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In-vivo analysis of the optical discontinuity zones at different accommodation demands

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1. Introduction

The focusing power of the human eye is supplied by the combined refractive powers of the cornea and crystalline lens, with the latter providing the capacity to alter and adjust the focus through the accommodation process. The effects of lens accommodation allow the maintenance of a sharp retinal image when the object is located at different distances. Among other processes associated with accommodation, the crystalline lens changes its shape, allowing it to adjust the focal length in response to accommodation demand. Optical cross-sectional images obtained with Scheimpflug imaging or optical coherence tomography show a non-homogenous distribution of light scattering in the crystalline lens, which are often referred to as the optical signal discontinuity (OSD) zones.

The study aims to reveal alteration of the eye morphology, mainly the crystalline lens, across various accommodation states, using an advanced OCT imaging technique. In particular, we present the changes in the characteristics of the OSD zones for different accommodation demands.

2. Methods and results

A commercial long-range swept-source optical coherence tomography (SS-OCT) instrument has been combined with a Badal system to control accommodation demand. Figure 1(a) shows the schematic diagram of the integrated setup consisting of an SS-OCT system (Atria, Thorlabs) modified for ophthalmic applications. The system uses a MEMS-tunable vertical cavity surface emitting laser at the central wavelength of 1060 nm and operates at the speed of 60 kA-scans/s, thus achieving the axial imaging range of 40 mm with the axial resolution of 11 µm. Modified Badal[1] setup consists of a target display (T; Sharp LS029B3SX04), placed at the front focal plane of the collimating lens (C:125 mm), followed by an auxiliary lens (A:200mm) on a movable mount on a rail. The system can provide accommodation demand from -9.5D to +4.6D and is calibrated to produce 1D change for every 13.1mm motion of the auxiliary lens (Fig. 1(b)).

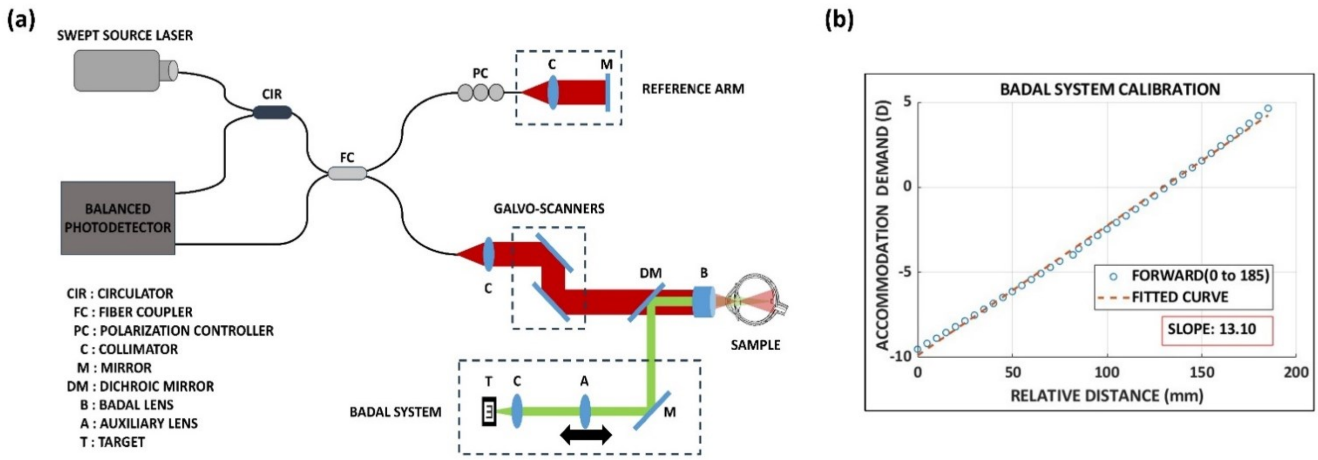

Figure 1. (a) Experimental set-up combining SS-OCT system with Badal System; (b) Calibration of Badal system: generated accommodation demand vs. relative distance (position) of the lens A.

The study adhered to the Tenets of the Declaration of Helsinki and was approved by the Bioethics Committee at the Nicolaus Copernicus University. Participants were informed about the nature of the study, and written consent was obtained from each participant. The pilot study involved two subjects (low myopic (31 yo F) and presbyopic (60 yo M)). The scanning procedure involved 10 B-scans, each containing 5000 A-scans, averaged over 5 A-scans during processing.

