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Towards Objective Corneal Transparency Assessment in the Clinical Setting: Correction of Acquisition Artifacts in Spectral-domain OCT Images

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Abstract: We present an automated data analysis procedure for clinical spectral-domain OCT, capable of correcting instrument-related hyperreflective artifacts, and its application to normal corneas. Quantitative parameters related to corneal transparency are extracted from 85 eyes. © 2021 The Author(s)

Introduction

There is a need for reliable and easy-to-use diagnostic procedures for objective and quantitative characterization, including monitoring ability, of corneal transparency, in current clinical practice. Our team previously developed a method for corneal transparency assessment based on a new optical data analysis-based approach, which was demonstrated and validated *ex vivo* using full-field OCT [1]. The present study extends our work to the clinical application of this method to *in vivo* spectral-domain (SD) OCT images. Particular attention is given to the detection and compensation of hyperreflective artifacts related to the instrumental configuration (see Fig. 1), such as occurring from inhomogeneous illumination and the wide field-of-view.

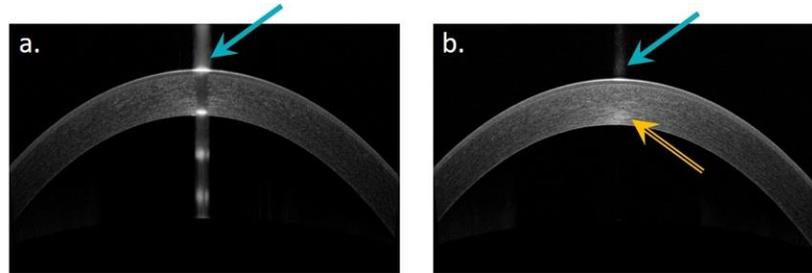


Fig. 1. Typical hyperreflective artifacts in clinical SD-OCT corneal images (RTVue-100 OCT device; Optovue, Inc.). (a-b. blue simple arrow) Column-like artifact due to specular reflection on corneal apex; (b. yellow double arrow) Posterior stromal artifact identified as the device PSF.

Methods

We have developed a pre-processing algorithm for standardization and correction of *in vivo* SD-OCT corneal images implemented in the Python programming language (Python Software Foundation, v2.7.4), that standardizes raw images (flattening, segmentation, normalization) and computes a correction mask from each OCT image (see Fig. 2). Our approach is based on the Principal Component Analysis (PCA) of the in-depth stromal OCT signal, which enables the statistical computation of the device's point spread function and permits its compensation. The mean stromal intensity depth profile is then extracted and analyzed by means of our previously developed Bayesian approach-based algorithm [1]. A selection of objective parameters relevant for light propagation and transparency assessment are derived from mono-exponential fitting of stromal OCT signal attenuation with depth. Among these are the Birge ratio, equivalent to a reduced χ^2 , that quantifies stromal homogeneity (homogeneous if $B_r \sim 1$, otherwise $B_r \gg 1$) and the scattering mean free path (l_s). We also compute the fraction of transmitted coherent light:

