Evaluation of Readout Schemes for Arterial Spin Labelling in the Human Kidney

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TARGET AUDIENCE: Researchers interested in abdominal Arterial Spin Labelling (ASL) measures, in particular for renal function.

PURPOSE: To evaluate gradient and spin echo based readout schemes for multi-slice ASL of the human kidney at 3 Tesla. A number of readout schemes have been proposed for renal ASL, these include gradient echo based methods of balanced fast field echo (bFFE) [1] and gradient echo echo-planar imaging (GE-EPI) [2] or spin echo based schemes of spin echo EPI (SE-EPI) [3] and turbo spin echo (TSE) [4]. Here, we directly compare these readout schemes in terms of temporal SNR, image SNR, spatial coverage, perfusion quantification and variability across slices/subjects, and with the aim of determining the optimal readout scheme for pulsed ASL (PASL) of the kidneys at 3 T in healthy volunteers with normal renal function.

METHODS: PASL was developed for combination with multi-slice bFFE/GE-EPI and SE-EPI/TSE readout schemes. Six healthy volunteers (age 31 ± 4 years) were then scanned for each scheme in a single scan session on a 3T Phillips Achieva scanner with MultiTransmit, and 16-channel SENSE torso receive coil. Localiser bFFE scans were first collected in 3 orthogonal planes to aid ASL planning. A respiratory triggered pulsed FAIR ASL scheme was used (minimum TR = 6 s, post-label delay (TI) for 1st slice = 1300 or 1800 ms (sequence dependent), in-plane pre-saturation, Non-Selective (NS) slab thickness 400 mm, Selective (S) slab thickness 45 mm, 25 S/NS pairs). Table 1 summarises the readout imaging parameters, all schemes were acquired using volume shimming with 3x3x5 mm voxels, in-plane FOV of 288x288 mm and SENSE factor 2. Coronal-oblique slices through the long axis of the kidney were acquired in descend (lateral-medial) order with minimum temporal separation allowed by specific absorption rate limits. A base magnetisation M_0 image and an inversion recovery data set from which to form a T_1 map were acquired for each scheme, as well as an inflow dataset (4 S/NS pairs, TI = 300, 500, 700, 900, 1100 ms).

Readout scheme (number of slices, slice gap (mm))	Post-label delay of 1st slice (ms)	Temporal slice spacing (ms)	Flip angle (deg)	TE (ms)
bFFE[1] (5, 0)	1300	280	45	1.5
GE-EPI[2] (5,0)	1800	40	90	8
SE-EPI[3] (5,0)	1800	60	90	18
TSE[4] (3, 5)	1300	480	90	50

Table 1: Readout scheme image parameters

Data Analysis: Analysis was performed using custom written matlab programs. Individual ASL perfusion weighted (PW) images (ΔM = S – NS) were calculated, inspected for motion and if necessary excluded before averaging. PW images were then normalised by the M_0 image. A kinetic model [5] was used to estimate renal blood flow (RBF) maps from the ΔM, M_0 and T_1 images. A mask of the kidney cortex was derived from the T_1 map. Background thermal (T) and physiological (P) noise was calculated from an ROI outside of the kidneys. For quantitative assessment of readout schemes the following were estimated in the cortex: (i) PW image SNR (PWI-SNR = $\Delta M_{mean}/\ \sigma_{background\_noise\_P\&T}$); (ii) temporal SNR (tSNR = maps of ($\Delta M_{mean}/\ \sigma_{\Delta M\ across\ PW\ time\ series}$)); (iii) variability in ΔM across slices ($var_{\Delta M} = \sigma_{\Delta M\ across\ slice}/\ \Delta M_{mean}$); (iv) RBF in units of ml/100g/min.

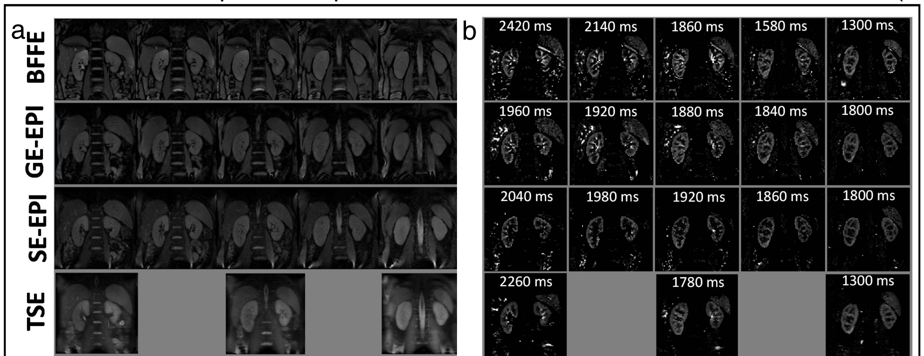

Figure 1: (a) M_0 images for each readout scheme and (b) corresponding perfusion weighted images ($\Delta M/M_0$) with post-label delay shown for each slice.

RESULTS: Figure 1 shows representative M_0 and $\Delta M/M$ images for each readout scheme. 5 slices were collected for GE-EPI, SE-EPI and bFFE, and 3 slices for TSE due to the longer SAR-limited temporal spacing. Table 2 compares quantitative measures between readout schemes. PWI-SNR was significantly lower for SE-EPI compared to all other schemes ($P < 0.05$), and tSNR was also lowest for SE-EPI. For bFFE and TSE, a change in ΔM (high $var_{\Delta M}$) was found across slices due to the large temporal slice spacing. However, on quantifying RBF, no significant difference in RBF was found across slices having accounted for slice acquisition time in the fit. RBF was found to be higher for GE compared to SE readouts, with a significant difference in measures of RBF between bFFE and SE-EPI ($P < 0.05$).

Readout scheme	PWI-SNR	tSNR	$var_{\Delta M}$ (%)	RBF (ml/100g/min)
bFFE	8.4	1.9	24 ± 13	331 ± 57
GE-EPI	7.9	2.0	13 ± 3	281 ± 37
SE-EPI	3.5	1.1	8 ± 2	250 ± 26
TSE	7.2	1.8	26 ± 19	256 ± 79

Table 2: Quantitative measures of readout schemes

DISCUSSION: We have presented the trade-offs associated with bFFE, GE-EPI, SE-EPI and TSE readout schemes for multi-slice renal ASL. RBF was higher for the bFFE scheme which can be attributed to the vascular signal present. Gradient echo based schemes (bFFE and GE-EPI) provide optimal PWI-SNR and tSNR, with GE-EPI yielding multi-slice coverage in a short acquisition time. Future work will assess the reproducibility of each readout scheme between scan sessions.

References: [1] Martirosian *et al.*, MRM. 2004; 51(2):353-61, [2] Sokolska *et al.*, ISMRM 2014, P2194, [3] Gardener *et al.*, MRM. 2010; 63(6):1627-36, [4] Robson *et al.*, MRM. 2009; 61(6):1374-87, [5] Buxton *et al.*, MRM. 1998; 40(3): 383-396.

Acknowledgement: This work was funded by the Dr Hadwen Trust. The Dr Hadwen Trust (DHT) is the UK's leading non-animal biomedical research charity that exclusively funds and promotes human-relevant research that replaces the use of animals whilst supporting the progress of medicine.