Int Ophthalmol (2019) 39:1803–1808
https://doi.org/10.1007/s10792-018-1007-y

ORIGINAL PAPER

Accuracy of minus power intraocular lens calculation using OKULIX ray tracing software

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Received: 12 March 2018 / Accepted: 17 August 2018 / Published online: 23 August 2018

Abstract

Purpose The purpose of this retrospective study was to assess the accuracy of minus power intraocular lens calculation using partial coherence interferometry and OKULIX ray tracing software.

Methods We included 25 consecutive, myopic eyes with axial length ≥ 30 mm (25 patients, 13 males and 12 females, and 57.6 ± 10.3 years old), which underwent phacoemulsification and implantation of a minus power intraocular lens in the capsular bag. Axial length measurement and corneal topography were performed using the OA-1000 optical biometer and Topographic Modeling System TMS-5, respectively. The IOL power was calculated using SRK/T formula and OKULIX ray tracing software. The implanted IOL power was chosen based on OKULIX ray tracing software calculation aiming for − 2 diopters (D) of myopia.

Results SRK/T calculated IOL power (− 6.3 ± 2.8 D) showed statistically significant difference compared to OKULIX calculated IOL power (− 4.7 ± 2.6 D), r_s 0.994 $p < 0.001$. The expected refraction with implanted IOL was − 1.7 ± 0.9 D based on OKULIX ray tracing software calculation. A statistically significant difference was reported between implanted IOL and OKULIX calculated IOL power (2.7 ± 1.4 D), r_s 0.981 $p < 0.001$. A statistically significant difference was reported between the expected refraction with implanted IOL and the achieved spherical refraction at 1 month postoperatively (1.4 ± 0.7 D), r_s 0.77 $p < 0.001$. The achieved spherical refraction at 1 month postoperatively was 0.2 ± 0.2 D.

Conclusions Although OKULIX ray tracing software yielded more accurate minus power intraocular lens calculation in extreme myopia, compared to SRK/T formula, yet it still shows tendency toward hyperopia.

Keywords Partial coherence interferometry · OKULIX ray tracing software · Minus power intraocular lens calculation · Extreme myopia

Introduction

Among the challenges in ophthalmic practice, accurate intraocular lens (IOL) power calculation in extreme myopia still represents an unbeaten frontier [1–4]. Although theoretical and regression IOL power calculation formulas operate well for average axial

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10792-018-1007-y) contains supplementary material, which is available to authorized users.

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length eyes (22.0–24.5 mm), accurate IOL power calculation in extreme myopic eyes, requiring minus power concave IOL, remains an unsolved issue [5–7]. A systematic deviation between target and postoperative refractions with a high tendency toward hyperopia is frequently reported in the cases of extreme myopia necessitating minus power IOL implantation [8, 9].

Optical biometry using partial coherence laser interferometry (PCLI) provides precise and reproducible axial length (AL) measurements together with superior comfort for the patient and the examiner in comparison with traditional ultrasound biometry [3, 10]. However, usefulness is constrained in circumstances of poor fixation, retinal detachment, and dense cataract [3].

The use of PCLI permits AL determination with an exactness 10 times greater than that of ultrasonographic biometry [3, 10]. Furthermore, ultrasound shows dilemmas in some clinical circumstances such as corneal leukomas, staphylomatous globes, silicone-filled eyes, or eccentric fixation [3, 10]. When compared with ultrasonographic biometry, the PCLI permits the measurement of the AL along the visual axis, which is a definite odd in highly myopic staphylomatous globes [3, 10].

Lately, a novel lens power calculation software called OKULIX has been introduced, which is based on numerical ray tracing [11–14]. It is capable of determining the monochromatic optical capacities of the pseudophakic human eye. Single light rays confined to the pupillary size are assessed. This is in contrast with traditional IOL calculation formulas, which use paraxial rays only, based on Gaussian optics. The calculation error inside OKULIX is the same for all distances to the optical axis (residual error ≤ 0.001 D). ALs can be entered either manually or by a computer link to the measuring device. Interfaces exist to the ultrasound and to the optical devices—from Tomey Corporation, Nagoya, Japan, to the Haag-Streit Lenstar (Haag-Streit Diagnostics, Bern, Switzerland), the Oculus Pentacam (OCULUS, Inc., Arlington, Washington, USA), and the optical and acoustical devices from Nidek CO., Gamagori, Japan [11–16].

