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Axial Length Change in Pseudophakic Eyes Measured by IOLMaster 700

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Purpose: The purpose of this study was to investigate the change in axial length (AL) after cataract surgery measured by swept source optical coherence tomography (IOLMaster 700), and explore ways to eliminate this AL measurement error in pseudophakic eyes.

Methods: Patients with cataract who underwent unilateral phacoemulsification with four types of intraocular lens (IOLs) implantation (Asphina 509M, Tecnis PCB00, enVista MX60, and Acrysof SN60WF) were enrolled. Bilateral AL measurements were performed before and 1 month after cataract surgery utilizing IOLMaster 700. The postoperative AL of the operated eye was evaluated using three different modes (phakic, aphakic, and pseudophakic), and the fellow eye was measured by phakic mode. Associations among the AL change and cataract grade, lens thickness, preoperative AL, or refractive index of IOL were investigated using stepwise multivariate linear regression.

Results: A total of 305 patients with cataract with mean age of 65.97 ± 13.39 years were recruited. The mean postoperative AL was 0.10 mm and 0.21 mm shorter than the pre-operative AL utilizing pseudophakic and phakic modes, respectively ($P < 0.001$). No significant difference was observed between pre-operative and postoperative AL using aphakic mode ($P = 0.264$). There were no significant associations among AL change in pseudophakic eye and cataract grade, lens thickness, pre-operative AL, or refractive index of IOL ($P > 0.05$).

Conclusions: A correction factor of 0.10 mm is suggested to eliminate AL measurement error of IOLMaster 700 in pseudophakic eyes before further improvement of AL measurement accuracy.

Translational Relevance: Our study may help to eliminate the AL measurement error of IOLMaster 700 in pseudophakic eyes.

Introduction

Axial length (AL), one of the most important biometric parameters, is mandatory for accurate calculation of intraocular lens (IOLs) power, and long-term evaluation of ocular development for a special population. The cataract surgical rate and population of pseudophakic eyes have been rapidly increasing, with the successful implementation of VISION 2020 global initiative to eliminate avoidable blindness.[1,2] It is a prerequisite to measure AL precisely in pseudophakic eyes in many scenarios, such as providing one of the essential biometric information in patients who require IOL exchange or a secondary piggyback IOL implantation,[3,4] or monitoring ocular development and refractive status in children or patients with high myopia.[5–8]

However, precise AL measurement in pseudophakic eyes remains a challenge because IOL implantation could influence the propagation speeds of the ultrasound or light wave. AL shortening or increasing after cataract surgery measured by classical ultrasound biometry has been previously reported, and different ultrasound velocities or correction factors ranging from +0.40 mm to −0.80 mm were suggested to be utilized to eliminate this AL difference in pseudophakic eyes.[9–11] Furthermore, AL reduction ranging from

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0.07 mm to 0.19 mm was observed in pseudophakic eyes even using optical biometry,[12,13] IOLMaster 500, which utilizes partial coherence interferometry (PCI) with a wavelength of 780 nm and has applied a built-in pseudophakic correction factor based on IOL material.[14]

The swept source optical coherence tomography (OCT) based biometry, IOLMaster 700 (Carl Zeiss, Germany), measures AL with a wavelength of 1055 nm and provides retinal OCT images to check the fixation status. IOLMaster 700 has been proven to have a higher AL detection rate compared with IOLMaster 500, especially in patients with posterior subcapsular and dense nuclear cataracts.[15] However, the AL measurement performance of IOLMaster 700 in pseudophakic eyes remains unknown.

The aim of this study was to evaluate the AL changes after cataract surgery measured by IOLMaster 700, and explore ways to eliminate this AL measurement error in pseudophakic eyes.

Methods

This cross-sectional study was conducted from August 1, 2020, to September 30, 2020, at Zhongshan Ophthalmic Center (ZOC), Sun Yat-sen University, Guangzhou, China. The study was under the approval of the Institutional Review Board of ZOC (2019KYPJ033). All procedures were in compliance with the Declaration of Helsinki. All participants included in the study signed an informed consent.

Selection Criteria

The inclusion criteria included: (1) patients with cataract who underwent uneventful unilateral phacoemulsification; (2) in the bag implantation of four types of IOL with different refractive indices, including Asphina 509M (Carl Zeiss, Germany), Tecnis PCB00 (Abbott Medical Optics, USA), enVista MX60 (Bausch & Lomb, USA), and Acrysof SN60WF (Alcon Laboratories, USA); and (3) pre-operative biometry performed by IOLMaster 700.

The exclusion criteria included: (1) ocular comorbidities including keratopathy, glaucoma, uveitis, lens dislocation, or ocular trauma; (2) previous corneal refractive surgery or any intraocular surgical history; and (3) incomplete follow-up information.

Ocular Examinations and Data Collection

All participants underwent comprehensively preoperative ocular examinations. The biometric parameters were obtained by IOLMaster 700, including keratometry, AL, anterior chamber depth (ACD) measured from cornea epithelium to lens, lens thickness (LT), and corneal diameter (CD). The measurements were assessed by the color of light in the quality indicator of IOLMaster 700. Only values from successful measurements (indicated by a green light) were included. If the light was yellow or red, the data were not accepted and the scanning was repeated. The fixation status was checked based on the macular OCT image, and the measurement was repeated if the image did not display the fovea.

