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Characterizing Adaptive Optics Choriocapillaris Images Using Feature Engineering

Zhen Hua, Tao Liu, Joanne Li, Nancy Aguilera, Andrew J. Bower, Catherine A. Cukras, Robert B. Hufnagel, Emily Y. Chew, Brian P. Brooks, Wadih M. Zein, Laryssa A. Huryn, Johnny Tam
National Eye Institute, National Institutes of Health, Bethesda, Maryland

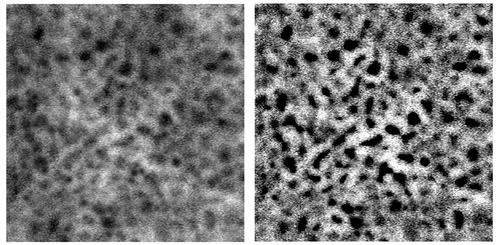
National Eye Institute

Purpose

Adaptive optics enhanced indocyanine green (AO-ICG) angiography enables visualization of microscopic changes in the choriocapillaris [1, 2]. We introduce a feature engineering framework to systematically extract and identify robust quantitative features that distinguish healthy from diseased choriocapillaris.

Methods

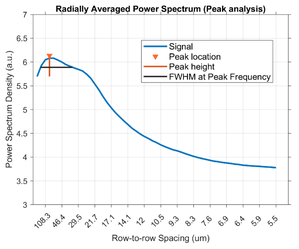
Choriocapillaris Image Enhancement



Visualization of choriocapillaris was achieved using AO-ICG by subtracting out the ICG signal associated with RPE uptake [2]. Imaging was performed in 36 participants aged 19–75 years, including 19 healthy individuals and 17 with disease (14 genetic eye diseases and 3 age-related macular degeneration).

Flow-void enhancement filtering was applied to further improve choriocapillaris contrast [3]. Radially averaged power spectrum (RAPS) analysis was subsequently performed to characterize spatial frequency variations within the choriocapillaris meshwork.

Three key spatial frequency parameters were extracted: peak location (reflecting dominant vessel spacing), peak height (prominence, representing pattern regularity), and peak width (full width at half maximum, FWHM, quantifying local structural coherence).



Radially averaged power spectrum (RAPS) analysis

•**Peak Location (Mesh Size):** Reflects the dominant spatial scale of the choriocapillaris meshwork; larger values indicate larger gaps and reduced capillary density.

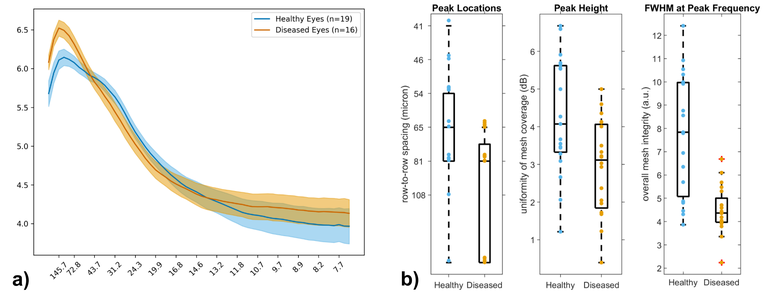
•**Peak Height/Prominence (Uniformity of Mesh Coverage):** Measures the consistency and strength of the choriocapillaris pattern; lower values indicate weakened regularity.

•**FWHM at Peak Frequency (Overall Mesh Integrity):** Quantifies the degree of structural coherence around the dominant spatial frequency; narrower widths indicate loss of vascular complexity.

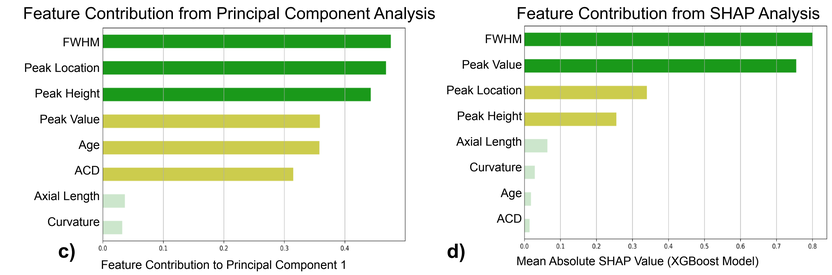
Results

Visual Evidence: Preservation Versus Pathology

- Healthy eyes exhibited fine, uniformly thin vascular networks, while diseased eyes showed irregular, disrupted capillary patterns with visible structural loss.
- Visual contrasts in vascular integrity suggested underlying structural differences requiring quantitative validation.



