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Variations in Lens Thickness Affecting the Anterior Chamber Length and Their Potential Measurement Using a Biometer

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Abstract: Biometry is a critical aspect of ophthalmology, since it facilitates the measurement of several ocular parameters and aids in the diagnosis of conditions like glaucoma. The advent of the IOLMaster in 1999 marked a pivotal moment in biometry by introducing non-contact and highly precise measurements that revolutionized the field. Low-coherence optical reflectometry devices such as Lenstar LS900 and Aladdin have further advanced biometry, due to the exceptional accuracy they offer. Axial length, a fundamental measurement in biometry, directly correlates with conditions like myopia and glaucoma. The accurate measurement of axial length is crucial for diagnosis and treatment planning. Biometry also guides intraocular lens power calculation during cataract surgery, relying on factors like axial length, anterior chamber depth, lens thickness, and effective lens position (ELP). Ensuring precision in these measurements is essential for optimal surgical outcomes. While several studies have explored biometric parameters, dynamic changes in crystalline lens thickness during rest or accommodation have received little attention. These changes may have a significant effect on the measurement of the anterior chamber length, and consequently impact the overall biometric assessment. This study delves into dynamic biometry, particularly in the context of age-related presbyopia, and aims to assess the feasibility of incorporating into the biometric process a specialized device capable of accurately considering crystalline lens changes during different states like rest and accommodation. This exploration seeks to enhance the understanding of ocular dynamics and contribute to improving the precision of diagnostic and surgical techniques. It underscores the importance of staying at the forefront of biometric research, especially in the context of emerging technologies and their potential to transform ophthalmology.

Keywords: biometer; accommodation; crystalline; ocular dynamics; lens thickness changes

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1. Introduction

Biometry is a fundamental part of a patient's ophthalmologic examination and is essential for calculating intraocular lens power, monitoring myopia, and detecting certain conditions such as glaucoma [1–4].

Several techniques have been used to measure ocular biometry, such as ophthalmophakometry and A-scan ultrasonography. The latter method has emerged as a potential tool for the early detection of ocular pathologies such as glaucoma [5,6].

However, the introduction of the IOLMaster (Carl Zeiss Meditec AG) in 1999, based on partial coherence interferometry, marked a significant improvement in ocular biometry. It made the technique non-contact and provided higher measurement resolution (about ±0.02 mm compared to ± 0.15 mm with ultrasound) [7]. The IOL-Master700 has established itself as a highly effective tool for evaluating ocular biometry parameters, demonstrating its capability even in challenging situations like the presence of a dense nucleus [8]. Since then, partial coherence laser interferometry (PCLI) has become a widely used method for ocular biometry [7,9–11].

Optical interferometry, used in ocular biometry, is a sophisticated and precise method for measuring the internal dimensions of the eye. This advanced technique uses the principles of light wave interference to provide highly accurate measurements of the eye's structure, which is essential for tailoring treatments in ophthalmology (Figure 1).

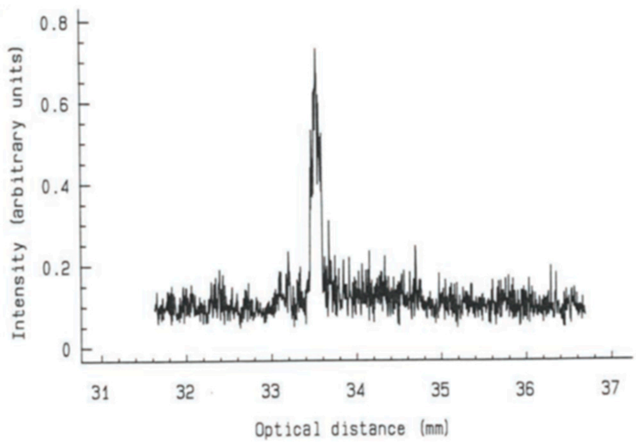

Figure 1. Interferogram: detailed visualization of interference patterns.

