Journal of Optometry (2014) **xxx**, xxx–xxx

Journal of Optometry
www.journalofoptometry.org

ORIGINAL ARTICLE

Errors Associated with IOLMaster Biometry as a Function of Internal Ocular Dimensions

Miguel Faria-Ribeiro[a,*], **Daniela Lopes-Ferreira**[a], **Norberto López-Gil**[b], **Jorge Jorge**[a], **José Manuel González-Méijome**[a]

[a] *Clinical & Experimental Optometry Research Lab, School of Sciences (Optometry), University of Minho, Braga, Portugal*
[b] *Ciencias de la Visión, Facultad de Óptica y Optometría, Universidad de Murcia, Murcia, Spain*

Received 26 August 2013; accepted 24 November 2013

KEYWORDS
Intra-ocular lens calculation;
IOL calculation;
Axial length measurement

Abstract
Purpose: To evaluate the error in the estimation of axial length (AL) with the IOLMaster partial coherence interferometry (PCI) biometer and obtain a correction factor that varies as a function of AL and crystalline lens thickness (LT).
Methods: Optical simulations were produced for theoretical eyes using Zemax-EE software. Thirty-three combinations including eleven different AL (from 20 mm to 30 mm in 1 mm steps) and three different LT (3.6 mm, 4.2 mm and 4.8 mm) were used. Errors were obtained comparing the AL measured for a constant equivalent refractive index of 1.3549 and for the actual combinations of indices and intra-ocular dimensions of LT and AL in each model eye.
Results: In the range from 20 mm to 30 mm AL and 3.6–4.8 mm LT, the instrument measurements yielded an error between −0.043 mm and +0.089 mm. Regression analyses for the three LT condition were combined in order to derive a correction factor as a function of the instrument measured AL for each combination of AL and LT in the theoretical eye.
Conclusions: The assumption of a single ''average'' refractive index in the estimation of AL by the IOLMaster PCI biometer only induces very small errors in a wide range of combinations of ocular dimensions. Even so, the accurate estimation of those errors may help to improve accuracy of intra-ocular lens calculations through exact ray tracing, particularly in longer eyes and eyes with thicker or thinner crystalline lenses.

---

* Corresponding author at: Clinical & Experimental Optometry Research Lab (CEORLab), Center of Physics (Optometry), University of Minho, 4710-057 Braga, Portugal. Tel.: +351 253 60 40 72; fax: +351 253 60 40 61.
E-mail address: mig.afr@gmail.com (M. Faria-Ribeiro).

http://dx.doi.org/10.1016/j.optom.2013.12.005

Please cite this article in press as: Faria-Ribeiro M, et al. Errors Associated with IOLMaster Biometry as a Function of Internal Ocular Dimensions. *J Optom.* (2014), http://dx.doi.org/10.1016/j.optom.2013.12.005

PALABRAS CLAVE
Cálculo de lentes intra-oculares;
Cálculo de LIO;
Medición de la longitud axial

Errores asociados a la biometría IOLMaster en función de las dimensiones oculares internas

Resumen

Objetivo: Evaluar el error en la estimación de la longitud axial (LA) con el biómetro IOLMaster de interferometría de coherencia parcial (ICP), y obtener un factor de corrección que varíe en función de la LA y el grosor del cristalino (GC).

Métodos: : Se realizaron simulaciones ópticas en ojos teóricos utilizando el software Zemax-EE. Se utilizaron treinta y tres combinaciones que incluían once LA diferentes (de 20 a 30 mm en pasos de 1 mm) y tres GC (3,6; 4,2 y 4,8 mm). Se obtuvieron los errores cometidos al comparar la LA medida para un índice refractivo equivalente constante de 1,3549 y para las combinaciones reales de los índices y dimensiones intraoculares de GC y LA en cada modelo de ojo.

Resultados: En el rango de 20 a 30 mm de LA y de 3,6 a 4,8 mm de EC, las mediciones instrumentales arrojaron un error comprendido entre -0,043 y +0,089 mm. Se combinaron los análisis de regresión para las tres situaciones de GC con el fin de calcular un factor de corrección en función de la LA medida instrumentalmente para cada combinación de LA y GC en el ojo teórico.

Conclusiones: El supuesto de un único índice refractivo ''medio'' en la estimación de LA mediante el Biómetro ICP IOLMaster, causa muy pocos errores en un amplio rango de combinaciones de dimensiones oculares. Incluso así, la estimación exacta de dichos errores puede ayudar a mejorar la precisión de los cálculos de las lentes intra-oculares mediante trazado de rayos, particularmente en ojos más grandes y ojos con mayor o menor espesor del cristalino.