$$T_{coh} = \exp\left(-\frac{\text{stromal thickness}}{l_s}\right)$$

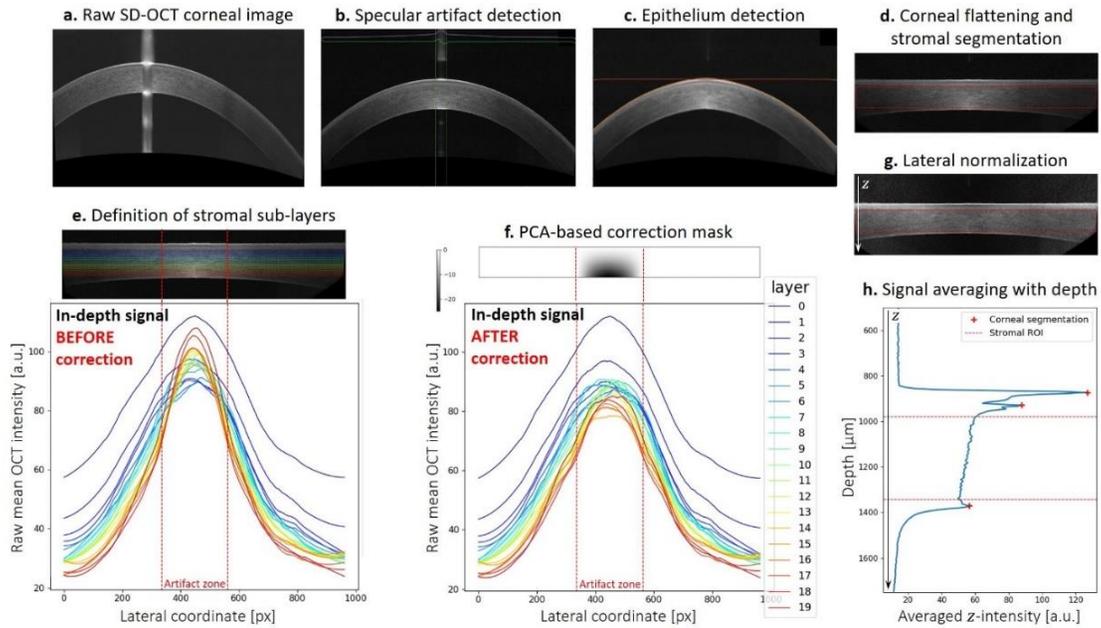


Fig. 2. Illustration of pre-processing steps, from raw SD-OCT image to averaged in-depth intensity profile.

Results

We applied our method to 85 normal corneas (age 31 ± 13 years), with two SD-OCT images per cornea. The Birge ratio (Fig. 3, left) varies slightly with OCT acquisition mode but remains of the order of unity ($B_r = 2.9 \pm 2.2$). Hence, every analyzed stroma appears homogeneous. The fraction of transmitted coherent light (Fig. 3, right) is compatible with literature values [2], even if our values appear to be slightly smaller ($\log(T_{coh}) = 6.5 \pm 1.6$; CV = 13%).

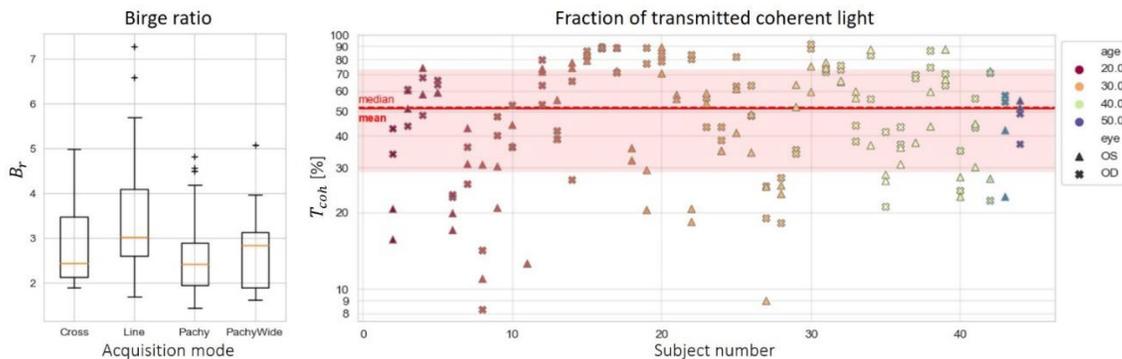


Fig. 3. Results from 85 normal corneas. The transparent red zone (right plot) corresponds to one standard deviation on both sides of the mean.

Conclusion and Discussion

We have demonstrated a robust SD-OCT pre-processing algorithm for *in vivo* corneal transparency quantification while eliminating device-related artifacts, including due to the wide field-of view and the inhomogeneity of the illumination. We successfully applied our method to normal corneas, establishing a normative database that may serve for further reference. Our values for transmitted coherent light being slightly lower than literature values ($T \sim 80\%$) may be partly explained by our computation of T_{coh} with respect to the analyzed stroma, which corresponds to $75 \pm 5\%$ of the full corneal thickness [2]. Furthermore, our method is exclusively sensitive to the attenuation of coherent light (equivalent to a plane wave) while literature data relies typically on methods needing a minimal solid angle. Future work will include the application of our method to corneas with specific pathologies.

References

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 [2] Boettner, E.A., Wolter, R. “Transmission of the ocular media”. Investigative Ophthalmology **1**, 776-783 (1962).