Multi-slice kidney perfusion using SE-EPI FAIR: Optimised acquisition and analysis strategies

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INTRODUCTION: The measurement of renal perfusion is critical for assessing kidney viability and is typically performed using contrast media. Recently it has been reported that gadolinium-based contrast agents can have side-effects leading to Nephrogenic Systemic Fibrosis (NSF) [1], highlighting the need for non-invasive perfusion methods. Arterial spin labelling (ASL) provides such a non-invasive method, and labelling has generally been followed by True-FISP [2] or SS-FSE [3] image acquisition. However ASL in the abdomen is challenged by abdominal motion, and current techniques generally use single slice acquisition (due to significant decay of the label during image acquisition and SAR issues) and no vascular crushing. Here multi-slice kidney perfusion maps are acquired in less than 3 minutes using FAIR with Spin-Echo (SE) EPI acquisition. The effect of breathing strategy, background suppression (BGS) [4] and realignment strategies are assessed.

METHOD: *Acquisition*: Data was acquired on a 1.5T Philips Achieva system using body transmit and 4-ch SENSE torso receive coil. Placement of image and label was planned from BTFE localizer scans. ASL data were acquired using coronal oblique SE-EPI with SPIR fat suppression (FOV 288 x 288 mm^2, 96 x 96 matrix, 5 mm slice thickness, 7 slices acquired in 400 ms). SENSE 2 and half scan 0.75 limited TE to 20 ms for sufficient SNR in both cortex and medulla. FAIR used a FOCI inversion pulse with 400 mm non-selective inversion and a selective inversion 10 mm wider than the imaging volume. In-plane saturation was applied using WET pre-saturation and sinc post-saturation and a TI of 1.1 seconds (to first EPI acquisition) was employed. To assess the effect of breathing-induced motion, ASL data sets were acquired on 8 healthy volunteers for: (i) free breathing (TR 3 s) (ii) respiratory triggering (minimum TR 3 s) and (iii) breath hold (inspire and breath-hold for 24 s with 3 ASL pairs acquired per breath hold). 30 sets of ASL pairs were acquired in total for each acquisition, and respiration was recorded using a respiratory belt. In addition, free and triggered breathing data sets were also acquired using a background suppression scheme (two inversion pulses: TI_1 = 450 ms and TI_2 = 400 ms) [4]. To assess reproducibility a test-retest experiment was performed on 4 subjects. In addition an M_0 image and a T_1 map were acquired, allowing segmentation of cortex and medulla and quantification of perfusion in these regions.

Analysis: Images were pair-wise subtracted and averaged to form a ΔM image, which was quantified on a pixel-by-pixel basis using a simplified perfusion model (Eq. [1]), where M_0 is tissue equilibrium magnetisation, T_1 is the relaxation time of tissue, f is the perfusion rate in ml 100g^{-1} min^{-1}, and λ blood-tissue partition coefficient for kidneys (0.8 ml g^{-1}).

$$f = \frac{\lambda}{2TI}\frac{\Delta M(TI)}{M_0}\exp\left(\frac{TI}{T_1}\right)$$

Eq [1]

To assess the effect of breathing induced motion on quantification, data was realigned using FLIRT [5], with a mask applied to the kidney region. For each data set, the mean perfusion rate and contrast to noise ratio (CNR) [CNR = $S_{sel} - S_{nonsel} / \sigma_{noise}$, where S_{sel} and S_{nonsel} are the image intensities for the selective and non-selective inversions] in cortex and medulla were calculated.

