Dual slice perfusion measured with PASL-SIR

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Introduction. Skeletal muscle perfusion quantifies microvascular blood flow and is an important parameter that provides information about delivery of oxygen and nutrients to tissue. It has been shown that perfusion dynamics during reactive hyperemia are altered in peripheral artery disease (PAD). This blunted reactive hyperemic response correlates with both disease presence and severity [1]. It is also hypothesized that perfusion measurements may be sensitive to improvements in disease severity, however, to investigate such a hypothesis, the perfusion measurement must have good longitudinal reproducibility. The use of a multi-slice perfusion technique would allow greater anatomic coverage, reducing potential errors due to subject repositioning and improving longitudinal reproducibility. While several methods for multi-slice perfusion exist [2-3], they use sequential image acquisition; therefore slices are acquired with different post-label delays (PLDs). A readout technique called simultaneous image refocusing (SIR) EPI [4] can be used to simultaneously acquire data from multiple slices. This work describes a pulsed arterial spin labeling (PASL)-SIR sequence to simultaneously measure dual-slice perfusion during reactive hyperemia in the leg.

Methods. Perfusion tagging was achieved using a FAIR variant [5], with the slice-selective (SS) inversion covering both slices. A partial Fourier SIR-EPI readout scheme was used for dual-slice acquisition following the PLD. Figure 1 shows the pulse sequence diagram for PASL-SIR. Each of the RF pulses excites a separate slice. The addition of a small readout prephase gradient between the two RF pulses causes the echoes from the two slices to be separated in time. Once the image is acquired, the k-space data from each slice is separated and perfusion is quantified as described in [5].

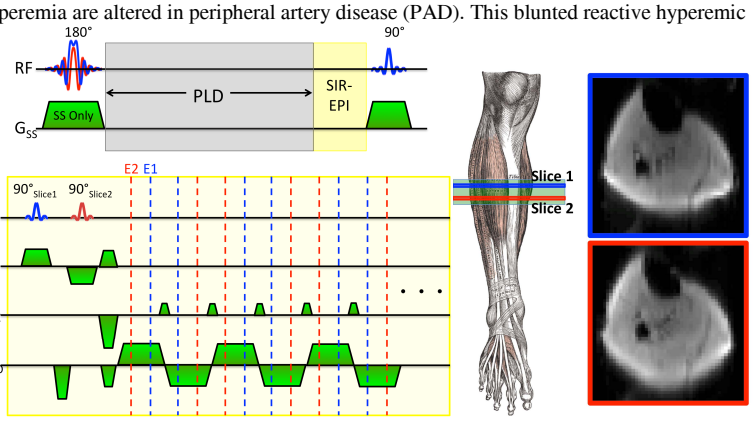

Figure 1. Pulse sequence diagram of PASL-SIR sequence. A FAIR tagging scheme labels blood, and a dual-slice partial-Fourier SIR-EPI readout simultaneously acquires data at Slice 1 and Slice 2. Dotted lines show the location of echoes for Slice 1 (blue) and Slice 2 (red). Relative location of slices and example images are shown on the right. Slice-selective (SS) inversion (green box) inverts the tissue magnetization in both slices.

Experimental methods: A PASL-SIR sequence was written in SequenceTree [6] and implemented at 3T. In order to evaluate the dual-slice perfusion measurement, a sequence with single-slice EPI readout was used for comparison at both locations. One young healthy subject was scanned with PASL-SIR twice, and single-slice PASL twice (once at each slice location) during a series of ischemia reperfusion paradigms. For each scan, there was 1 min baseline, 3 min arterial occlusion with pneumatic tourniquet inflated to >225 mmHg, and 3 min recovery. The subject was scanned again on a separate occasion with only PASL-SIR to investigate longitudinal reproducibility of the measured parameters. Scan parameters were: FOV = 25×25 cm^2, ST = 1 cm, matrix = 80×50 (reconstructed to 80×80), BW= 1562.5 Hz/pixel, TR/TE_{Slice1}/ TE_{Slice2} = 1000/16.26/13.86 ms, PLD = 931 ms. The two slices were centered 7 mm superior (Slice 1) and inferior (Slice 2) from isocenter, and SS inversion thickness was 2.5 cm.