This method is critical to several aspects of ophthalmology, most notably the calculation of intraocular lens (IOL) power for cataract surgery and the assessment of refractive errors [4,8,12,13]. It is based on the principle of superimposing two or more sources of coherent light (typically lasers) to create an interference pattern. This pattern can be analyzed to determine the wavelength of the light and the phase differences between the beams, thus allowing extremely high-precision distance measurements. In ocular biometry, devices like the IOLMaster use partial coherence interferometry (PCI) or optical low-coherence interferometry (OLCI) to measure the axial length of the eye, with the remarkable advantage of being non-contact.

Currently, devices based on optical low-coherence reflectometry (OLCR) are available, including the Lenstar LS900 (Haag-Streit Köniz), Aladdin (Topcon), AL-Scan (Nidek), and OA-2000 (Tomey) [13–16]. The accuracy and repeatability of measurements with these instruments are excellent and have been verified in various studies, where the values were similar to the values obtained from these instruments [9,11,17,18]. The ability to accurately measure various components of the eyeball, as shown in Figure 2, plays a critical role in providing reliable and robust data in ophthalmic biometry. This improved accuracy is critical to advancing our understanding and treatment of a range of eye diseases, with significant implications for eye care and research.

It is well established that there is a direct relationship between axial length and spherical ametropia [19]. Increasing myopia leads to the elongation of the eyeball and a reduced expansion in the vertical height of the eye [20–22]; therefore, detecting changes in the axial length of the eye is essential for carrying out any interventions to control it.

There are pathologic conditions in which the axial length of the eye is involved, most notably in glaucoma. There is evidence that this length is involved in primary open-angle glaucoma [23], and it is associated with a short axial length and shallow anterior chamber in closed-angle glaucoma [24].

Another specific function of biometry is the calculation of the power of intraocular lenses to be implanted in cataract surgery, as it determines the expected postoperative outcome and the visual quality of the patient [25,26]. Three parameters are essential for the calculation of IOL power: axial length, anterior chamber depth, and lens thickness. With the development of fourth- and fifth-generation IOL calculation formulas, lens thickness has gained significant interest due to the introduction of the concept of effective lens position (ELP) [27].

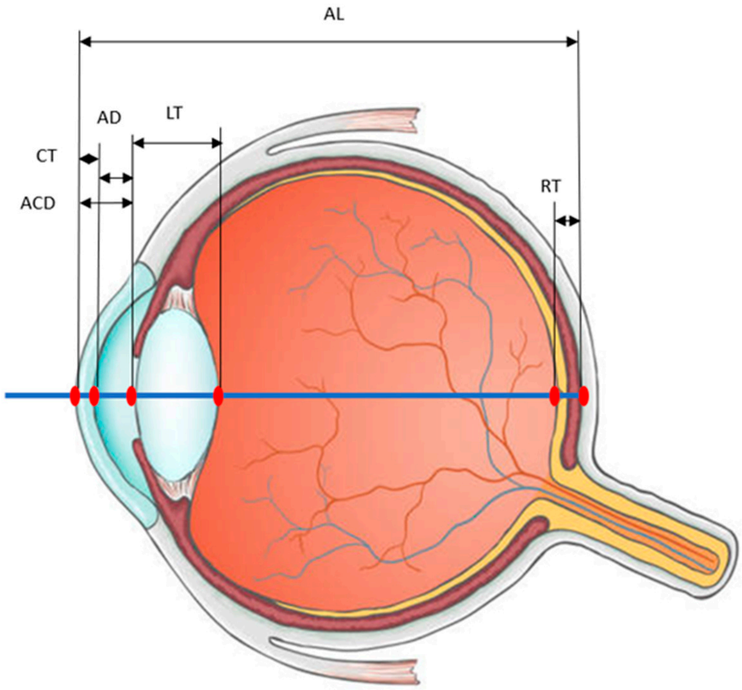

Figure 2. Detailed biometer measurement parameters. AL (Axial Length)—distance from cornea to retina; LT (Lens Thickness)—eye's lens thickness; RT (Retinal Thickness)—thickness of the retina; CT (Corneal Thickness)—cornea's thickness; AD (Aqueous Depth)—space between cornea and lens. ACD (Anterior Chamber Depth)—space between the cornea and lens plus corneal thickness.