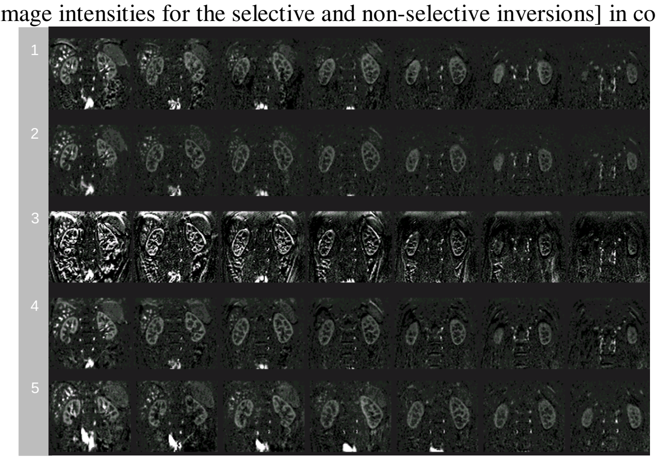

Figure 1:*Multi-slice ΔM images for different breathing strategies and background suppression. 1) free breathing; 2) free breathing with BGS; 3) respiratory triggering; 4) respiratory triggering with BGS and 5) breath-hold.*

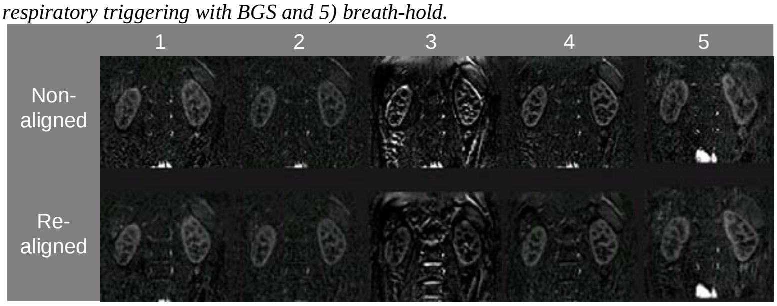

Figure 2*: Comparison of non-aligned and realigned data for breathing and acquisition strategies (1-5) in Figure1.*

RESULTS: Figure 1 shows the realigned multi-slice ΔM images for the various image and background suppression strategies. Figure 2 comparing non-aligned and realigned data for a representative (central) slice. Perfusion rates and CNR measured for the various schemes assessed are given in Tables 1 and 2 respectively. BGS visually improves the detection of kidney perfusion, but this can be seen to be at the expense of a significant reduction the measured perfusion signal (with a reduction of ~20 % and $P < 0.005$ for free breathing). Realignment significantly improved the CNR of both data acquired with and without background suppression. It can be seen that respiratory triggered images in the absence of BGS show a clear outline after subtraction which cannot be removed following realignment (3); respiratory triggered data should be acquired using BGS (Figure 2). Breath hold data gave similar perfusion values to free breathing when realigned, but took ~2 times longer to acquire.

	No BGS	*BGS*
Free breathing	*464*	*365*
Triggered	*530*	*381*
Breath hold	*405*	*-*

Table 1: Perfusion rate in cortex (ml/100g/min) for each breathing strategy following data realignment.

Breathing strategy	***BGS***	***realigned***	***Non-aligned***
Free breathing	*No*	*6.0*	*4.0*
Free breathing	*Yes*	*5.4*	*3.9*
Triggered	*No*	*4.7*	*0.3*
Triggered	*Yes*	*4.5*	*2.6*
Breath hold	*No*	*5.2*	*3.5*

Table 2: Cortex CNR for each breathing and analysis strategy.

DISCUSSION: FAIR with SE-EPI acquisition using parallel imaging provides a rapid method for multi-slice assessment of kidney perfusion. BGS visually improves ΔM images, but this is at the expense of reduction in perfusion signal and underestimation of perfusion rate, even with realignment. Often retrospective sorting of images is performed to discard large movements in ASL data before averaging, but this reduces CNR. Here it is shown that by the acquisition of multi-slice SE-EPI permits realignment algorithms to be applied to the data, significantly improving CNR and retaining perfusion signal and true estimation of perfusion rate. Realignment fails to correct respiratory triggered images in the absence of BGS (3). This study suggests the optimal scheme for estimating kidney perfusion is acquisition of data during free breathing, and subsequent realignment. This method also benefits from being the most rapid acquisition method and most suitable for patient compatibility and comfort.

REFERENCES: 1. Endre, IMJ, 2007; 2. Martirosian, MRM, 2004; 3. Robson, Proc. ISMRM, 2008; 4. Garcai, MRM, 2005; 5. Jenkinson, Neuroimage, 2002.