Ray tracing calculation is performed from the cornea to the fovea. This is possible because the geometric optical pathway can invariably be mirrored [11–16]. Rays undergo various refractions on several surfaces where there is change in refractive index (vitreous, lens, aqueous, and cornea). The surface shape is generally determined by its central radius of curvature [11–16]. Moreover, IOL data, including thickness, radius, and refractive index, together with corneal topographic data, are incorporated in the IOL calculation [11–16].

The purpose of this retrospective study was to assess the accuracy of minus power intraocular lens calculation using OKULIX ray tracing software.

Patients and methods

All patients were recruited from the Department of Ophthalmology, Faculty of Medicine, Alexandria University (Alexandria, Egypt). Informed consent was obtained from all patients. This study was approved by the Ethics of Research Committee, Faculty of Medicine, University of Alexandria, Egypt.

In this retrospective study, 25 consecutive, myopic eyes with an AL of at least 30 mm (25 patients, 13 males and 12 females, and mean age: 57.6 ± 10.3 years) were enrolled. The patients were subjected to AL measurement using the OA-1000 optical biometer (Tomey Corporation, Nagoya, Japan) and corneal topography using Topographic Modeling System TMS-5 (Tomey Corporation). The IOL power was calculated using SRK/T formula and OKULIX ray tracing software. The implanted IOL power was chosen based on OKULIX ray tracing software calculation aiming for -2 diopters (D) of myopia.

All patients underwent cataract surgery including phacoemulsification using Alcon Infiniti System (Alcon Laboratories, Fort Worth, Texas, USA) and in the capsular bag implantation of AcrySof MA60MA acrylic IOL (Alcon, Inc.). Surgeries were performed by a single surgeon (K.M.N.). Postoperative refraction was assessed by a TOPCON RM-8900 Auto Refractometer (Topcon Medical Systems, Tokyo, Japan). Uncorrected and best spectacle-corrected visual acuity (BCVA) were measured for each eye using a Tumbling E's chart, yet BCVA was not analyzed statistically as it is affected by factors other than the accuracy of IOL power calculation such as myopic macular degeneration and myopic choroidal neovascularization.

The exclusion criteria were: (1) subjects with a history of intraocular surgery or intraoperative or

postoperative complications; (2) preexisting ocular pathologies that might influence postoperative refraction, such as keratoconus, corneal scars, corneal endothelial dystrophy, macular edema, and retinal detachment; (3) subjects undergoing combined surgical procedures; and (4) subjects with less than 1 month of follow-up.

Statistical analysis

All data were analyzed with the SPSS version 15 (SPSS Inc., Chicago, IL, USA). Values were recorded as mean ± SD (standard deviation). A paired *t*-test was used for parametric comparison of the means. Spearman coefficient (r_s) was used to correlate between quantitative variables. The mean axial length, anterior chamber depth, and keratometric measurements were calculated. Difference between SRK/T and OKULIX calculated IOL power was analyzed. Deviation of the achieved 1 month postoperative refraction from the expected refraction was calculated and evaluated. The confidence interval was 95%, and $p < 0.05$ was considered statistically significant.

Results

The present study was conducted on 25 highly myopic cataract patients with AL of at least 30 mm. They included 13 (52%) males and 12 (48%) females. The age of the studied patients ranged from 30 to 74 years (57.6 ± 10.3 years). The axial length of the subjects included ranged from 30.1 to 35.7 mm (32.4 ± 1.4 mm) (Table 1).

SRK/T calculated IOL power (− 6.3 ± 2.8 D) showed statistically significant difference compared to OKULIX calculated IOL power (− 4.7 ± 2.6 D), r_s 0.994 $p < 0.001$ (Fig. 1). The expected refraction with implanted IOL was − 1.7 ± 0.9 D based on OKULIX ray tracing software calculation. A statistically significant difference was reported between implanted IOL power and OKULIX calculated IOL power (2.7 ± 1.4 D), r_s 0.981 $p < 0.001$ (Fig. 2). The achieved spherical refraction at 1 month postoperatively was 0.2 ± 0.2 D. A statistically significant difference was reported between the expected refraction with implanted IOL and the achieved spherical refraction at 1 month postoperatively (1.4 ± 0.7 D), r_s 0.77 $p < 0.001$ (Fig. 3).

Discussion

IOL power calculation formulas perform best for normal AL eyes; however, accurate biometry prediction in extreme myopic eyes requiring concave IOLs remains challenging, although SRK/T formula is probably the most precise and is now widely applied [5].

