Reducing Contamination in PASL using BASSI RF pulses

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Introduction

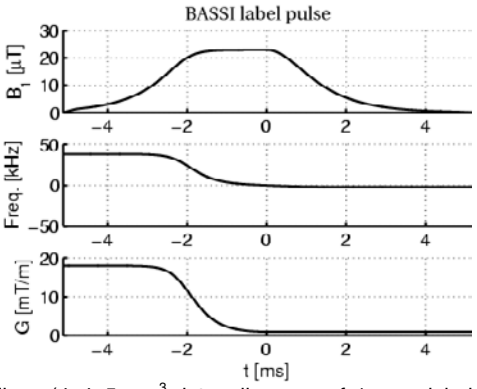
Arterial spin labeling is sensitive to contamination due to off-resonance effects of the RF label. While it has been argued that in PASL these effects are small compared to pulse profile effects [1], this assessment has to be re-evaluated in view of the advent of highly selective gradient-modulated adiabatic pulses such as FOCI [2], requiring several times more RF energy than the classic hyperbolic secant (HS) RF pulses. BASSI (Bandwidth Modulated Adiabatic Selective Saturation and Inversion) pulses are a class of frequency- and gradient-modulated RF pulses, derived from the hyperbolic secant pulse by temporal variation of the bandwidth parameter [3,4]. These pulses achieve uniform and highly selective profiles at any effective flip angle, while reducing RF energy significantly compared to FOCI pulses of similar performance. Here we present our work on optimizing BASSI RF pulses for use in PASL and evaluate their performance in terms of off-resonance contamination detectable in *in vivo* perfusion images.

Methods

Accurate quantification of perfusion requires saturation pulses in the label region to limit the temporal width of the tag. Q2TIPS [5] is a common scheme to implement those pulses, improving saturation selectivity by the use of a train of thin-slice pulses, as opposed to the QUIPSS II [6] geometry in which the entire label region is saturated. However, BASSI pulses can be parameterized to yield equally high selectivity for saturation and inversion, largely surpassing the selectivity of thin-slice sinc pulses. We therefore preferred the simpler QUIPSS II sequence, notably circumventing potential issues related to incomplete spoiling of the transverse magnetization from the long train of saturation pulses in Q2TIPS.

Pulse	T_p [ms]	α [deg]	β [rad]	b_0	f_0	$B_{1,max}$ [μT]	G_{max} [$\frac{\text{mT}}{\text{m}}$]	BW [kHz]
sinc	5.12	90°	N/A	N/A	N/A	8.0	0.5	[7]
BASSI	8.1	90°	5.3	168	3	23.1	15.7	66.7
FOCI	10.24	175°	6.3	22.8	22	23.0	14.7	62.7
BASSI	10.24	170°	5.4	36.9	19.4	23.0	18.0	76.5

BASSI pulses are based on the HS pulse, increasing its selectivity by modulating the bandwidth parameter during the beginning and end of the pulse. However, only one of the two transitions of any inversion or saturation band in a QUIPSS II geometry requires high selectivity. To minimize the required RF energy, we therefore employed asymmetric BASSI pulses, for which one transition employs bandwidth modulation, while the other remains that of an unmodulated hyperbolic secant pulse with a correspondingly lower selectivity. We centered the sharp transition of all pulses on the distal edge of the inversion band and used identical spatial width for all inversion and saturation regions. The figure to the right shows the amplitude, frequency and gradient modulation functions for an asymmetric BASSI label pulse and the table details the parameters of the RF pulses used in this study (naming convention as in [4]).

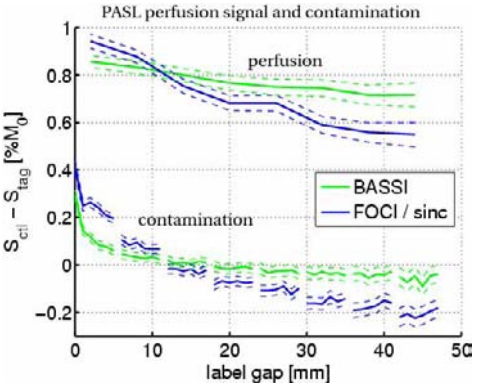


Accurate assessment of contamination of the perfusion signal was obtained *in vivo* by immediately following the label (as well as the control) pulse by a rapid succession of two BASSI saturation pulses in a slab of the same width as the inversion pulses, but offset by 3 mm proximally. Saturation of the proximal 97% of the label region corresponds to an elimination of 96% of the flow signal, when taking T_1 relaxation into account. Contamination due to off-resonance effects, unaffected by the saturation pulses, can thus be reliably isolated.