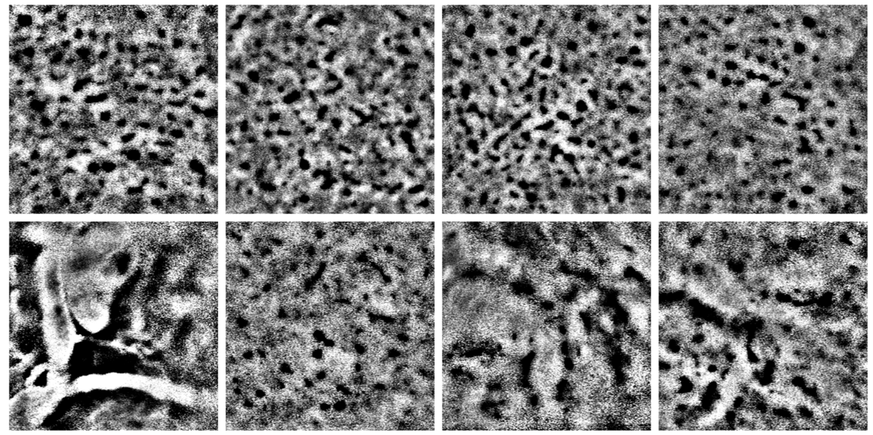
(a) Healthy eyes show higher row-to-row spacing, deeper peak height (prominence) and broader peak FWHM, compared to diseased eyes, as reflected by averaged power spectra. (b) Box plots compare peak location, peak height (prominence) and peak FWHM between cohorts, showing significant differences ($p < 0.01$).



(c) Ranked feature importance based on Principal Component Analysis. (d) Ranked feature importance based on SHapley Additive exPlanations Analysis. Features include spatial frequency metrics (peak location, peak height and peak FWHM) and anatomical factors (ACD: anterior chamber depth; Axial Length: eye length; Curvature: corneal steepness).

Biological Validation: Feature-Based Unsupervised Clustering

- Selected features enabled unsupervised clustering that separated healthy and diseased eyes, as shown by hierarchical clustering and similarity matrix visualization.
- Cluster assignments strongly aligned with clinical labels, as confirmed by confusion matrix analysis.

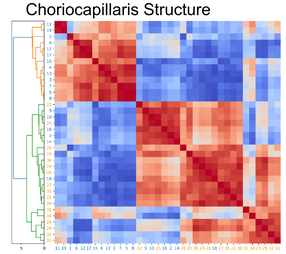


Top row displays healthy eyes with a vibrant, uniform meshwork indicative of robust vascular integrity, whereas bottom row reveals the disrupted, irregular network characteristic of diseased eyes.

Quantitative Analysis: Feature Extraction and Selection

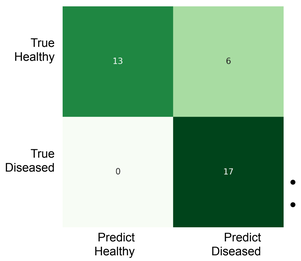
- Spatial frequency analysis revealed broader peaks and richer vascular variation in healthy eyes.
- Quantitative parameters (peak location, height, and FWHM) differed significantly between cohorts, and PCA and SHAP analyses consistently identified peak location, peak FWHM, and peak height as key distinguishing features.

Unsupervised Clustering of Choriocapillaris Structure



Dendrogram and Similarity Matrix

Confusion Matrix



- Accuracy: 83%
- Sensitivity: 100%

Summary and Acknowledgments

Conclusion: Feature engineering applied to AO-ICG angiography revealed three spatial frequency features — peak location, peak height (prominence), and peak width (FWHM) — that quantitatively distinguish microscopic differences in the choriocapillaris between healthy and diseased eyes.
PCA and SHAP analyses consistently identified these features as key contributors, and unsupervised clustering based on them aligned well with clinical diagnoses, supporting their potential use for monitoring vascular health.

Acknowledgements: This work is supported by Intramural Research Program of the National Institutes of Health, National Eye Institute

Reference:

[1] Tam, J. et al. In vivo imaging of the human retinal pigment epithelial mosaic using adaptive optics enhanced indocyanine green ophthalmoscopy. *Invest Ophthalmol Vis Sci.* 57,4376 (2016).
[2] Jung, H. et al. combining multimodal adaptive optics imaging and angiography improves visualization of human eyes with cellular-level resolution. *Comm Bio 1*, 189 (2018).
[3] Frangi, A et al. Multiscale vessel enhancement filtering. Lecture Notes Computer Science 1496, 130 (1998).