Anatomical and ASL imaging of the retina at 7 T

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Target Audience The work will be of interest to ophthalmologists, and researchers working in ultra-high field (UHF) MR.

Purpose Abnormal retinal blood flow (RBF) is thought to play an important role in many retinal diseases, including glaucoma, diabetic retinopathy (DR) and age-related macular degeneration (AMD). AMD affects 2 % of the population, glaucoma affects 1 in 50 people over the age of 40, while DR affects over 8000 people in the UK alone every year. All of these conditions can lead to permanent blindness, with AMD being the number one cause of blindness in the developed world. RBF can be measured invasively using fluorescein or indocyanine-green angiography, and potentially non-invasively through laser Doppler flowmetry and laser speckle imaging. However, these methods are qualitative, depth ambiguous and can be impeded by disease-induced opacity and/or deformation in tissues of the eye. MRI provides a potential method by which RBF can be quantified non-invasively without these practical limitations and arterial spin labelling (ASL) of the human retina has previously been performed at 3 T [1-3]. Here we describe the implementation of ASL in the retina at 7T. The increased field yields a higher signal to noise ratio (SNR), potentially allowing higher spatial resolution and/or reduced acquisition times to be realised, while the increased longitudinal relaxation times also provides increased ASL sensitivity. **Methods** Data were collected on a Philips Achieva 7 T system using a standard head transmit, radio frequency (RF) coil (Nova Medical) and custom built RF receive coil. *Coil Design:* The receive coil (Figure 1) consists of two coaxial loops (r = 65 mm and r = 35 mm) which are intentionally coupled so that they are resonant at 298 MHz and provide a more spatially homogeneous sensitivity than a single loop. This coil design is based on the work presented by Tomanek et al.[4]. *Data Acquisition*: Scans were performed on six healthy volunteers with local ethical approval. High resolution structural images were acquired using a 3D FFE acquisition schemes (see Figure legends for acquisition parameters) to allow visualisation of the retina. To assess retinal perfusion, ASL data were collected using a FAIR labelling scheme (image slice angled coronal-oblique, selective inversion thickness 10 mm, non-selective inversion slab thickness 230 mm, in-plane pre- and post-saturation pulses were applied, ASL TR of 6 s per tag/control series with 50 averages collected for baseline measures) at a range of post-label delay times from 800 -1500 ms, using a TurboFLASH readout scheme ($2x2x3mm^3$ resolution, flip angle = 15^0, TR/TE = 5/2.5 ms, FOV = $192x192mm^2$). A fixation cross was used to help to limit eye movement. Subsequently a spin density (M_0) image was acquired without spin preparation. In addition, ASL data (with post-label delay of 1200 ms) were also collected during visual stimulation consisting of a 8Hz flashing stimulus delivered by light pipes (30 s ON, 30 s rest, repeated 5 times). *Data Analysis*: Images were subtracted pairwise and averaged to form perfusion weighted images, and retinal signal was then assessed as a function of post-label delay. For the functional study, perfusion weighted images were correlated to the stimulation timecourse and a correlation map displaying voxels showing a significant correlation (Z> 3.2) was formed. ASL signal changes were converted to perfusion rates using a simple kinetic model.

Results Figure 2 demonstrates the good SNR and coverage of the eye provided by the receive coil. The lens, ciliary muscle and optic nerve are all clearly visible. Figure 3 shows that by suppressing the signal from the vitreous humour using an inversion recovery sequence, the retina can be clearly visualised. Figure 4 shows a base image and corresponding ASL images collected at a range of post-label delay times, with greatest perfusion signal at the longest post-label delay of 1550 ms. Mean perfusion measured at baseline was 104 ± 41 ml/100 mL/min (mean ± stdev across 5 subjects). Figure 5A depicts the areas showing perfusion changes that are significantly correlated with the visual stimulus and the corresponding ASL signal timecourse. Mean perfusion in the retina during the rest period was 83 ± 2 ml/100 mL/min and 133 ± 5 ml/100 mL/min during stimulation, corresponding to a 61 ± 9 % increase in perfusion to the visual stimulus (Fig 5B). The most significant change can be seen to overlay the ophthalmic artery, with lower intensity changes detected in the retina.

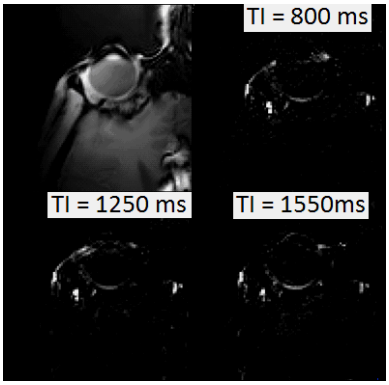

Figure 4: Base image and ASL images collected at a range of post-label delay (TI) times of 800, 1250 and 1550 ms.

Discussion Based on our preliminary results, we have confirmed that it is possible to obtain clinically useful anatomical images of the eye at 7 T using a surface receive coil (as previously shown by Richdale et al.[5]). The use of eye fixation, short scan times and multiple averages and dynamics is sufficient to overcome artefacts due to random motion of the eye while still yielding usable high resolution images. Using a FAIR ASL scheme at 7 T, perfusion of the retina is assessed with mean perfusion values of the retina within the range reported using ASL at 3T [2]. Here we demonstrate that this provides sufficient sensitivity to detect changes in the blood flow in the ophthalmic artery and the retinal induced by visual stimulation.

References 1. Maleki et al. NMR Biomed 24:104, 2010. 2. Peng et al. MRM 65:1768, 2011 3. Zhang et al. Investigative Ophthalmology & Visual Science 53:4299, 2012. 4. Tomanek et al. MRI 15:1199, 1997. 5. Richdale et al. JMRI 30:924, 2009.

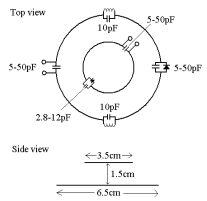

Figure 1: Receive coil schematic

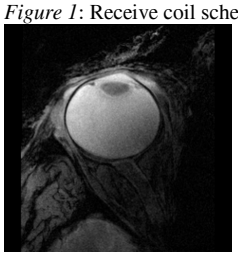

Figure 2: FFE, flip angle = 25°, 0.25x0.25x3 mm^3, TR/TE = 500/8.9 ms, 2 averages. 205 second scan time.

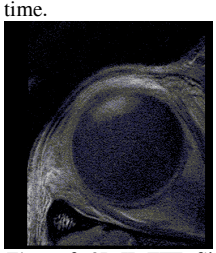

Figure 3: 3D IR FFE, flip angle = 20°, 0.125x0.125x1 mm^3, TR/TE = 14/3.1 ms, TI = 1500 ms, halfscan = 0.8, 4 dynamics, 3 averages. 5 minute scan time.

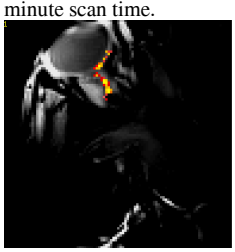

Figure 5A: Statistical map showing correlation map of voxels activated to the visual stimulus (Z > 3.23).

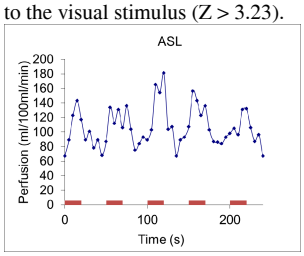

Figure 5B: ASL perfusion time course from active voxels shown in Figure 5A, red blocks denote the periods of light stimulation.