_1.
For plug flow, the magnetization before the TF read-out was calculated as the steady-state value after repeated imperfect p_{90} pulses. The magnetization during the TF read-out was modeled with reduced number of α-pulses and prolonged saturation delay, inversely proportional to the depth into the slice.
$M_z(T_s)$ was simulated using the inflow-model for T_1=[1000 300]ms, α=8°, p_{90}=92°, and M_{0z}=1. Also, $M_z(T_s)$ was measured in a human volunteer, and in a flow phantom, d=16mm, at four velocities and two concentrations of Gd-DTPA (T_1≈1000, 300ms) using Philips Intera 1.5T, head coil, nominal α=8°, nominal p_{90}=90°. In both simulations and MR measurements, T_s was [200 300 400 500 600 800 1000 1600 2000]ms. Finally, the no-flow model was fitted to both simulated and measured data to obtain estimates of T_1, α, and M_{0z}. This was repeated with p_{90} fixed at [88°, 90°, 92°, 94°].

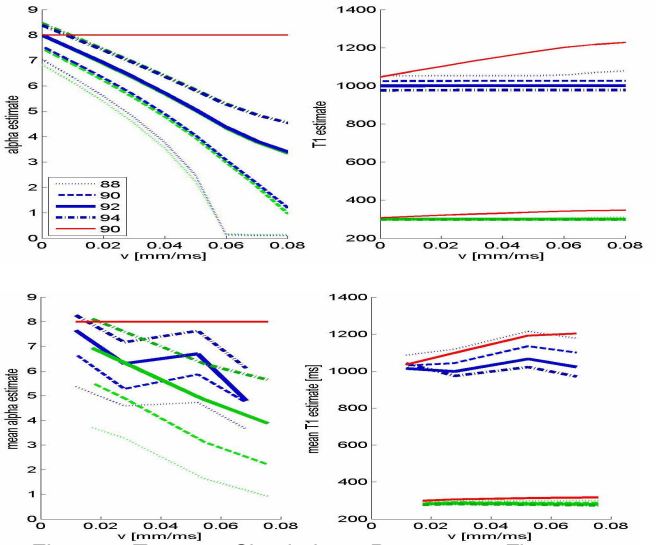

Figure 1. Top row: Simulations. Bottom row: Flow phantom. Left column: no-flow model α-estimates when fitted to inflow data (blue: T_1=1000ms; green: T_1=300ms) for different p_{90} (see legend). Right column: corresponding T1 estimates. Red curves: fixed α during optimization.

Results: The T_1 estimates of the simulations were independent of the flow-velocity (fig.1 top right), and unbiased when the original p_{90} was chosen (p_{90}=92). The α-estimates decreased with flow velocity virtually independent of T_1 when p_{90}=92 (fig. 1 top left). Also, T_1 was independent on flow-velocity in the flow measurement when p_{90}=92 (fig. 1 bottom right). Table 1 shows that the mean α-estimate increased with p_{90}, and T_1 decreased to a value reasonable for blood when p_{90}=92 or 94. The T_1 values obtained with α fixed at the nominal value was greatly overestimated in simulations, phantom and human data (red curves fig.1 right, tab.1). Thus, the results of the human and flow experiments supported the simulations.

Table 1. Parameter estimates averaged over 8 input pixels from human volunteer. Red numbers: α fixed during optimization.

p_{90}	88	90	92	94	90
α (+/-SEM)	1 +/- 0.7	3 +/- 1	5 +/- 1	4 +/- 1	8
T_1 (+/-SEM)	1698 +/- 100	1442 +/- 113	1224 +/- 99	1226 +/- 83	2182 +/- 97

Discussion and Conclusions: This study shows that the inflow effect in a saturation-recovery turbo-flash T_1 measurement may be compensated for in a no-flow model where also the TF flip angle α is fitted in addition to M_{0z} and T_1. The α-estimate shows a linear dependency on the flow velocity virtually independent on T_1, and the T_1 estimate is independent on the flow velocity. The independency of the α-estimate on T_1, ensures that the baseline parameters may be used in the succeeding perfusion experiment. However, correct T_1 estimates are obtained only if the model accounts for the actual saturation in the measurement.

References

[1] Haase A., [1990],MRM_13:77-89.
[2] Larsson HWB et.al, [2001],MRM_46:272-281.