Introduction

Accurate measurement of the axial length (AL) of the eye is critical in several research and clinical applications. Partial coherence interferometry (PCI) is a non-invasive objective method to measure axial length (AL) and is the election method for total or partial measurement of intra-ocular dimensions[1,2] as a main variable for intra-ocular lens calculation. It is also used in clinical trials involving emmetropization and myopia progression[3] and, recently, to evaluate the actual shape of the posterior segment of the eye.[4,5] However, such biometers determine optical path lengths (OPL) and convert them into geometric/anatomical lengths by assuming estimate values for the eye internal refractive indices. In the case of the IOLMaster (Carl Zeiss Meditec, Jena, Germany), it uses a unique average index (1.3549) based on the average group refractive index of a Gullstrand's 24 mm model eye for an envelope of waves at the instrument's infrared radiation wavelength λ=780 nm.[6]

Atchison and Smith[7] calculated the errors that this assumption might induce in axial length measurement during accommodation, and more recently in retinal shape estimation.[8] However, no correction factor was suggested within the normal range of AL and crystalline lens thickness (LT) which might have an impact in the final estimations, as the authors acknowledge.

Beyond solely measuring AL and other biometric parameters, current intra-ocular refractive surgical procedures require a high level of accuracy in the estimation of the power of the intra-ocular lenses (IOL) to be implanted. This is particularly relevant in patients with very good preoperative visual acuity as in the case of presbyopic patients undergoing clear lens exchange (CLE) with implantation of multifocal IOL's.[9] IOL power calculation has evolved from the initial empirical methods to the newest generation formulas.[10] The potential errors involved in AL measurement within the normal range seem to be assumed by correction factors in the IOL formulas, but for eyes with out-of-the-normal-range internal dimensions significant errors might be involved.[11,12]

In the search for more accurate estimations, several authors have made significant efforts to develop new customized methods to estimate the IOL power through optical modelization[13] based on the patient' own data, obtained with the most recent methods of ocular imaging.[14] As the axial length of the patient's eye is paramount in these efforts for higher accuracy, better estimations of the AL should be useful to improve the accuracy of these models.

The goal of this paper was to evaluate the impact of different combinations of AL and LT in the measurement obtained with the IOLMaster through optical ray tracing simulation, and to derive a correction method for such measurements.

Methods

Optical design programs are used to model and analyze different kinds of imaging systems including the human eye. They use Snell's law to trace the propagation of light through the surfaces of an optical system. Using ray-tracing software Zemax-EE (Zemax Development Corporation, Washington, USA) a set of unaccommodated eyes were designed based on the Navarro Eye Model.[15] Three different LT values (3.6 mm, 4.2 mm and 4.8 mm) were combined with eleven eye lengths (from 20 mm to 30 mm in 1.0 mm steps), resulting in 33 combinations. The LT values were based on the age related changes obtained by Atchison et al.[16] who pointed an average LT shift from of 3.6 mm to 4.8 from 20 to 70 years of age. An additional 4.2 mm intermediate value was included

Please cite this article in press as: Faria-Ribeiro M, et al. Errors Associated with IOLMaster Biometry as a Function of Internal Ocular Dimensions. *J Optom.* (2014), http://dx.doi.org/10.1016/j.optom.2013.12.005

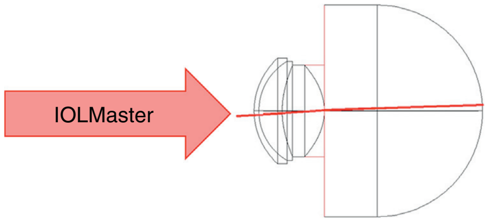

Figure 1 Ray-trace simulation of the IOLMaster infrared beam, in the Navarro Eye Model, along the visual axis. Due to the temporal decentration of the fovea the beam will be slightly deviated after refraction in the internal surfaces of the eye.

as a value representative of a middle-aged population from 39 to 51 years.[17]

Corneal thickness, curvatures and asphericities were kept constant. Anterior chamber depth (ACD) was set to vary as a function of the change in LT such that 50% of the change in LT resulted in a change in the same magnitude in the ACD. Vitreous chamber depth (VCD) was set to vary as a function of ACD and eye length as most of the axial elongation of the eye is attributed to VCD elongation.[18] This was assumed for simplicity after previous simulation demonstrated no implication in the error calculations presented. As ACD and VCD have similar refractive indices, the sum of their optical path lengths (OPL) will be the approximately the same regardless of their physical length distribution. The individual group refractive indices were derived by Hitzenberger,[6] starting from the known phase refractive indices at λ=550 nm and assuming the dispersion of water for the ocular media.

Unlike ultrasound biometry that measures AL along the optical axis of the eye, PCI – as a fixation-bound method – measures AL along the eye's visual axis. Because of the temporal displacement of the fovea in the human eye, the horizontal field angle was adjusted so that the chief ray would maintain a 5-degree angle at the 2nd nodal point (Fig. 1). Normal incidence with the first corneal surface was maintained in all theoretical simulations.