Experiments were performed on four healthy adult volunteers. The PASL acquisitions covered 8 slices (4×4×5 mm^3; inter-slice gap of 1 mm; label thickness 100 mm; TI_1=0.7 s; TI_2=1.2 s; 160 frames/run; TR=2 s; TE=28 ms). Two sequences were employed, with either FOCI label RF pulses and sinc saturation pulses in a Q2TIPS geometry or BASSI label and saturation pulses in a QUIPSS II geometry. For each sequence, we performed one run measuring perfusion (label gap 2 mm) and 6 runs measuring contamination (label gaps 0–5 mm), randomizing the order of the 12 "contamination" runs. All experiments were performed on a Siemens 1.5 T Magnetom Sonata system.

Results

The results from the *in vivo* contamination study are shown on the right. The average gray matter perfusion signal in absence of suppression of the label is shown for reference. The contamination data represents the subject-average of the residual signal in the control-tag difference images after suppression of the label as described above. Dashed lines represent the standard error of the mean. Absence of contamination is detected at the position where the control pulse perfectly mimics the off-resonance properties of the label pulse. We chose this position to be between the second and third slices, more proximal than the customary center of the imaging region, to minimize the contamination in the proximal slices, which potentially provide the most accurate perfusion measurements due to their high SNR and low transit times. We estimate that the contamination curve would have been shifted by about 0.08 % of M_0 (10 % of the perfusion signal) towards positive contamination for a conventional implementation of the FOCI control pulse. The Q2TIPS/FOCI sequence exhibits pronounced contamination. The difference in overall image intensity due to contamination, between a slice positioned at a label gap of 10 mm and one positioned 36 mm further distally, is (33±5) % of the typical gray matter perfusion signal. The contamination remaining in the QUIPSS II/BASSI sequence is lower by about a factor of three, at (10±5) % of the perfusion signal. The gray matter perfusion data closely match the results from the contamination study, showing a decline of the perfusion signal with increasing distance from the label. This decline is perfectly explained by the contamination effects.



Conclusion

We presented an optimized PASL implementation based on BASSI RF pulses for labeling and saturation in a QUIPSS II scheme and evaluated its performance in terms of contamination detectable in an *in vivo* study. Significant contamination was present in a conventional PASL implementation used for comparison. Due to the low RF energy of the BASSI label pulse, absolute contamination was noticeably reduced in the optimized sequence, remaining below 10 % of the average gray matter perfusion signal for label gaps of 3 mm and above. Further optimization of the spatial selectivity of RF pulses are likely of little interest for PASL, as head motion will become a limiting factor to using lower label gaps *in vivo*. However, any progress towards label pulses requiring even less RF energy will likely result in further improvements of the precision of PASL perfusion measurements. In cases where a PASL protocol is to be optimized but implementation of a custom RF pulse is not feasible, proper calibration of the label pulse amplitude [7] is the second most important step to minimize contamination.

References

[1] L. R. Frank *et. al.*; Magn Reson Med; 38(4):558-64; 1997.
[2] R. J. Ordidge *et. al.;* Magn Reson Med; 36(4):562-6; 1996.
[3] J. M. Warnking *et. al.;* Proc. ISMRM 2004; abstract #2654.
[4] J. M. Warnking *et. al.*; Magn Reson Med; 52(5):1190–9; 2004.
[5] W. M. Luh *et. al.;* Magn Reson Med; 41(6):1246-54; 1999.
[6] E. C. Wong *et. al.*; Magn Reson Med; 39(5):702-8; 1998.
[7] J. M. Warnking *et. al.;* Proc. ISMRM 2004; abstract #1622.