Minimizing Slice Profile Effects in T1W Perfusion Imaging

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INTRODUCTION: T_1 perfusion measurements during bolus passage may be performed using a saturation-recovery TurboFLASH sequence with a small flip angle, α. The repeated use of α with imperfect slice profile generates an imperfect signal profile. The sequence may be used for a baseline T_1 measurement to estimate, in addition to T_1, the parameters, M_0 and α, that are to be fixed during the succeeding boluspassage. It is shown here that fixating α on the nominal value during parameter estimation may cause severe underestimation of T_1 and lead to erroneous perfusion estimates. If however, α is allowed to vary, T_1 is accurately estimated. Based on this observation, a procedure for estimating T_1 at a realistic noise level is proposed.

THEORY: T_1 perfusion may be measured using saturation-recovery TurboFLASH[1]. The transverse magnetization from the saturation-recovery turboFLASH[2] sequence at time T_s is:

$$M_{xy}(T_s)= \int M_0*\sin(\alpha(z))[(1-b)(1-a^n(z)\, b^n)/(1-a(z)b) + (1-c)\, a^n(z)b^n]\, dz, \quad \text{Eq. (1)}$$

where $a=\cos(\alpha(z))$, $b=\exp(-T_r/T_1)$, and $c=\exp(-(T_s- (n-1)*T_r)/ T_1)$, n is the number of lines to the centre of k-space, and T_r is the delay between α pulses. α is a function of position, z.

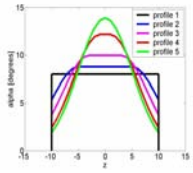

Fig.1 Simulated slice profiles

METHODS: Baseline Mxy(T_s) profiles were generated 200 times using the above equation for each of five artificial slice profiles (fig.1) ranging from box to the more realistic Gaussian shaped[3] all with mean α of 8°, T_r =3.4ms, n=37, M_0=1, T_1=900ms for nine values of T_s [150-2000]ms. Fig.2 shows examples of M_{xy} before averaging over z. Random noise with standard deviation of 1% of $M_{xy}(\max(T_s))$ for the box was added to all signals. 3 strategies were then used when fitting Eq.(1) with one common α (not a function of z) to the data: 1) α fixed at 8°; 2) α estimated; 3) α fixed at the mean α estimate from the second method. M_0 and T_1 were also estimated.

The M_0 and α estimates of methods 1 and 3 were then kept fixed and only T_1 was estimated in 200 new data sets for 10 $R_1(=1/T_1)$ from [1-10]s^{-1} representing bolus R_1 values.

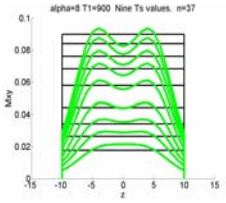

Fig.2 Simulated signal profiles for increasing Ts (bottom to top) for profiles 1 and 5 (see fig1). T_1=900ms.

RESULTS: Fig.3 shows the baseline T_1 estimate for the 3 strategies. Fixating α produced the correct estimate for the most rectangular pulse profiles, but for the guassian-shaped profiles, an error of about 5% was encountered. Estimating α produced correct T_1 estimates regardless of the slice profile with large standard deviations. Repeating the estimation with α fixed on the mean of the estimated α's also resulted in correct T_1 estimates and reduced the standard deviations.

Fixating α and M_0 found at T_1=900ms (baseline) during estimation of T_1 in the second data set (bolus passage) produced the relative R_1 estimates shown in fig.4 as a function of the true R_1. The error encountered for guassian shaped profiles at T_1=900ms propagated as R_1 increased. Fixating α on the mean baseline value successfully estimated R_1 regardless of the underlying slice profile.

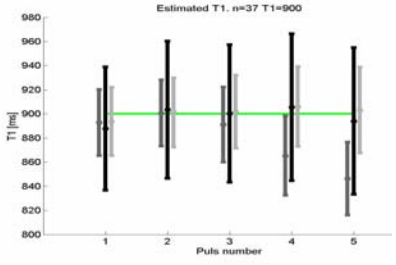

Fig.3 Estimated T_1 values for 5 profiles. Dark gray: fixed nominal α. Black: fitted α. Light gray: fixed on mean α estimate. True T_1=900ms.

CONCLUSIONS: The non-ideal slice profiles of the turboFLASH pulse may lead to an underestimation of T_1 in a baseline T_1 measurement if the flip angle is fixed at the nominal value. This error increases when the baseline values are used for signals measured at other T_1 values as would be the case during bolus passage.

If, however, α is estimated, the T_1 estimate accurately resembles the true T_1. To increase the precision of the T1 estimate in human studies, α may initially be estimated in many pixels, and then low-pass filtered and fixed at this value in a repeated fit. This approach is applicable, since even though T_1 varies, α only has low spatial frequency variations due to B_1-inhomogeneities. The approach leads to more accurate and precise T_1 estimates, and hence also to improved perfusion quantification.

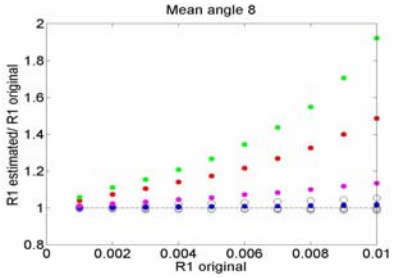

Fig.4 Relative R_1 values as function of true R_1 for different slice profiles (colors of fig1). Dots: fixed nominal α. Open circles: fixed on mean α-estimate.

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