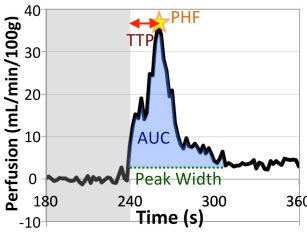

Figure 2. Typical time course showing quantified parameters. Gray box indicates period of arterial occlusion. TTP (red arrow), PHF (yellow star), AUC (blue region), and peak width (green line) are shown.

Analysis: Temporal matching between non-selective (NS) and SS data was performed by linear interpolation of the NS data, allowing perfusion quantification at 2 s temporal resolution. Average perfusion from ROIs in the gastrocnemius, soleus, peroneus, and tibialis anterior muscles was determined at each time point. The average perfusion during cuff inflation was subtracted for normalization, and peak hyperemic flow (PHF), time to peak perfusion (TTP), area under the curve (AUC), and peak width were determined as shown in Figure 2.

Results. Figure 3 shows time course data in the gastrocnemius measured with one SIR scan and two single-slice EPI scans, each resulting in perfusion at two slice locations. Table 1 shows average SIR compared to single-slice EPI results from all muscle groups for slice 1 (top) and slice 2 (bottom).

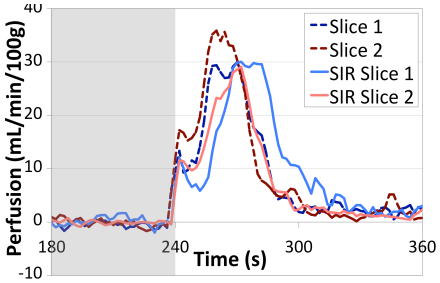

Figure 3. Perfusion time course for one dual-slice SIR scan (solid lines), and two single-slice scans (dotted lines) for both slices.

Discussion and Conclusion. Here we have demonstrated initial feasibility of PASL-SIR for dual-slice acquisition of perfusion in the leg. The average perfusion values for PHF and TTP agree with previously reported data [7]. Exploration of AUC and peak width may provide additional insight into the overall post-hyperemic oxygen delivery to the capillary bed. Despite the similar appearance of the perfusion curves in Figure 3 and similar extracted values, additional data are needed to determine whether the single-slice EPI and dual-slice SIR-EPI methods are consistent. It is possible to acquire more than two slices using SIR, however several factors must be considered. Increasing the number of slices prolongs TE and increases the thickness of the SS inversion, necessitating a longer PLD for blood to enter all slices, but yields more data per TR and hence per ischemia reperfusion paradigm. Perfusion varies physiologically with time of day, caffeine intake, hydration level, and many other factors, therefore the ability to determine whether PASL-SIR is capable of accurately assessing perfusion longitudinally will require many more subjects to be scanned.

References. [1] Wu et al, JACC 2009; [2] Kim, et al. NMR in Biomed 1997; [3] Yang, et al. MRM 1998; [4] Feinberg et al, MRM 2002; [5] Raynaud et al, MRM 2001; [6] Magland et al, ISMRM 2006; [7] Englund et al, ISMRM 2012. **Acknowledgements**. NIH Grants R01HL075649 and R01HL109545.

Table 1. Time course parameters for each muscle group using SIR, reporting average (standard deviation) of three scans, and for single-slice EPI in slices 1 and 2.

		SIR-Gastroc	EPI-Gastroc	SIR-Soleus	EPI-Soleus	SIR-Peroneus	EPI-Peroneus	SIR-TA	EPI-TA
Slice 1	PHF (mL/min/100g)	36.1 (5.1)	31.1	41.0 (11.3)	38.8	26.5 (9.6)	32.6	38.5 (14.4)	33.1
	TTP (s)	36 (6)	32	26 (5)	16	19 (3)	18	19 (7)	18
	AUC (mL/100g)	14.2 (1.9)	13.3	8.3 (3.9)	8.9	6.8 (2.5)	6.9	11.1 (7.1)	9.0
	Peak width (s)	60 (4)	48	41 (9)	38	43 (11)	36	49 (20)	34
Slice 2	PHF (mL/min/100g)	29.8 (1.8)	39.0	35.3 (1.2)	36.1	22.3 (10.0)	28.6	35.2 (4.1)	43.7
	TTP (s)	25 (6)	28	23 (5)	18	22 (5)	18	19 (3)	18
	AUC (mL/100g)	13.0 (1.7)	15.9	13.0 (2.1)	9.5	4.6 (2.0)	6.7	9.2 (1.1)	10.4
	Peak width (s)	57 (10)	62	71 (20)	38	35 (2)	32	44 (11)	38