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RETINAL OXIMETRY USING HYPERSPECTRAL IMAGING

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PURPOSE

Hyperspectral imaging of the human retina is a relatively new concept that has the potential to determine the metabolic status of the retina. Oximetric studies have been the main focus of previous research as the differential spectral characteristics of the two functional haemoglobin derivatives may be exploited to determine the oxygen saturation in the blood vessels.[1,2,3]

This study aims to demonstrate the ability to detect oximetric variations in the retinal circulation amongst normal subjects and in patients with retinal vasculopathy and glaucoma using hyperspectral imaging and spectral analysis techniques.

METHODS

A hyperspectral retinal imaging system consisting of a modified commercial fundus camera, a liquid crystal tuneable filter and a low-noise CCD detector (figure 1) was used to capture sequential hyperspectral images of the human retina. A hyperspectral data cube with a spectral bandwidth of 500nm to 700nm and a spectral resolution of 10nm at wavelength steps of 2nm were obtained for each subject. Normal subjects (n = 11) were examined and compared to subjects with retinal arterial occlusion (n = 3), retinal vein occlusion (n=1) and advanced primary open angle glaucoma (POAG)(n = 1).

Pre-processing algorithms were used to dark calibrate and co-register the raw retinal images. A further image processing algorithm produced a reflectance optical density map of the retina for each wavelength (figure 2).

Linear spectral unmixing is used in spectral imaging to determine the relative abundance of materials (endmembers) in each pixel of a scene through the analysis of its spectral characteristics. An average spectral profile of the arteries in the optic disc were calculated from all normal eyes (figure 3). This spectral profile was used to represent a pure endmember of arterial blood. In addition, a region within the optic disc cup was included into the analysis and represents a relatively non-oxygenated and spectrally inert endmember. Linear spectral unmixing, performed in ENVI 4.1 (ITT Visual Information Solutions), incorporating these two endmembers was used to produce a qualitative abundance map of oxygenated blood in the retina.

Figure 1.Schematic arrangement of the Hyperspectral Retinal Camera.

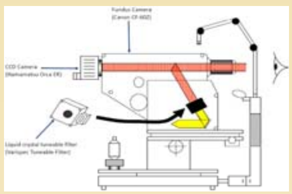


Figure 2. Pre-processing methods of the hyperspectral retinal images.

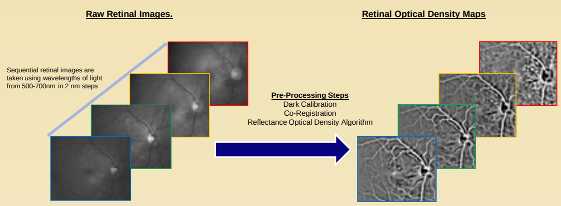
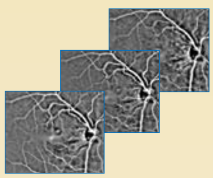
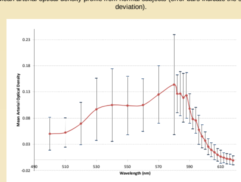


Figure 3. Linear spectral unmixing methods

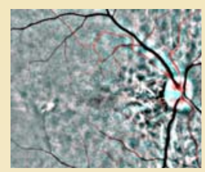
Arterial (red) regions of interest selected at the optic disc from all normal eyes.



Mean arterial optical density profile from normal subjects (error bars indicate the standard deviation).



Linear spectral unmixing producing a map of oxygenated blood in the retina



RESULTS

Linear spectral unmixing produced consistent oximetric maps of the retina in normal subjects (figure 4) where oxygenated blood (red) has been identified within the arteries and arterioles. In subjects with retinal vasculopathy and advanced POAG, this technique was able to detect changes in the oximetric status of the retinal circulation. Figure 5 illustrates one of these subjects with arteritic retinal vasculopathy caused by giant cell arteritis. The oximetry maps demonstrate an improvement in oxygenation of the retinal vasculature and retina following treatment with intravenous methylprednisolone. Figure 6 illustrates the oximetric variation in the retinal circulation of a patient with advanced POAG which corresponds with the severity of visual field loss. Figure 7 demonstrates retinal venous saturation changes associated with retinal ischaemia as a result of a branch retinal vein occlusion.

Figure 4. Oximetric retinal maps from a selection of normal subjects.
Oxygenated blood (red) has been identified in the retinal arteries and arterioles.
Venous blood, containing less oxygenated haemoglobin resulting in a different spectral characteristic to oxygenated arterial blood, is shown in black.

