Turbo-QUASAR: a signal-to-noise optimal arterial spin labeling and sampling strategy

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INTRODUCTION: Arterial Spin Labeling (ASL) is a promising noninvasive technique for assessment of perfusion in disease and functional studies. Depending on the method used, the optimized sequences aim at a compromise between high temporal signal-to-noise (tSNR) and minimal flow quantification errors. In CASL, the labeling last for 1-2s followed by a similar post-labeling delay allowing the label to reach the tissue and clear from the feeding vasculature before acquisition. This is similar for the pulsed methods except that labeling occurs instantaneously. However, valuable acquisition time is wasted between labeling and actual acquisition, a reason that Look-Locker readouts have been applied to take advantage of the waiting time and at the same time gain information about parameters such as bolus arrival time and tissue T1. However, due to T1 decay of the blood bolus and the fact that repeated low flip-angle excitations are used, the tSNR is reduced at each post labeling delay and it significantly limits the spatial coverage.

Here we propose an optimal labeling and acquisition scheme where the labeling is repeated during the Look-Locker readout, allowing for full-brain acquisition while keeping optimum perfusion signal. The sequence is an extension to the QUASAR sequence[1] and therefore dubbed Turbo-QUASAR.

THEORY: Buxton et al.[2] described a general kinetic model for the magnetization difference ΔM between the label and control experiment using the following convolution integral:

$$\Delta M(t) = 2 \cdot M_{a,0} \cdot f \cdot \int_0^t c(\tau) \cdot r(t-\tau) \cdot m(t-\tau) d\tau \qquad [1]$$

where $M_{a,0}$ is the equilibrium magnetization in a blood filled voxel, f is the perfusion value, $c(t)$ is the delivery function or fractional arterial input function (AIF), $r(t-\tau)$ is the residue function describing the fraction of labeled spins arriving to a voxel at time τ, that still remains within the voxel at time t. The magnetization relaxation term $m(t-\tau)$ quantifies the longitudinal magnetization fraction of labeled spins arriving to the voxel at time τ that remains at time t. From equation [1] it is clear that the only sequence dependent parameter is $c(t)$ and any true gain in tSNR therefore has to come from here when assuming that the readout, physiological and instrumental noise remains the same. This is indeed what Turbo-QUASAR achieves by prolonging $c(t)$ while acquiring data.

METHODS: The method rely on the QUASAR implementation which has been described in detail elsewhere[1,3]. In short it acquires multi timepoint data at several post labeling delays and by interleaving acquisitions with and without vascular crushers it allow the extraction of the arterial input function ($AIF(t)= 2M_{a,0}\, c(t)$) and $\Delta M(t)$. The flow f can subsequently be found by deconvolution. Instead of a single initial label pulse, Turbo-QUASAR adds labeling in front of the individual Look-Locker readouts. The resulting effect is shown in figure 1 on the left, instead of the usual single bolus, a series of boluses are generated. This in turn produces a prolonged tissue signal which plateau is proportional to the flow (Fig.1 on the right). In the current work, the model free deconvolution approach[1] is used for cerebral blood flow (CBF) quantification; however model fitting is also possible. Four healthy volunteers were scanned (3T Philips Achieva) using Turbo-QUASAR according to institutional guidelines. The scan parameters were: TR/TE/ΔTI/TI1=6000/13/600/30ms, 9 phases, 7 boluses, 80x80 matrix, FOV=240x240, flip-angle=35°, 6 mm slice, SENSE=2.5. Total scan time 5:15. Either a slab selective labeling (15cm, gab=2cm) or velocity selective (Venc=2cm/s) was applied.

