Vitreous Oxygenation Measured by $T_1$ mapping in the Eye Reveals No Increased Oxygenation Following Vitrectomy
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Aim: To determine whether the partial pressure of oxygen ($pO_2$) of the vitreous humour (the clear gel that fills the eyeball between the lens and the retina) is increased in patients undergoing a vitrectomy (the extraction of the vitreous).

Background: Vitrectomy is a surgical procedure that involves the replacement of the vitreous humour with a balanced salt solution (BSS) of $CaCl_2$, $MgCl_2$, $NaCl$, $KCl$ and $CaH_2NaO_7$. It is conducted as a therapy for various eye conditions such as retinal vascular disease and diabetic retinopathy. It has been proposed that the beneficial effect of vitrectomy may be due to improved oxygenation of the inside of the eye and hence the retina [1]. However, owing to the highly invasive measurement techniques currently available, there have been no post-operative or longitudinal $pO_2$ measures in a group of patients who have undergone a vitrectomy to confirm this hypothesis. MRI may be used to measure $pO_2$ indirectly since $T_1$ is subtly reduced by the presence of paramagnetic $O_2$ (a change of $T_1=6$ ms for every 1 mmHg change in $pO_2$ at physiological oxygenation and pressure). [2-5]. Here, we perform $T_1$ measurement on 11 patients pre- and post-vitrectomy to determine whether the extraction of the vitreous humour provides an increase in $pO_2$.

Methods: Participants. 11 patients (7 female, 4 male, age range 59-84) diagnosed with a macular hole (MH) or an epiretinal membrane (ERM) volunteered for this study. Each was scanned less than 1 week before vitrectomy and invited to return for an identical scanning session 1 month post-operation (two participants declined a post-operative scan). Vitreous oxygenation was also measured peri-operatively with a polarographic oxygen probe (Licox, Integra NeuroSciences) that was inserted into the eye cavity during vitrectomy.

Scanning Protocol. Images were acquired with a Siemens Avanto 1.5 T scanner. $T_1$ mapping was performed using an inversion recovery (IR)-trueFISP sequence with 17 inversion times in the range $T_I=0.75-30s$. A single slice was positioned through the centre of both eyes in the axial oblique plane. Other trueFISP parameters were: $TR=(20+TI)$ s, $TE = 1.52$ ms, $FA = 80^\circ$, matrix = 256x256, voxel dimensions = 0.9x0.9x4 mm³. The total scan time for $T_1$ measurement was 15 mins. Eye movement was controlled by instructing the participant to fixate on a target attached to the scanner room wall and visible via the mirror attached to the head coil. Fixation was only required for the duration of k-space acquisition for each $T_I$ (approx. 1 sec only) [6].

Data Analysis. $T_1$ mapping involved a pixel-by-pixel three-parameter fit of the signal intensity $S$ (at each $T_I$) to the equation $S(TI) = A + Be^{-TI/T_1}$; A and B are parameters that account for inversion pulse flip angle, equilibrium signal intensity and TR. Since flip angle is included, the technique is resilient to B1 errors. Absolute $pO_2$ was determined using the peri-operative $pO_2$ measures and a phantom study that quantifies the dependence of oxygenation on $T_1$.

Results: Peri-operative $pO_2$ measured in the affected eye with a polarographic $O_2$ probe showed that all patients had $pO_2$ readings in the range 6.5-8.1 mmHg (mean 7.2, SD 0.6). Undistorted $T_1$ maps of the eyes were obtained (Fig 1) with estimated Bland-Altman [7] within-subject variability of $T_1 < 1\%$ (equivalent to $pO_2 < 8$ mmHg), and between subject variability of $T_1 < 1.5\%$ (equivalent to $pO_2 < 12$ mmHg). The $pO_2$ determined pre- and post-operatively by this technique revealed that there is no detectable change in $pO_2$ ($\Delta pO_2$) in the affected eye, with a mean difference of 0 mmHg across all participants. The normal eye was used as a control for this technique and again showed no statistical difference between $pO_2$ measured before and after surgery (Table 1).

Discussion and Conclusion: This study has revealed that vitrectomy does not provide a significant improvement in oxygenation of the eye. Only 1 study [1] reported large $pO_2$ increases (up to 60 mmHg) as a result of vitrectomy, but these measures were made with an $O_2$ probe during surgery. At this time, elevated $pO_2$ was probably observed due to atmospheric levels of oxygen present in the replacement BSS. Within a few hours, the $pO_2$ would be expected to return to physiological levels but, until now, this has only been speculated. This current work strongly suggests that, indeed, such large improvements in oxygenation do not occur. This finding could have important implications for understanding the therapeutic mechanisms of vitrectomy and may lead to new considerations for patient treatment. Furthermore, we have shown this technique provides a non-invasive measure of $pO_2$ that will permit serial or longitudinal study of the oxygenation mechanisms in the eye and may be of wider benefit to other eye studies e.g. retinopathy or optic nerve.