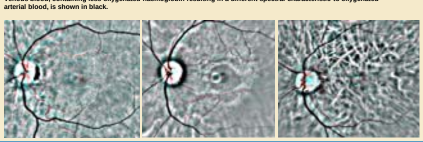


Figure 5. Oximetric maps of an 81 year old female with a right retinal vasculitic arteriopathy secondary to giant cell arteritis.
(*Top Left*) Colour photograph of the right retina 3 days after presentation whilst on intravenous methylprednisolone.
(*Top Right*) Grayscale image of the right retina at presentation taken by the hyperspectral camera using light filtered at 580nm.
(*Bottom Left*) Oximetric map of the right retina at presentation. Linear spectral unmixing reveals a reduction in oxygenated blood in the retinal arteries (pale red/white) and an increase in oxygenated blood in the superior retinal veins. This indicates a reduced metabolic activity in the retina consistent a visual acuity of perceiving hand movements.
(*Bottom Right*) Oximetric map of the right retina 8 days after presentation. Linear spectral unmixing reveals an improvement in the amount of oxygenated blood within the retinal arteries associated with a change in the oxygenation of the blood in the veins. This indicates an improved metabolic activity in the retina which corresponds with an improvement in the visual acuity to 6/24.

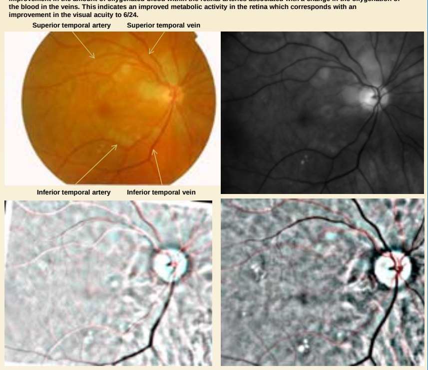
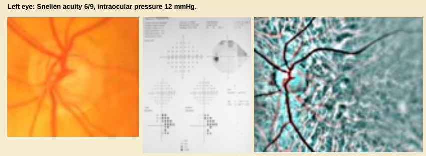


Figure 6. A 76 year old male with advanced POAG.
(*Left*) Colour photographs of the optic discs showing advanced cupping (cup-disc ratios 0.9).
(*Middle*) Humphrey visual field examination demonstrates asymmetrical visual field loss affecting the right eye more than the left eye.
(*Right*) Oximetric maps of the retina shows an increased oxygenation in the venous circulation of the right retina compared to the left retina. This suggests a reduced metabolic activity in the right eye.

Left eye: Snellen acuity 6/9, intraocular pressure 12 mmHg.



Right eye: Snellen acuity 6/9, intraocular pressure 13 mmHg.

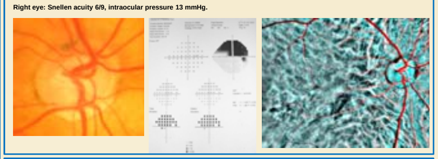
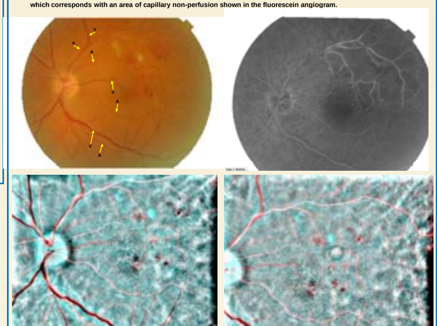


Figure 7. A 64 year old female with a left supero-temporal Branch Retinal Vein Occlusion with localised retinal ischaemia.
(*Top Left*) Colour photograph of the left retina. (A: arteries, V: Veins)
(*Top Right*) Midphase fluorescein angiogram of the left retina illustrating an ischaemic retina in the superotemporal quadrant.
(*Bottom left and right*) Oximetric map of the left retina showing an increased oxygenation in the venous circulation most notably in the superotemporal quadrant. This suggests a reduced metabolic demand of oxygen in the retina which corresponds with an area of capillary non-perfusion shown in the fluorescein angiogram.



CONCLUSIONS

Hyperspectral imaging is capable of detecting oximetric changes in the retina and monitoring its response to treatment. However, the sequential technique of capturing retinal images described here is heavily dependent on other factors such as accurate co-registration of the images This limitation will be addressed in the near future with the optimization of our co-registration algorithms and the development of a "snapshot" spectral retinal camera.

Linear spectral unmixing offers a powerful and visually useful method of producing semi-quantitative oximetric maps of the retina, but to increase the effectiveness in detecting changes caused by diabetic retinopathy and early glaucoma increased and absolute accuracy is required. This requires the incorporation of a physical model for light propagation in the retina into the calculation of oxygenation. A quantitative method to measure oxygen saturation in the retinal circulation is currently being developed for future clinical application..

REFERENCES

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COMMERCIAL RELATIONSHIPS

•QinetiQ, AstraZeneca. **Alcon; Allergan; MSD; Pfizer.

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