Movement-Artefact-Free Measurement of T_1 in the Human Eye to Determine Oxygenation of the Vitreous Humour

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Aims: 1. To develop a convenient method for imaging the eye that is free of movement artefact. 2. To measure oxygenation (pO_2) in the vitreous humour (the clear gel that fills the eyeball between the lens and the retina).

Background: Eye measurements are complicated by eye movement since subjects frequently find the need to blink [1]; suppression of blinking beyond about 3 s can be painful. Although eye drops could be used, these must be administered by skilled personnel. We demonstrate a method for rapid imaging of eye movement and have developed an imaging technique that reduces this movement and permits the measurement of T_1 without image artefact.

Poor oxygenation of the vitreous humour leads to retinopathy and, in patients with low oxygenation (pO_2) at the retina, a vitrectomy may be performed, where the vitreous humour is extracted and replaced by saline. However, there is no clear evidence that an increase in vitreous pO_2 is actually achieved by this procedure and a MRI measurement of pO_2 would provide an important validation for ophthalmologists. Accurate and precise measurement of T_1 could provide such a non-invasive determination of eye oxygenation since T_1 times are subtly increased by reduced pO_2. In pure water at 1.5T and 37 ^{o}C T_1=4.74s [2], and T_1 decreases by 47 ms (1.14 %) for an increase in pO_2 of 10 mmHg (calculated from ref [3]).

Methods: Healthy volunteers were imaged on a Siemens Avanto 1.5 T scanner.

Eye Movement. Three approaches were adopted to quantify eye movement and determine the best strategy to reduce movement artefact: (i) fixate on a point with eyes open and blink whenever needed (ii) eyes closed but keep them still, (iii) the control case: no instruction, just relax. Eye movement was quantified by tracking the position of the pupil using coronal HASTE images (Fig 1, inset) acquired at 2-s intervals for a total of 5 minutes.

T_1 Measurements. Vitreous humour T_1 values were estimated using an inversion recovery (IR) TrueFISP (balanced steady-state free precession) imaging sequence that was repeated using nine inversion times TI = 0.26 s, 1 s, 2 s, ..., 8 s. The IR pulse is non-selective and thus provides resilience to eye movement during the preparation phase (TI) of the acquisition sequence. TrueFISP parameters were: TR=8.3 s, TE = 1.52 ms, slices = 5, thickness = 5 mm (1.2 mm gap), FA = 80°, matrix = 256x194, voxel dimensions = 1.25x1.40x5 mm^3. The total scan time for each TI acquisition was 43 s, resulting in a total measurement time of 6.5 min for the T_1 measurement. Before the scan, subjects were informed that an image acquisition would occur every TR ≈ 8 s. In this way, subjects are able blink and move their eyes between the relatively short (~0.5 s) k-space acquisitions. T_1 was estimated by performing a 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, equilibrium signal intensity and TR. Since flip angle is included in the fit, this technique is resilient to B_1 errors.

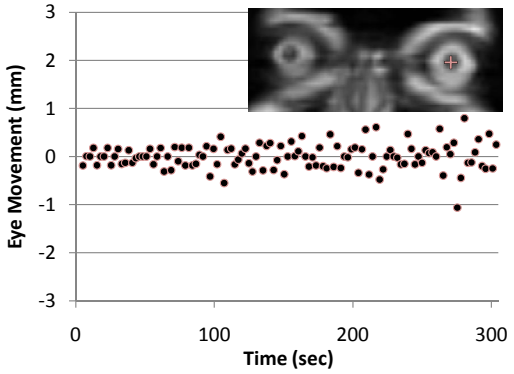

Figure 1 Eye movement between 2-second acquisition time points. Fixation is good in the early stages (time < 60 s) but is worse at longer times. Blinking was permitted whenever necessary. Eye movement was measured by tracking the pupil (shown by the cross) from coronal HASTE images (inset).

Table 1 The mean eye movement measured between 2-second time points during a five-minute scan.

Instruction to participant	Mean Eye Movement (mm) in 1st min	5th min	Overall
Eyes relaxed	0.47	0.94	0.70
Eyes closed, still	0.41	0.60	0.60
Eyes fixated	0.09	0.27	0.19

Results: The eyeball undergoes significant movement (Table 1) when it is not fixated on a single point. However, for longer time periods, it is evident that fixation becomes increasingly difficult and eye movement increases at longer scan times (Fig. 1), in spite of being free to blink whenever needed. The TrueFISP images of the eyes (Fig. 2, inset) shows no noticeable distortions and the SNR is good. The signal recovery curve for multiple TI is also shown (Fig. 2). The vitreous humour in the eye was calculated to have T_1 = 5.05 s from the fitting of signal intensity vs inversion time (Fig. 2) over the central three slices through the eye.

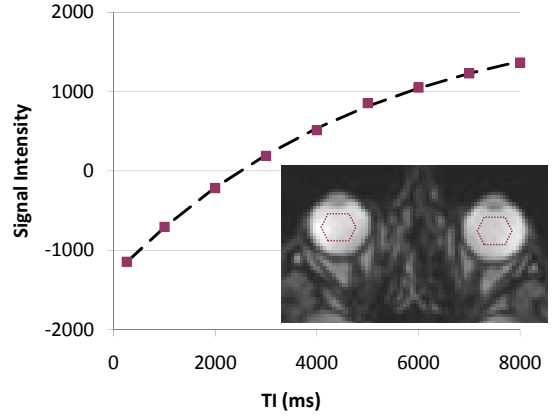

Figure 2 Fit of model (dashed line) to the experimental data (squares) to yield T_1 of the vitreous humour of the human eye. Inset: the artefact-free TrueFISP images of the eyes (vitreous humour ROIs are shown by the dotted line).

Discussion: The current model for signal vs TI is too simple (estimated T_1 value is 5% too high). After a TrueFISP readout, M_z is in an intermediate state, neither destroyed nor unaffected [4], and a more complex model is needed to describe this accurately. Increasing overall TR or reducing TrueFISP FA [4] would also probably improve accuracy. A reduction in the number of TI values, within an optimisation scheme, would shorten the total acquisition time whilst preserving SNR. To enable subjects to prepare for the fixation period we will introduce an audio-visual cue that will provide a countdown to the next acquisition period.

Conclusions: Eye-imaging is notoriously degraded by movement. Fixation is a simple way of reducing this motion, but is only effective over relatively short time periods (less than 60 s). This imaging method, using a non-selective inversion pulse, allows the subject to blink or move their eyes for the majority of the time; only for about 2 s need they remain open and fixated. This sequence, with high SNR and freedom from artefacts, could dramatically improve imaging of the eye (e.g. for retinopathy [5] and the optic nerve [6] studies).

References: [1] Berkowitz MRM **2001**;46:412-416, [2] Tofts MRM **2008**;59:190-195, [3] Zaharchuk MRM **2005**;54:113-121, [4] Scheffler MRM **2001**;45:720-723, [5] Berkowitz NMR Biomed **2008**;21:957-967, [6] Dowell JMRI **2009**;29:454-460