Figure 2 demonstrates the thickness of the components of the accommodating crystalline lens revealed in OCT images. The presbyopic subject was able to accept a maximum demand of 1.5 D. The results show that the lens and the nucleus thickness increase with increasing demand for both subjects, which agrees with the previous studies [2]. However, the anterior cortex is found to be decreasing with accommodation demand, while the posterior cortex showed not much change; the statistical significance needs to be studied with a large group of subjects. Further studies will focus on extracting the radii of curvature of the lens and detailed modification of the thickness of the OSD zones.

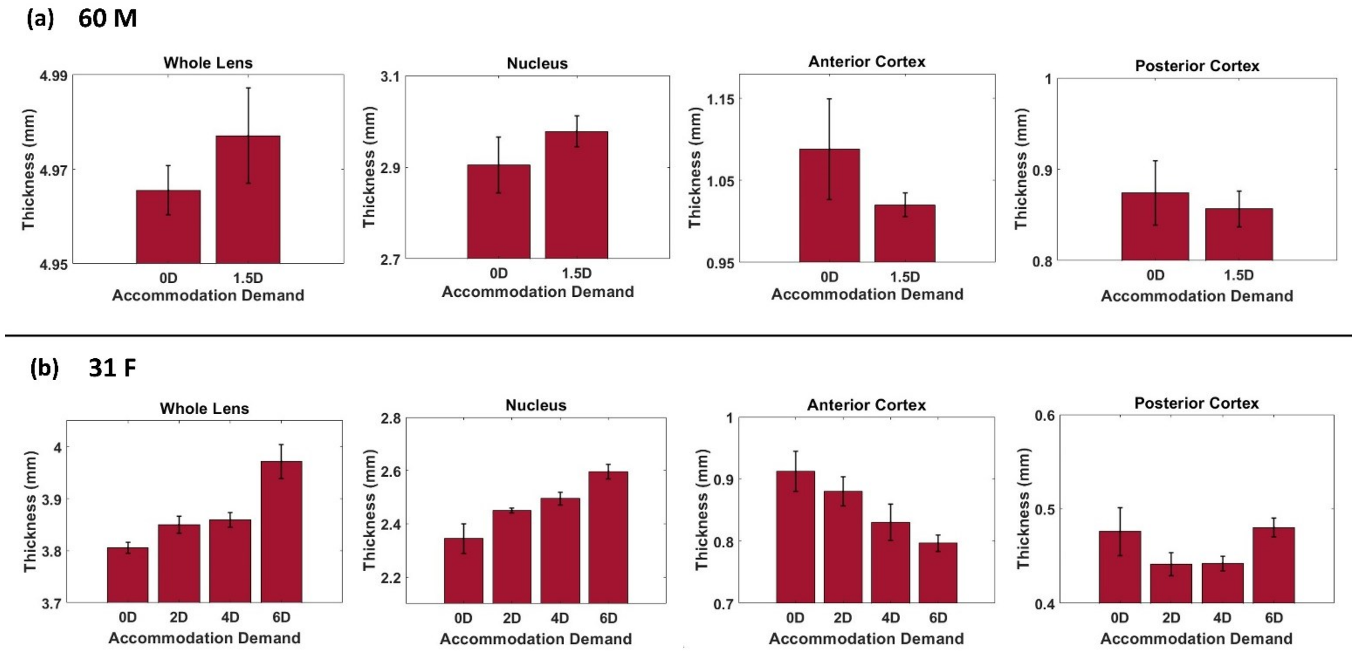

Figure 2. Relation between the thickness of the structures and the accommodation demand (a) For a 60 y/o male subject with presbyopia (b) For a 31 y/o female subject with mild myopia of 0.75D.

3. Conclusions

The modified OCT combined with the Badal system enabled real-time capturing of the crystalline lens morphology at different accommodation demands. The nucleus underwent the most significant change with accommodation, which impacts the whole lens thickness. However, in contradiction to previous studies, the anterior cortex was found to reduce its thickness with accommodation rather than remain constant. These insights help improve our understanding of ocular structure dynamics and their functional relationships and motivate deeper studies into the OSD zones.

4. References

[1] Atchison DA, Bradley A, Thibos LN, Smith G. Useful variations of the Badal Optometer. Optom Vis Sci. 1995;72(4):279-284. doi:10.1097/00006324-199504000-00010

[2] Xiang Y, Fu T, Xu Q, et al. Quantitative analysis of internal components of the human crystalline lens during accommodation in adults. Sci Rep. 2021;11(1):6688. doi:10.1038/s41598-021-86007-6