Dual-conjugate adaptive optics imaging of foveal capillary network in human eyes

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Purpose

To demonstrate imaging of foveal capillary networks with a high-resolution wide-field dual-conjugate adaptive optics (DCAO) imaging instrument [1, 2].

Methods

We imaged the foveal capillary networks of five normal subjects, 30-58 years of age and with no prior history of ocular or neurologic disease or surgery, at a wavelength of 575 nm. The DCAO instrument (see [1, 2] for a detailed description) has a field of view of approximately 7x7 degrees, and a diffraction limited resolution of approximately 2 μm.

Image magnification was calibrated with respect to individual parameters of axial length (AL) of the investigated eye of participating subjects, which were measured with a Zeiss IOL Master (Carl Zeiss Meditec AG, Jena, Germany). Individual retinal scaling factors (RSF) were calculated using the formula RSF = IPS·q·P (IPS - instrument plate scale, q - individual retinal scaling factor, and P - retinal imaging camera pixel size).

Image processing and analysis was performed in Matlab (Natick, MA, USA) using publicly available and custom written code. Uneven illumination of camera raw images was reduced using a combination of noise-filtering, contrast-limited adaptive histogram equalization (CLAHE), and flat-fielding. A central region of interest (ROI) corresponding to the foveal avascular zone (FAZ) was defined by a spline curve fit to manuallyselected points around the FAZ border. Morphological FAZ parameters were obtained using built-in Matlab ROI functions. An automated algorithm based on a publicly available implementation of a Hessian-based vesselness filter[3]and custom written code was used to identify vessels and calculate vessel densities. Densities were calculated in two annular ROI outside the FAZ,ROI_{500} with 500 μm and ROI_{750} with 750 μm outer radius from the foveal center, and the superior, inferior, temporal, and nasal quadrants within the two ROI (Figure 1).

Results

Mean FAZ area for the five normal subjects was 0.302 ± 0.100 mm^2 (mean ± SD), and mean FAZ equivalent diameter was 612 ± 106 μm.Mean capillary density (length/area) was 38.0 ± 4.0 mm^{-1} in $ROI_{500}$and 36.4 ± 4.0 mm^{-1} in ROI_{750}. There was no significant difference in capillary density between ROI_{500}quadrants ($p = 0.556$) orROI_{750}quadrants ($p = 0.519$), and the highest densities were found in the inferior quadrants of both ROI. A box plot of quadrant capillary density distributions including outliers is shown in Figure 2. Examples of a final post-processed image with FAZ outline and images of identified vessels (full field image and magnified sections) are shown in Figure 3.

Mean FAZ area and mean equivalent diameter were similar to published data from the literature [4-7]. DCAO imaging yields lower capillary densities than histology [8] but similar results compared to published fluorescein angiography [8] and AO-SLO [7] data.

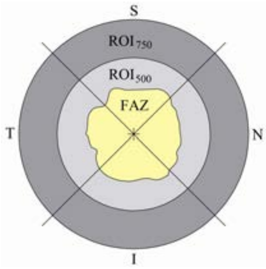

Fig. 1. Schematic drawing of the two ROI and corresponding quadrants (N - nasal, I - inferior, T - temporal, S - superior) in a right eye. The quadrants were horizontally mirrored for left eyes.

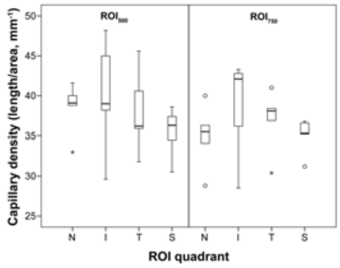

Fig. 2. Box plot of capillary densities (length [mm]/area [mm^2]) in the nasal, inferior, temporal, and superior ROI_{500} and ROI_{750} quadrants.

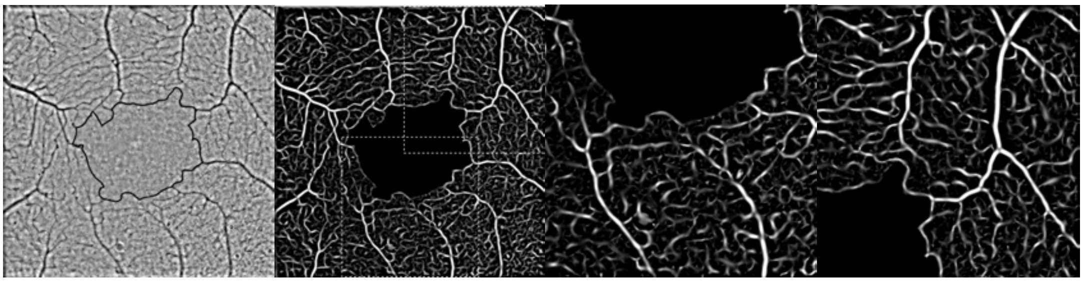

Fig. 3. Final post-processed image with FAZ outline (first image) and image of identified vessels and capillaries (second image). Two magnified regions, indicated by dashed lines in the middle left image, are shown to the right.

Conclusions

We demonstrate a technique for imaging and automated detection and analysis of foveal capillaries. In comparison to other studies, our method yields lower capillary densities than histology but similar results compared to AO-SLO findings.

The technique of DCAO with an increased field of view opens up new possibilities for high-resolution imaging of foveal capillaries.

References

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