LL-FAIR: Implementation and application at 7T

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INTRODUCTION: Look Locker–FAIR (LL-FAIR- also known as ITSFAIR and QUASAR) acquires data at multiple time points in a single shot following arterial spin labelling. Depending on sequence timings this provides rapid measurement of arterial cerebral blood volume (CBV_a) [3] or cerebral blood flow (CBF) [1,2] with simultaneous measurement of transit times. To date these techniques have been applied at field strengths of 3 T and below. Increasing field strength to 7.0 T improves signal-to-noise ratio (SNR) and increases blood and tissue T_1, and hence improves the contrast-to-noise ratio (CNR) of CBV_a and CBF measures. Here LL-FAIR was used to measure CBV_a and CBF at high spatial resolution at 7 T. LL-EPI readout pulses suppress the static tissue signal thus providing some inherent background suppression, reducing physiological noise [4]. In this work the timing and flip angle of the readout pulses were optimised to maximize background suppression, whilst maximizing sensitivity to CBV_a and CBF at 7T. LL-FAIR was used to measure CBV_a and CBF changes in response to a finger tapping task.

METHOD: Four subjects were scanned on a Philips Achieva 7.0 T scanner using head volume transmit and 16-ch SENSE receive coil. Scan parameters were: resolution 2 x 2 x 3 mm^3, SENSE 2; CBV_a: TR/TE/TA/TI = 2400/10/150/100 ms, CBF: = 2400/20/650/380 ms with 6 readouts at 35° flip angle and V_{enc} = 4.4 cm/s. Optimised WET pre-saturation and post-saturation pulses were applied to limit static signal contamination. Using in-plane saturation and LL-readout parameters described above, the steady state static signal across all readouts was less than 0.1 M_o for CBV_a and CBF. CBV_a and CBF data was acquired during a bilateral finger tapping task: 12 s ON, 24 s OFF repeated for 8 cycles. In addition a standard EPI with a long TR and IR-EPI was acquired for T_1 mapping and M_{bo} estimation. ΔM images were calculated from the difference between selective and non-selective images. Data were fitted on a voxel-by-voxel basis for CBV_a and CBF, accounting for readout flip angle and M_o across the slice, and using estimation of M_{bo} from cerebral arteries (improved by reduced partial volume effects at high spatial resolution). CBV_a, CBF (and BOLD) activated areas were identified by correlating the interpolated ΔM and (sum of tag and control) time-series with a canonical HRF. CBV_a/CBF/BOLD and transit time changes on activation were mapped.

RESULTS: Fig. 1a shows CBV_a weighted images and Fig. 1b the corresponding CBF weighted images across the LL-readout pulses. The advantages of 7.0 T are evident in the high CNR of the images, and Fig. 1b shows perfusion signal is still clearly visible following the final readout pulse (at 2550 ms) due to the longer longitudinal relaxation times. Fig. 2a show the correlation maps in response to finger tapping: CBV_a and CBF show more localised activation with
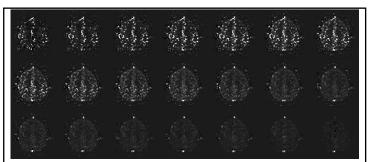
Figure 1a: CBV_a weighted signal following each of 21 LL-readout pulses (average of 10 sets).

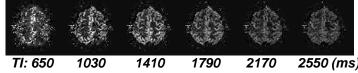**TI: 650   1030   1410   1790   2170   2550 (ms)**

Figure 1b: CBF weighted signal (average of 10 sets). Note: high signal remains even at the final readout pulse.
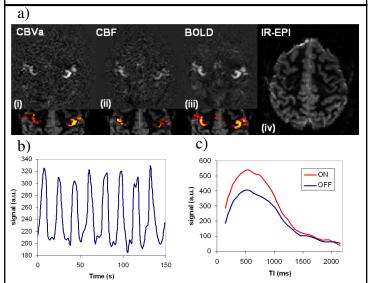
Figure 2: a) Unthreshold (i) CBV_a, (ii) CBF and (iii) BOLD correlation maps and (iv) IR-EPI image b) CBVa time-series. c) Signal change across LL-EPI readouts for CBVa sequence between ON and OFF periods.

reduced physiological noise compared to BOLD, in the lower panel these maps are overlaid on the IR-EPI. These activated areas could also be detected from a single ON period due to the high CNR of changes (as shown in the time course in Fig. 2b for CBV_a). Mean CBV_a increased by 46 ± 12 % (rest 3.73, active 5.45 %) with arterial transit time reducing by 117 ± 30 ms (rest 354 ms; active 237 ms). Mean CBF increased by 83 ± 15 % (rest 78 ml/100g/min; active 143 ml/100g.min) with a 234 ± 46 ms reduction in arteriolar transit time (rest 801 ms; active 567 ms).

DISCUSSION: At ultra-high field background suppressed LL-FAIR benefits from increased CNR due to increased SNR and relaxation times, as demonstrated by the significant signal change persisting at late CBF readouts. The increased CNR was used to produce high resolution (2x2x3 mm^3) CBV_a and CBF maps; increased spatial resolution provided improved M_{bo} estimation for quantification. Changes in CBF and CBV_a could be detected from a single fMRI cycle of a finger tapping task, and the increase in CBV_a and CBF, and reduction in transit time for this task were quantified. The reduced averaging required for CBF, CBV_a and transit time measurement using LL-FAIR at 7T will allow dynamic changes on activation to be studied, and the high spatial resolution achieved at 7T can be used to study patients with vascular disease.

REFERENCES: [1] Petersen ET et al, MRM 2005:55:219-232. [2] Francis ST et al., MRM 2007: 59(2):316-25. [3] Brookes et al., MRM, 2007: 58:41-54. [4] Garcia et al, MRM 2005:54,336-372. Acknowledgements: This work was supported by the MRC.