The challenging accurate biometry prediction in extreme myopic eyes may be partly attributed to posterior pole anatomy. The fovea is approximately 4.5 mm (3 disk diameters or 15°) from the optic disk head center. Posterior pole staphyloma temporal to the fovea is common in eyes with axial lengths ≥ 30.0 mm, and the distance from the corneal vertex to the fovea is 0.5–1.5 mm shorter than the length from the corneal vertex to the bottom of the staphyloma, where the A-scan usually extends the perpendicular axis and records the axial length [17].

Several studies have concluded that optical AL measurement is more accurate than ultrasonic biometry in myopia, particularly if combined with the staphylomatous posterior pole [3]. Postoperative depth of the anterior chamber and preoperative AL present crucial probable etiological factors for inaccurate IOL power calculation. Nonetheless, the anterior chamber depth is less relevant with increased AL, as the refractive error per mm IOL deviation is three times greater in short globes when compared with myopic eyes with AL above 27 mm [18]. For this reason, the majority of reports are concentrated on AL determination and IOL power calculation formulas in highly myopic patients [9].

However, in a recent study assessing measurement of AL using partial coherence interferometry, with IOL power calculation using Barrett Universal II, SRK/T, Haigis, Holladay and Hoffer Q formulas, an unexpected hyperopic outcome was found with all formulas in eyes with minus power IOL [1]. Improvement in the accuracy and reliability of AL measurement with PCI biometry did not eliminate the error [9].

Lately, OKULIX lens power calculation software has become applicable, based on numerical ray tracing, assessing single light rays confined to the pupillary size, in contrast with traditional IOL calculation formulas that used paraxial rays only, which are based on Gaussian optics. The calculation error inside OKULIX is the same for all distances to the optical axis (residual error ≤ 0.001 D). The principles of ray

Table 1 Distribution of the studied cases according to different parameters (n = 25)

	No. (%)
Sex	
Male	13 (52%)
Female	12 (48%)
Age (years)	
Mean ± SD.	57.6 ± 10.3
Median (Min.–Max.)	59 (30–74)
Keratometric R1 (mm)	
Mean ± SD.	7.5 ± 0.4
Median (Min.–Max.)	7.5 (6.4–8.2)
Keratometric R2 (mm)	
Mean ± SD.	7.3 ± 0.4
Median (Min.–Max.)	7.4 (6–7.9)
Anterior chamber depth (ACD) (mm)	
Mean ± SD.	5.3 ± 0.21
Median (Min.–Max.)	5.4 (4.9–5.8)
Axial length (AL) (mm)	
Mean ± SD.	32.4 ± 1.4
Median (Min.–Max.)	32.5 (30.1–35.7)
SRK/T calculated IOL power in diopters (D)	
Mean ± SD.	− 6.3 ± 2.8
Median (Min.–Max.)	− 7 (− 12 to − 1.5)
OKULIX calculated IOL power in diopters (D)	
Mean ± SD.	− 4.7 ± 2.6
Median (Min.–Max.)	− 5 (− 10 to − 0.50)
Implanted IOL power in diopters (D)	
Mean ± SD.	− 2.1 ± 1.3
Median (Min.–Max.)	− 2 (− 5–0)
Power difference between OKULIX calculated IOL and implanted IOL (D)	
Mean ± SD.	2.7 ± 1.4
Median (Min.–Max.)	3 (0.5–5)
Expected refraction with implanted IOL (D)	
Mean ± SD.	− 1.7 ± 0.9
Median (Min.–Max.)	− 2 (− 3 to − 0.1)
1 month achieved spherical refraction (D)	
Mean ± SD.	− 0.2 ± 0.2
Median (Min.–Max.)	− 0.3 (− 0.5 to 0)
Difference between expected and 1 month achieved spherical refraction (D)	
Mean ± SD.	1.4 ± 0.7
Median (Min.–Max.)	1.8 (0.1–2.6)

tracing have existed since the 17th century, but only recently have they been applied to calculations for optical devices in ophthalmology. Although many surgeons rely on the use of third-generation IOL power calculation formulas such as the Haigis-L, Hoffer Q, Holladay 2, Olsen, and SRK/T, ray tracing is a modern technique based on a different set of principles that should be considered a potentially useful strategy [19].

