Measurement of eye pO2 using T1 mapping has precision ~8 mmHg and shows oxygenation gradient between retina and lens

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Aims: 1. To measure oxygenation (pO_2) in the vitreous humour (the clear gel that fills the eyeball between the lens and the retina). 2. To detect regional variation of oxygenation through the vitreous humour of the eye.

Background: Vitrectomy (removal of vitreous humour from the eye, and replacement with saline) is a highly invasive clinical procedure that is carried out for various conditions such as retinal vascular disease and diabetic retinopathy. It has been proposed that the beneficial effect of retinopathy may be due to improved oxygenation of the inside of the eye and hence the retina. Although the partial pressure of oxygen (pO_2) has been measured during vitrectomy (using a very unpleasant procedure involving an intraocular probe) there has been no direct evidence that an increase in pO_2 is achieved or how the regional variation of pO2 is affected within the eye. MRI provides a non-invasive method of measuring pO_2 in the eye [1]. In pure oxygen-free water at 1.5 T and 37°C T_1=4.74s [2]. T_1 relaxation times are decreased by the presence of paramagnetic O_2: an increase in pO_2 of 10 mmHg results in a decrease in T_1 of 47 ms (1.14 %) [3]. Therefore, an accurate and precise measure of T_1 could provide a reliable measure of pO_2. Here we demonstrate that we can precisely measure pO_2 by overcoming the challenges of eye imaging [4]: we control eye movement and blink artefacts and eliminate image distortion around the eye by careful implementation of the MRI acquisition sequence.

Methods: Healthy volunteers were imaged on a Siemens Avanto 1.5 T scanner. Each participant was scanned twice (removed from the scanner and replaced) in the same session to assess reproducibility. T_1 mapping was performed using an inversion recovery (IR)-trueFISP sequence with 17 inversion times in the range TI=0.7s – 30s. We screened for banding artefacts with a low flip angle truefisp acquisition and, if present, the banding artefacts were moved away from the eyes by changing the frequency offset. A single slice was positioned through the centre of both eyes in the axial orientation. Other trueFISP parameters were: TR=(20+TI) s, TE = 1.52 ms, FA = 80°, matrix = 256x256, voxel dimensions = 0.9x0.9x4 mm^3. The total scan time for T_1 measurement is 15 mins. T1 mapping was achieved by performing a pixel-by-pixel three-parameter fit of the signal intensity S (at each TI) to the equation $S(TI) = A + Be^{-TI/T1}$; A and B are parameters that account for inversion pulse flip angle FA, equilibrium signal intensity and TR. Since FA is included, the technique is resilient to B_1 errors. Eye movement was controlled by providing the subject with an audio countdown to alert them to the acquisition of the slice. They were instructed to fixate on a spot on the scanner room wall for the duration of the acquisition (<1 s). Thus, eye movement was eliminated during data acquisition. Subjects were encouraged to relax or close their eyes between acquisitions to avoid eye fatigue. Precision (reproducibility) was estimated from the repeats using the Bland-Altman method [5].

Results: The trueFISP sequence provides high-resolution undistorted eye images with excellent SNR. Slice acquisition time is <1 s, during which the participant can easily fixate to eliminate eye-movement artefacts without inducing eye fatigue (Fig. 1a). Bland-Alman estimation of within-subject variability is calculated as 40 ms (<1%) for T_1 (8 mmHg for pO_2). T_1 measurements show a subtle decrease towards the lens of the eye (Fig. 1b,c), indicating an increase in oxygenation towards the air-eye interface and away from the retina (Fig. 1d). The range in pO_2 is about 20 mmHg, which agrees with *in vivo* pO_2 ranges measured with an intraocular pO_2 probe. [6]

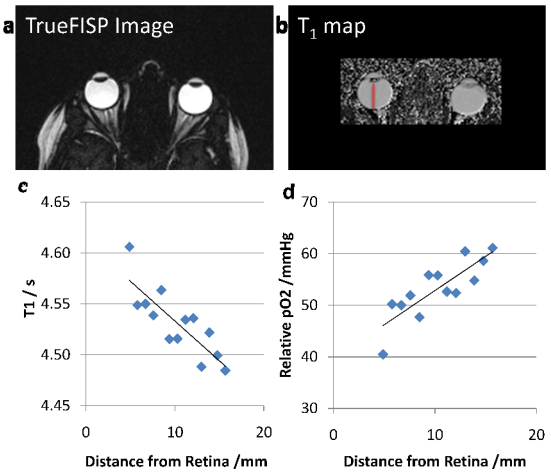

Figure 1
(a) TrueFISP image and (b) T_1 map showing an undistorted image of the eyes. (c) T_1 gradient through left eye along the profile shown in the T_1 map. (d) Relative pO_2 gradient calculated from the T_1 measures in (c). A similar calculation was performed for the right eye (not shown).

Discussion: We have demonstrated that it is possible to acquire T_1 maps of the human eye without image distortion or eye movements. This technique has important implications for a wide range of eye imaging studies e.g. in retinopathy [7] or optic nerve [8]. Furthermore, it may be possible to assess the therapeutic value of highly invasive eye surgery such as vitrectomy without the need for an invasive eye probe.

References: [1] Dowell *Proc. ISMRM* **2010**;2408, [2] Tofts *MRM* **2008**;59:190-195, [3] Zaharchuk *MRM* **2005**;54:113-121, [4] Berkowitz *MRM* **2001**;46:412-416, [5] Bland *Lancet* **1986**;1(8476):307-310, [6] Williamson *Graefes. Arch Clin Exp Opthal* **2009**;247:1019-1023, [7] Berkowitz *NMR Biomed* **2008**;21:957-967, [8] Dowell *JMRI* **2009**;29:454-460