PULSAR and QUASAR: Two STAR sequences for regional perfusion imaging at 3T

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INTRODUCTION: Recently, arterial spin labeling (ASL) methods have been introduced for noninvasive regional perfusion imaging (RPI) of individual perfusion territories (1). RPI methods provide vascular-anatomical information and thereby make the assessment of collateral flow possible. Combined with diffusion-weighted imaging for instance, these methods are of potentially great clinical value for the diagnosis of neurovascular diseases like arteriosclerosis or focal cerebral ischemia. One implementation is based on the transfer insensitive labeling technique (TILT) at 1.5T (1,2). However, in order to increase perfusion sensitivity, high-field imaging is appealing due to higher SNR and increased relaxation time T_1 of the label, but with the drawback of reduced RF penetration rendering the TILT labeling particularly inefficient. Therefore, a field inhomogeneity insensitive sequence is proposed (2), based on a modified EPI **S**ignal **T**argeting by **A**lternating **R**adio-frequency pulses (EPISTAR) sequence (4), preceded by an optimized 4-pulse **w**ater suppression **e**nhanced through **T**1-effects (WET) saturation pulse (5). This multi-slice capable sequence was named **pul**sed **S**TAR labeling of **a**rterial **r**egions (PULSAR). However, absolute perfusion quantification from single time-point acquisition is questionable, as duration and arrival time of the label is uncertain especially for the targeted patient population in which vascular occlusions and delayed collateral flow may exist. Furthermore, the problem may be amplified by the use of separate labeling of each major artery. To overcome these problems, the PULSAR labeling sequence was extended using a Look-Locker strategy for sampling at multiple time-points (6) and a repetitive Q2-TIPS like bolus saturation scheme for clear definition of the arterial blood bolus (7). This makes absolute perfusion quantification possible even in patients, and was therefore named **qua**ntitative **S**TAR labeling of **a**rterial **r**egions (QUASAR).

METHODS: Both PULSAR and QUASAR sequences have identical labeling, pre- and post-saturation schemes which are depicted in Fig. 1 whereas the difference remains in the readout. Control and labeling pulses are conventional adiabatic hyper-secant pulses performed at the same location. The RF power of the labeling 180° inversion pulse is counterbalanced using two consecutive pulses of half RF power during the control phase, resulting in a net 180° + 180° = 0° pulse. This ensure identical magnetization transfer effects for both cases, allowing multi-slice and independent positioning of the labeling slab with respect to the slices of interest. The WET saturation preceding the labeling has been chosen for its insensitivity over a broad range of B_1-field inhomogeneities and T_1 values. Using an inter-pulse interval of 10 ms and optimizing for $400 \le T_1 \le 4200$ ms and $\Delta B_1 = \pm 10\%$, the resulting flip angles were (3): $\theta_1 = 88.9°$, $\theta_2 = 98.7°$, $\theta_3 = 82.5°$and $\theta_4 = 159.0°$ resulting in a saturation efficiency suitable for oblique planning of the labeling slab in relation to the image slices. A single 90° saturation pulse is applied subsequently to insure identical timing between both labeling and control experiments. PULSAR uses a conventional multi-slice single-shot EPI readout at a predefined inversion time TI after the labeling. The QUASAR readout is similar but applied with small flip angles over multiple time-points starting at TI_1 and spaced by ΔTI (Fig. 2). Then, each slice acquisition is preceded by a bolus saturation slab applied inferior to the volume of interest, when within the time $\tau_b < t < \tau_b + \tau_s$ (Gray in Fig. 2). Its width must be chosen according to the time between successive slice acquisitions and the expected speed of the blood in order to reach proper bolus saturation (7). In particular, the bolus saturation must be initiated before the fastest flowing of the tag leaves the inversion region. The duration τ_s during which this saturation is applied should be chosen long enough so that the remaining part of the label has been saturated, while time must be allowed for fresh blood to fill up the vessels before the next spin preparation. Both sequences have the option of applying "crusher" or bipolar gradient pulses, allowing elimination of the signal from fast moving spins. For validation of the sequences, 4 healthy volunteers were scanned, all giving written informed consent before participation. The experiments were approved by the local ethics committee. Scan parameters: 3 slices; thickness = 8 mm; gap = 2 mm; matrix = 64 × 64; FOV = 240 mm; $\alpha = 90°(30°)$; T_R / T_E = 3000 (4000) / 23 ms; TI / (TI_1, ΔTI) = 1500/ (50, 200) ms; (time points = 18); (τ_b / τ_s = 1250 / 2250 ms); SENSE = 3; labeling slab = 150 mm; inversion gap = 30 mm; crusher encoding velocity V_{enc} = 3 cm/s; 60 (80) averages; total scan time for 3 perfusion territories × 3 to 5 min = 9 to 15 min. Planning of the labeling volume for the left- and right-ICA as well as the posterior circulation was performed on the basis of the MIPs from TOF- and PC- MR angiograms in a way similar to Hendrikse et al (1).