For the cornea-to-fovea physical distance to be the same between the eye model and the instrument estimated AL, the average group refractive index of the eye model must equal the one assumed by the instrument for the same wavelength. Whenever these values are different, depending mainly on varying distribution of AL and LT values, the optical measurement will result in an estimation error. The error was obtained using Eq. (1).

$$\text{Error} = \text{Instrument AL} - \text{Eye Model AL} \tag{1}$$

Here the instrument measured AL is the result of dividing the calculated OPL by the estimated group refractive index ''wired in'' the instrument (1.3549), and the Eye Model AL is the result of ray tracing simulation by adding each individual surface physical path length.

Linear regression was used to evaluate the error as a function of LT and AL and then combined into a single correction equation. In each step the residual error was calculated.

Results

The errors for each one of the eye models under evaluation have been calculated and plotted as a function of the axial length, for each crystalline lens thickness. Fig. 2 shows the error variations in the instrument measurements for all the 33 eye model combinations. From 20 mm to 30 mm axial lengths and 3.6–4.8 mm lens thickness, the instrument measurements will yield an estimated error between −0.043 mm and +0.089 mm.

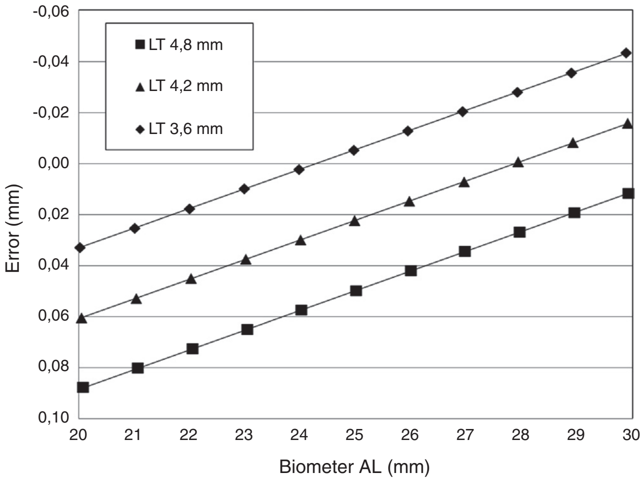

Figure 2 Error from the instrument measure as a linear function actual AL and LT combinations.

Table 1 Equations Coefficients from the Regressions in Fig. 1.

LT (mm)	Slope_R1	Constant_R1	R^2
3.6	−0.007735	0.187912	1.00000
4.2	−0.007735	0.21559	1.00000
4.8	−0.007735	0.24328	1.00000

The slope obtained in the three linear regression equations was the same (−0.007735), with the equation constant values corresponding to the thinner and the thicker LT configuration presenting a difference of approximately ±0.028 mm with respect to the middle thickness equation constant value (LT=4.2 mm). The coefficient of determination (r^2) was 1.0000 for the three equations as expected due to the linear relation between the optical path length and the real distance.

Using the parameters in Table 1, a new regression equation was derived in order to predict the variation from the constant terms in each equation for each LT. This allowed us to create a combined regression equation that will be able to estimate the amount of error as a function of AL and LT within the range of values considered in this work (Eq. (2)).

$$\text{Error} = -0.007735 \times \text{Instrument AL} + 0.046140 \times \text{LT} + 0.021806 \tag{2}$$

Discussion

Nowadays, accurate determinations of AL are of paramount importance in several research and clinical applications.

Please cite this article in press as: Faria-Ribeiro M, et al. Errors Associated with IOLMaster Biometry as a Function of Internal Ocular Dimensions. *J Optom.* (2014), http://dx.doi.org/10.1016/j.optom.2013.12.005

From the results of the present study we can observe that the equivalent refractive index of 1.3549 used by the instrument is optimized for an AL value near 24 mm with a LT around 3.6 mm. This does not seem to be consistent with the normal LT value found in the general elderly population,[16] especially when considering that these instruments are primarily used in pre-surgical evaluation of cataract patients. Although the errors found are quite small, usually lower than 0.1 mm, which corresponds to error in the power of the IOL around 0.25 D, these errors are expected to be higher for AL values out the range than the ones plotted in Fig. 2 due to the linear relation between the error and the AL. Even so, we stress that the correction of the AL measured by the IOLMaster might not be clinical relevant when the calculation of the IOL is done using one of the traditional formulas, due to the lack of precision that they offer. On the other hand, personalized eye models can help to improve the accuracy of IOL power choice through numerical ray-tracing software like Zemax,[13] but the biometric data used in the customization of the eye models must be corrected for the errors here reported, and the parameters of the IOL geometry other than the lens constant must be known. Also better estimates of group refractive indices in the infrared are needed; there is not enough information in the literature on dispersion in the various ocular media to make better estimates than the ones reported by Hitzenberger.[6]

Another important area that might benefit from these corrections is the clear lens exchange (CLE) surgery. In CLE, patients expect high precision results. Improving the estimation of the actual axial length will certainly improve the prediction of the most accurate post-surgical refraction.