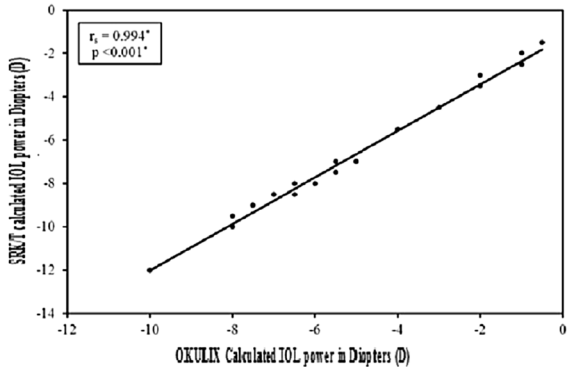

Fig. 1 Correlation between SRK/T calculated IOL power and OKULIX calculated IOL power

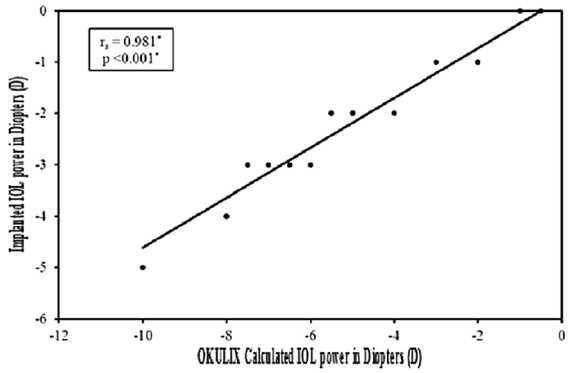

Fig. 2 Correlation between implanted IOL power and OKULIX calculated IOL power

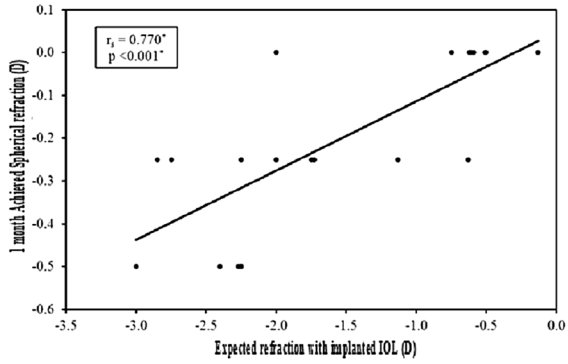

Fig. 3 Correlation between expected refraction with implanted IOL and the achieved spherical refraction at 1 month postoperatively

In the present study, SRK/T formula showed greater tendency to hyperopic error compared to OKULIX software. The expected refraction with implanted IOL was − 1.7 ± 0.9 D based on OKULIX ray tracing software calculation. The achieved spherical refraction at 1 month postoperatively was 0.2 ± 0.2 D. A statistically significant difference was reported between the expected refraction with implanted IOL and the achieved spherical refraction at 1 month postoperatively (1.4 ± 0.7 D), r_s 0.77 $p < 0.001$. Although OKULIX ray tracing software yielded more accurate minus power intraocular lens calculation in extreme myopia, compared to SRK/T formula, yet it still shows tendency toward hyperopia.

Among The possible explanations for the inability to eliminate hyperopic error with minus power IOLs are, although measurement of AL using partial coherence interferometry is more accurate than conventional ultrasound; however, since it assumes a standard value for the refractive index of the eye, it may be a source of error in highly myopic eyes where the vitreous is more liquefied [20].

The IOL constants could be another possible etiology for the hyperopic error. Haigis illustrated how IOL geometry altered the principal lens optical plane, switching sides when the IOL power sign is changed [21]. Thus, IOL constants differ significantly between positive power IOLs and negative power IOLs. Using model calculations, Haigis demonstrated the application of plus power IOL constants for both positive power IOLs and negative power IOLs as a possible etiology for the hyperopic error. In fact, negative diopter IOLs are concave, while positive diopter IOLs are convex. Thus, they should be considered to be two different IOLs requiring separate constants [1, 21]. Abulafia et al. [2] also highlighted the requirement for different constants for plus and minus power IOLs. However, even with optimized constants, IOL power calculation for highly myopic eyes is not as predictable as for emmetropic eyes [22].

Conclusion

Although OKULIX ray tracing software yielded more accurate minus power intraocular lens calculation in extreme myopia, compared to SRK/T formula, yet it still shows tendency toward hyperopia.

Compliance with ethical standards

Conflict of interest The author declares no conflict of interest.

Availability of data and materials Datasets are available in additional supporting files.

Ethics approval and consent to participate All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent to participate in the study was obtained from all individual participants included in the study.

Informed consent Informed consent to publish the results of the study was obtained from all individual participants included in the study.

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