Clinically useful wide-field high-resolution retinal imaging with a dual-conjugate adaptive optics instrument

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Background

Conventional AO is performed with one point source, or guide star (GS), to probe the aberrated wavefront, and one active component, usually a deformable mirror (DM), to correct the aberrations in the pupil plane for that GS location. It is the prevalent technology in today's applications, and will be referred to as single-conjugate AO (SCAO). The eye suffers from field dependant aberrations which leads to varying image quality with eccentricity. Using a single GS, as in SCAO, will result in a small corrected field of view (FOV) in the vicinity of the GS. A method to deal with this limitation is known as multi-conjugate AO (MCAO), which uses multiple DMs and several GS to increase the corrected FOV.

Purpose

The aim of this project is to apply the technique of multi-conjugate adaptive optics (MCAO) to obtain improved optical quality in eyes for high-resolution imaging of the retina over a wide field-of-view (FOV).

Method

Our proposed solution for the eye exploits the technique of MCAO by using several GS (three to five), and two DMs in separate planes. Optically the two DMs correspond to different planes along the optical axis of the eye, thereby allowing correction of field-dependent aberrations and subsequent wide-field high-resolution retinal imaging over a 7x7 degree^2 FOV.

Results

We have demonstrated the MCAO concept with a current FOV of 7x7 deg^2 on both model and human eyes[1]. The diffraction-limited resolution is around 2 µm on the retina, allowing cone photoreceptors to be resolved.

A quantitative measure of the cone photoreceptor mosaic of one healthy subject is presented in Figure 1. Cone separations were obtained by calculating the power spectrum of 128x128 pixel subregions with a 64 pixel overlap over the entire image in Figure 1. The spatial frequency corresponding to the local cone separation in each subregion was then identified and is presented as a color surface map in Figure 2.

A relatively narrow depth of focus (30 µm) enables imaging of different retinal layers. Focusing on deeper layers allows us to image the cone photoreceptor layer. By focusing on the upper layers we can also image the perifoveal capillary network (Figure 3) and the superficial capillaries of the nerve fibre layer (Figure 4) with the same high resolution.

Conclusions

Our instrument allows retinal features down to 2 µm to be resolved over a 7x7 deg^2 FOV. We believe that this new technique has a future potential for clinical imaging with an impact particularly important for early diagnosis of retinal diseases.

References

1. J. Thaung, P. Knutsson, Z. Popovic, and M. Owner-Petersen, "Dual-conjugate adaptive optics for wide-field high-resolution retinal imaging," Opt. Express **17**, 4454-4467 (2009)

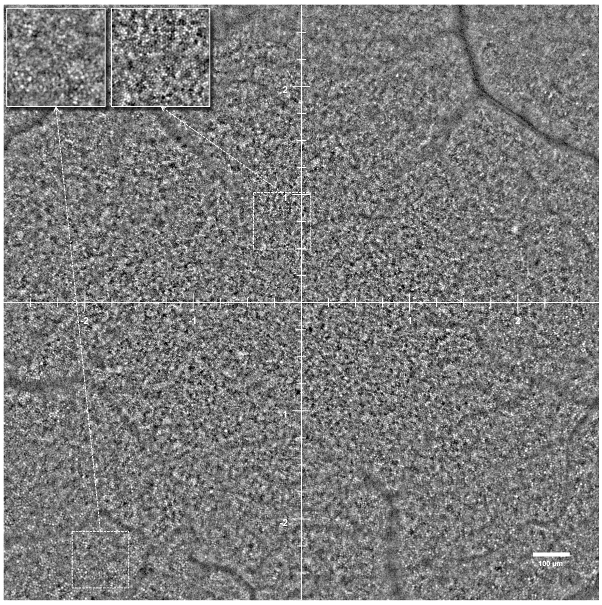

Figure 1. Sum of two registered images focused on the photoreceptor layer covering 5.5 × 5.5 deg^2 (1.6 × 1.6 mm^2). Magnified insets at 0.8 deg (upper right) and 3.2 deg (upper left) from the fovea (image center) showing increasing cone size and separation.

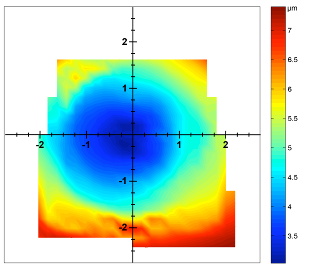

Figure 2. Color surface map of cone separation (µm) in Figure 1.

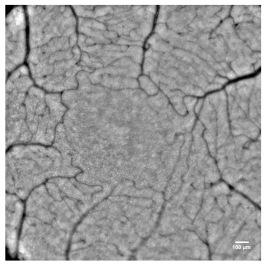

Figure 3. Image of perifoveal capillary network (7 x 7 deg)

Figure 4. Photomontage of four images (illumination changes removed and histogram equalized) showing major blood vessels and superficial capillaries of the retinal nerve fibre layer (approx. 15 x 14 deg).

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