In summary the present results demonstrates minor deviations between the AL obtained with an optical biometer and the actual value predicted using optical modelization. However, correction of AL accounting for distortions induced by refraction within the ocular media and variations in the average refractive index of the eye might help to progress further toward the desirable error-free biometric calculations in cataract surgery and CLE, particularly in longer eyes.

Conflict of interest

The authors declare that there is no conflict of interest.

References

1. Chan B, Cho P, Cheung SW. Repeatability and agreement of two A-scan ultrasonic biometers and IOLMaster in non-orthokeratology subjects and post-orthokeratology children. *Clin Exp Optom*. 2006;89:160–168.
2. Santodomingo-Rubido J, Mallen EA, Gilmartin B, Wolffsohn JS. A new non-contact optical device for ocular biometry. *Br J Ophthalmol*. 2002;86:458–462.
3. Fledelius HC, Goldschmidt E. Oculometry findings in high myopia at adult age: considerations based on oculometric follow-up data over 28 years in a cohort-based Danish high-myopia series. *Acta Ophthalmol*. 2010;88:472–478.
4. Mallen EA, Kashyap P. Technical note: measurement of retinal contour and supine axial length using the Zeiss IOLMaster. *Ophthalmic Physiol Opt*. 2007;27:404–411.
5. Faria-Ribeiro M, Queiros A, Lopes-Ferreira D, Jorge J, González-Méijome JM. Peripheral refraction and retinal contour in stable and progressive myopia. *Optom Vis Sci*. 2013;90:9–15.
6. Hitzenberger CK. Optical measurement of the axial eye length by laser Doppler interferometry. *Invest Ophthalmol Vis Sci*. 1991;32:616–624.
7. Atchison DA, Smith G. Possible errors in determining axial length changes during accommodation with the IOLMaster. *Optom Vis Sci*. 2004;81:283–286.
8. Atchison DA, Charman WN. Can partial coherence interferometry be used to determine retinal shape. *Optom Vis Sci*. 2011;88:E601–E607.
9. de Vries NE, Webers CAB, Touwslager WRH, Bauer NJC, de Brabander J, Berendschot TT, et al. Dissatisfaction after implantation of multifocal intraocular lenses. *J Cataract Refract Surg*. 2011;37:859–865.
10. Narvaez J, Zimmerman G, Stulting RD, Chang DH. Accuracy of intraocular lens power prediction using the Hoffer Q, Holladay 1, Holladay 2, and SRK/T formulas. *J Cataract Refract Surg*. 2006;32:2050–2053.
11. Tsang CS, Chong GS, Yiu EP, Ho CK. Intraocular lens power calculation formulas in Chinese eyes with high axial myopia. *J Cataract Refract Surg*. 2003;29:1358–1364.
12. Aristodemou P, Knox Cartwright NE, Sparrow JM, Johnston RL. Intraocular lens formula constant optimization and partial coherence interferometry biometry: refractive outcomes in 8108 eyes after cataract surgery. *J Cataract Refract Surg*. 2011;37:50–62.
13. Ribeiro FJ, Castanheira-Dinis A, Dias JM. Personalized pseudophakic model for refractive assessment. *PLoS ONE*. 2012;7:e46780.
14. Tang M, Li Y, Huang D. An intraocular lens power calculation formula based on optical coherence tomography: a pilot study. *J Refract Surg*. 2010;26:430–437.
15. Navarro R, Santamaria J, Bescos J. Accommodation-dependent model of the human eye with aspherics. *J Opt Soc Am A*. 1985;2:1273–1281.
16. Atchison DA, Markwell EL, Kasthurirangan S, Pope JM, Smith G, Swann PG. Age-related changes in optical and biometric characteristics of emmetropic eyes. *J Vis*. 2008;8:29–30.
17. Richdale K, Bullimore MA, Zadnik K. Lens thickness with age and accommodation by optical coherence tomography. *Ophthalmic Physiol Opt*. 2008;28:441–447.
18. Shih YF, Chiang TH, Lin LL. Lens thickness changes among schoolchildren in Taiwan. *Invest Ophthalmol Vis Sci*. 2009;50:2637–2644.

Please cite this article in press as: Faria-Ribeiro M, et al. Errors Associated with IOLMaster Biometry as a Function of Internal Ocular Dimensions. *J Optom*. (2014), http://dx.doi.org/10.1016/j.optom.2013.12.005