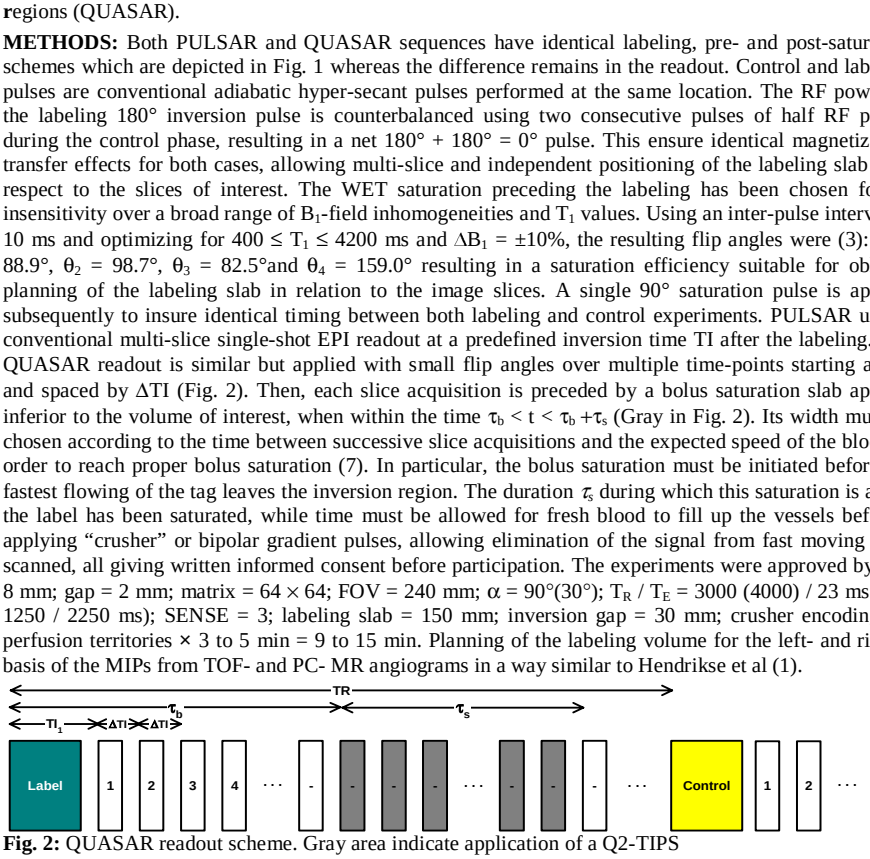

Fig. 1: PUSLAR labeling scheme, comprising a WET presaturation, followed by a STAR labeling and a single RF pulse for clear definition of the start of the bolus

Fig. 2: QUASAR readout scheme. Gray area indicate application of a Q2-TIPS

CBF [ml/min/100g]			
	Left-ICA	Right-ICA	Posterior
PULSAR	69±3	63±2	62±2
QUASAR	67±2	64±2	65±3

Table 1: CBF values in corresponding territories

RESULTS and DISCUSSION: Table 1 lists the perfusion values in each individual territory over 4 volunteers, as measured by both methods, in agreement with each other and with literature values (1). Figure 3 shows the CBF-map of a representative volunteer acquired using PULSAR and QUASAR respectively. All three perfusion maps from each technique were combined into an RGB (red-green-blue) frame, without thresholding of any kind. In particular, the left internal carotid artery (ICA) was colored in green, the right ICA in red, and the posterior circulation in blue. Any area demonstrating mixing of perfusion coming from more than one vessel will show a combined color, e.g. perfusion coming from both ICA will turn yellow = red + green. For this healthy volunteer, the quality of the QUASAR approach seems superior to the PULSAR, partly due to the relative late arrival of the bolus to the borderzone between posterior and ICA territories. It therefore demonstrates that QUASAR is insensitive to bolus arrival time, which is crucial in e.g. atherosclerotic patients. Furthermore, unlike PULSAR, QUASAR will allow to get arrival time or bolus duration maps (fitted using the general kinetic model (data not shown) (6). On the other hand the SNR in PULSAR is higher, due to the reduced flip angle used in QUASAR.

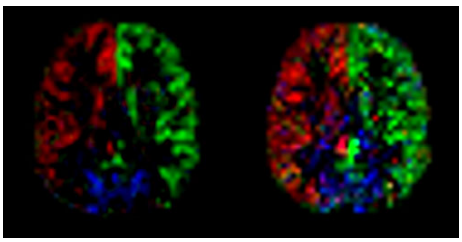

Fig. 3: PULSAR (left) and QUASAR (right) RPI maps. CBF range: 0-120 ml/min/100g

CONCLUSION: In the present work, we proposed new implementations of the RPI technique suitable for high field imaging, which can provide high spatial coverage in either a shorter scan time (3 min / perfusion territory instead of 5 min) or with a higher resolution as compared to what can be reached at 1.5T. The clear temporal bolus definition and the measurements of the bolus arrival time obtained using the QUASAR sequence make it a robust method for perfusion quantification in different pathophysiological situations. However, more work needs to be done on the reproducibility of these measurements.

REFERENCES: [1] Hendrikse et al., Stroke 2004;35(4):882-887 [2] Golay et al., JMRI 1999;9(3):454-461. [3] Golay et al., MRM 2004; In Press. [4] Edelman et al., MRM 1998;40(6):800-805 [5] Ogg et al.,JMRB 1994;104(1):1-10 [6] Günther at al., MRM 2001;46(5):974-984 [7] Luh et al., MRM 1999;41(6):1246-1254