There have been studies worldwide that have analyzed the axial length of the eye, anterior chamber depth, and lens thickness [28–30]. However, there is no device that can analyze the changes that occur in lens thickness at rest or in the accommodative state and, therefore, the consequences that this may have on the anterior chamber length.

Research into biometric variations of the crystalline lens and ciliary body during dynamic accommodation is crucial for understanding its process, as age-related alterations lead to presbyopia.

Some studies have shown that the anterior surface of the lens moves and increases its thickness during accommodation. Measurements of anterior chamber depth, lens thickness, and anterior segment length have even been correlated using techniques such as A-scan ultrasonography or partial coherence interferometry, with refraction measured simultaneously in the same eye or in the contralateral eye [31,32].

The main objective of this study is to assess the feasibility of incorporating the objective accommodation measurement device into the biometric process, capable of accurately considering crystalline lens changes during different states like rest and accommodation.

2. Results

The objective accommodation measurement device represents a theoretical advancement in optical instrumentation. It is meticulously designed with an advanced set of internal lenses whose main function is to generate a detailed and specific ray tracing pattern. The unique nature of this pattern lies in its ability to capture highly versatile images, which can be precisely modified to adapt to a wide range of focal planes. Figure 3 illustrates this instrument that can be integrated as an additional tool, like those currently used to perform topography with the Lenstar LS900 biometer (Haag-Streit, Wedel, Germany). This visual representation helps to understand how the instrument complements and enhances the existing capabilities of the Lenstar LS900, and provides a clearer insight into its practical application in ocular measurement.

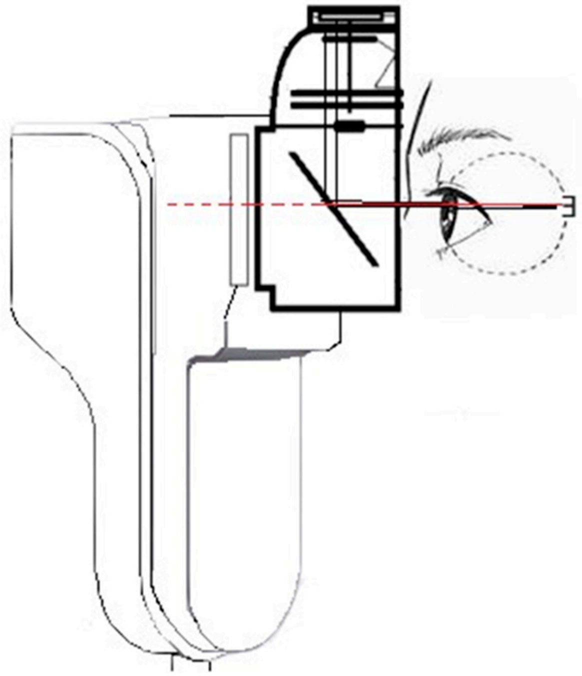

Figure 3. Objective accommodation measurement device: a graphical overview of the design and functionality of the instrument.

One of the most notable features of the device is the incorporation of a semi-silvered sheet, strategically placed with meticulous precision and tilted at 45 degrees. Theoretically, this sheet can project images perpendicular to the line of sight of the eye, which maximizes the accuracy of the analysis. The device's innovative design contemplates the use of toothed discs, which house lenses of both positive and negative powers. These discs, when manipulated and combined, have the theoretical potential to offer an optical power spectrum ranging from −20 to +20 diopters.

Within the design scheme, an illuminated sheet is positioned, which synchronizes perfectly with the semi-silvered sheet. This versatile natured sheet can display images ranging from optotype letters to other graphical representations. As the image moves through this intricate lens system, another set of lenses specifically designed to adjust and compensate for any ametropic condition the eye may present is activated. This auxiliary lens system is of notable complexity, as it can integrate various combinations that include spherical and cylindrical components, all structured in a dual plate design.