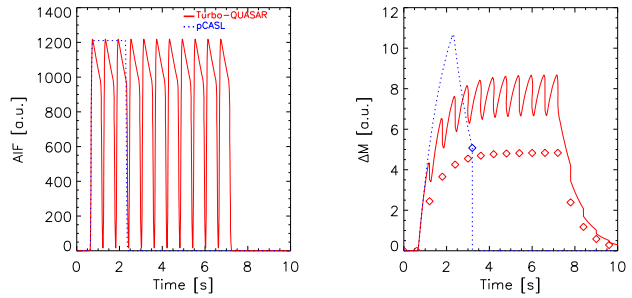

Figure 1. Left) *The arterial bolus or AIF over time.* ***Blue*** *is for a typical pCASL experiment with a label duration of 1.65s and a post label delay of 1.55s allowing for a 3.8s TR while keeping 0.6s for a single full brain acquisition.* ***Red*** *is for the Turbo-QUASAR sequence with 17 Look-Locker readout phases and a TR of 10s. The inter pulse spacing ΔTI is 0.6s thereby also allowing full brain coverage.* ***Right)*** *The corresponding tissue ΔM(t) with the diamonds being the actual signal readout. In this particular example (CBF=60ml/100g/min, ATT=0.6s) the temporal SNR gain is 4 for the Turbo-QUASAR sequence.*

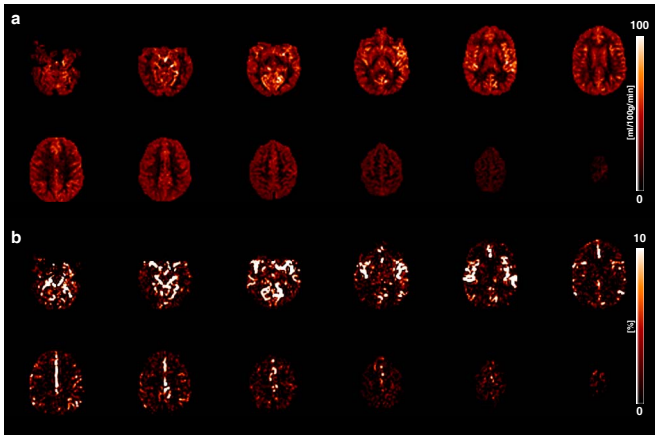

Figure 2. a) *CBF map,* ***b)*** *aBV map acquired with slab selective Turbo-QUASAR*

RESULTS and DISCUSSION: Monte-Carlo simulations showed tSNR gains of up to fourfold as compared to existing pCASL sequences[4], depending on parameters such as actual bolus length achievable with PASL (5-700ms assumed) and the bolus arrival time, while at the same time restraining each sequence to have a 500ms acquisition window for full brain coverage. Example CBF maps from Turbo-QUASAR are shown in figure 2. Reasonable quality perfusion weighted maps can be acquired in just 12s, making the approach suitable for functional studies as well. An intrinsic problem with the dynamic ASL[5] (DASL) approach, which also aim at boosting the tSNR by interleaved continuous labeling and acquisition, is the fact that no acquisition can be performed during labeling and therefore during the entire combined label duration. Turbo-QUASAR on the other hand takes say 20ms to generate a label which last up to 5-700ms thereby allowing for continuous acquisition so full brain coverage can be performed within the temporal length of the label. Therefore, Turbo-QUASAR also gains higher tSNR than DASL as long full brain acquisition is required (~ factor of 2).

CONCLUSION: A signal-to-noise optimal arterial spin labeling and sampling strategy has been proposed which maximizes both the bolus duration and the acquisition window and thereby temporal SNR. At the same time Turbo-QUASAR provides information about auxiliary parameters needed for quantification such as bolus arrival time, tissue T1, arterial input function and arterial blood volume. The method is applicable for all labeling schemes which label at a single instance of time (Slab-, Velocity- and Acceleration- selective).

REFERENCES: [1] Petersen et al, MRM 2006;55(2):219-32 [2] Buxton et al, MRM 1998;40(3):383-96 [3] Petersen et al. Neuroimage 2010;49(1):104-13 [4] Dai et al, MRM 2008;60(6):1488-97 [5] Barbier et al, MRM 1999;41(2):299-308

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