Additionally, a high compatibility of the device with a wide variety of biometers currently on the market has also been considered. In order to ensure seamless integration, the incorporation of an anchor ring supplement has been theorized, which would fit perfectly in the specific dimensions of the biometer's objective lens in question.

Finally, one of the primary objectives of the theoretical design is the ability to manipulate the relative distance of the image using lenses. This manipulation seeks to alter the perceived size of the image, which theoretically could induce variations in aspects such as pupil size and lens characteristics, like its curvature and thickness. Through this operation, valuable information about the structure and behavior of the lens could be obtained, thereby allowing for a precise evaluation of the accommodation amplitude and its adequacy in different visual contexts.

3. Discussion

Ocular biometry has undergone a major transformation with the introduction of devices based on partial coherence interferometry and optical low-coherence interferometry. These technological advances provide accurate and non-invasive measurements of crucial ocular parameters, such as lens thickness, anterior chamber depth, and axial length. However, a gap exists in the ability of these devices to measure dynamic changes in lens thickness during resting and accommodation states. These dynamic lens thickness changes may have substantial implications for the anterior chamber length, a parameter that can influence diagnostics and treatments.

To understand this, it is essential to comprehend the accommodation mechanism that depends on the lens's mechanical capabilities and shape changes during the process. The increase in lens thickness during accommodation is greater than the decrease in anterior chamber depth, which suggests that the posterior surface of the lens moves backward during accommodation. During accommodation, the lens's anterior surface becomes more hyperbolic [33].

An initial attempt has already been made to relate these properties to a mechanism for the young human lens using certain simplifying assumptions such as spherical curvature on the lens's anterior surface and elastic isotropy [34]; however, it has been shown that the lens behaves as an anisotropic body [35].

Dynamic accommodation measurements have been conducted in previous studies that used monkeys as research subjects [36]. These studies revealed accommodative changes in the anterior and posterior lens curvature radii using a Purkinje imaging method. Regarding curvature changes per diopter of accommodation, slopes of 0.006 mm $-1/\mathrm{D}$ and 0.00485 mm $-1/\mathrm{D}$ were observed for the anterior and posterior lenses, respectively.

Furthermore, research in humans has produced similar results. In a study involving a 19-year-old subject, an average change of -0.33 mm/D and 0.15 mm/D was observed in the anterior and posterior lens curvature radii, respectively [37]. Other studies have also documented changes in anterior lens curvature, reporting variations up to -0.62 mm and 0.17 mm/D, with a change in radius per diopter of the anterior surface 4.7 times greater than the posterior surface [33,38].

The results highlight the importance of understanding and quantifying changes in lens curvature during human accommodation, and contribute to achieving a more comprehensive grasp of ocular dynamics and its potential clinical implications. These findings further underscore our research's relevance, which demonstrates that ocular accommodation is a highly dynamic process. Understanding variations in lens thickness during accommodation may have a significant impact on diagnosing and treating ocular disorders, thus emphasizing the importance of continuing to explore this area of study to advance ophthalmology.

Additionally, the device's integration with existing biometers offers a practical solution for clinics and hospitals already invested in biometric technology. The device's modular design would allow for easy adaptation to various biometer models, enhancing its applicability and versatility.

However, it is essential to acknowledge potential challenges and limitations associated with implementing the proposed device.

4. Conclusions

The present study underscores the need to address current limitations in ocular biometry, particularly in measuring dynamic lens thickness changes. The introduction of the objective accommodation measurement device may be a significant step toward enhancing biometric measurements' accuracy and comprehensiveness.

The proposed device not only promises to enhance the precision of accommodation measurements but also holds the potential to influence how various ocular conditions are diagnosed and treated. The ability to measure dynamic changes in lens thickness may offer new insights into age-related presbyopia and other accommodation disorders.

In summary, the objective accommodation measurement device introduced in this study has the potential to revolutionize ocular biometry, since it provides more detailed and accurate measurements that can influence the diagnosis and treatment of various eye conditions. Future studies are anticipated to validate the device's efficacy and precision in clinical settings.

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