Two experienced ophthalmologists (authors J.Q.Z. and X.H.T.) graded the lens opacity based on slit lamp anterior-segment photography with a dilated pupil over 6 mm in diameter using the Lens Opacities Classification System III (LOCS III).[16] A senior cataract specialist (author L.X.L.) made the final decision when discrepancy existed. Cataract stage was evaluated by calculating the sum of the cortical grade, nuclear color and opalescence grade, and subcapsular grade.

One month after surgery, all participants underwent AL measurement using IOLMaster 700 with 3 modes (phakic, aphakic, and pseudophakic) in the operated eye, and with phakic mode in the fellow eye. The AL change was evaluated using the following equator: AL change = postoperative AL and pre-operative AL.

Statistical Analysis

The best corrected visual acuity (BCVA) was recorded in decimal units and converted to logarithm of the minimum angle resolution (logMAR) units for the statistical analyses. Continuous variables were presented as mean ± standard deviation (SD), and the Kolmogorov-Smirnov test was assessed to determine whether the variables were normally distributed. The AL difference between pre and post cataract surgery was evaluated using the paired *t*-test, and agreement between pre- and postoperative AL was assessed by Bland-Altman plot and R^2 analysis. The AL changes of four types of IOLs were compared using analysis of variance (ANOVA). Multivariable linear regression models were used to determine the associations between the AL change in pseudophakic eyes and cataract grade, lens thickness, preoperative AL length, or IOL refractive index. All statistical analyses were performed using SPSS 24.0 (IBM, USA). A value of $P < 0.05$ was considered to have statistical significance.

Table 1. Demographic and Clinical Characteristics of Participants

Parameter	Operated Eye		Fellow Eye
No. of eyes		305	
Age, year		65.97 ± 13.39	
Male, *n* (%)		110 (36.07)	
Diabetes, *n* (%)		54 (17.70)	
Hypertension, *n* (%)		119 (39.02)	
Pre-operative BCVA, logMAR	1.00 ± 0.59		0.47 ± 0.40
Axial length, mm	24.27 ± 2.47		24.00 ± 1.85
Corneal astigmatism, D	0.46 ± 1.22		0.60 ± 0.93
ACD, mm	3.10 ± 0.49		3.08 ± 0.43
LT, mm	4.51 ± 0.52		4.55 ± 0.52
CD, mm	11.79 ± 0.49		11.85 ± 0.48

BCVA = best corrected vision acuity; logMAR = logarithm of the minimum angle resolution; mm = millimeter; D = diopter; ACD = anterior chamber depth, as measured from corneal epithelium to lens; LT = lens thickness; CD = cornea diameter.

Scatter plots and Bland-Altman plots were plotted with GraphPad Prism 6 (GraphPad Software, USA).

Results

A total of 305 patients (110 men and 195 women) with a mean age of 65.97 ± 13.39 years were recruited in this study. Table 1 summarizes the pre-operative demographics and clinical characteristics of the included eyes. The mean pre-operative AL was 24.27 ± 2.47 mm in the operated eyes, and 24.00 ± 1.85 mm in the fellow eyes. There were 45 eyes with AL less than 22 mm, 204 eyes with AL between 22 mm and 26 mm, and 56 eyes with AL longer than 26 mm. The mean preoperative BCVA was 1.00 ± 0.59 logMAR in the operated eyes, and 0.47 ± 0.40 logMAR in the fellow eyes. Fifty-four patients (17.70%) suffered from diabetes mellitus, and 119 patients (39.02%) reported having hypertension.

The pre-operative and postoperative AL difference measured by three modes in the operated eyes and by phakic mode in the fellow eyes are displayed in Table 2. The agreement between pre- and postoperative AL in the operate eyes is displayed in Figure 1 and Figure 2. Although a highly significant correlation was observed between pre- and postoperative AL in

Table 2. Axial Length Change After Cataract Surgery Measured by IOLMaster 700

	Operated Eye						
Parameter	Total	509M	PCB00	MX60	SN60WF	*P* Value[b]	Fellow Eye
No. of eyes	305	51	76	83	95		305
Pre-operative AL, mm	24.27 ± 2.47	24.57 ± 2.36	24.15 ± 2.35	24.69 ± 2.84	23.84 ± 2.22		24.00 ± 1.85
Postoperative AL, mm							
Pseudophakic mode	24.17 ± 2.47	24.47 ± 2.32	24.03 ± 2.36	24.59 ± 2.86	23.76 ± 2.22		
AL change[c]	−0.10 ± 0.09	−0.11 ± 0.08	−0.12 ± 0.08	−0.10 ± 0.12	−0.08 ± 0.07	0.107	
P value[a]	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*		
Phakic mode	24.06 ± 2.47	23.38 ± 2.36	23.92 ± 2.35	24.48 ± 2.84	23.65 ± 2.23		24.01 ± 1.85
AL change[c]	−0.21 ± 0.11	−0.20 ± 0.05	−0.23 ± 0.11	−0.22 ± 0.17	−0.18 ± 0.07	0.110	0.002 ± 0.03
P value[a]	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*		0.305
Aphakic mode	24.28 ± 2.47	24.57 ± 2.29	24.14 ± 2.36	24.70 ± 2.86	23.86 ± 2.22		
AL change[c]	−0.01 ± 0.10	−0.001 ± 0.13	0.01 ± 0.08	0.01 ± 0.11	0.03 ± 0.07	0.107	
P value[a]	0.264	0.993	0.123	0.541	<0.001*		

AL = axial length; mm = millimeter.

*Statistical significance ($P < 0.05$).

[a] Paired *t*-test.

[b] Analysis of variance (ANOVA).

[c] AL change = postoperative AL – pre-operative AL.

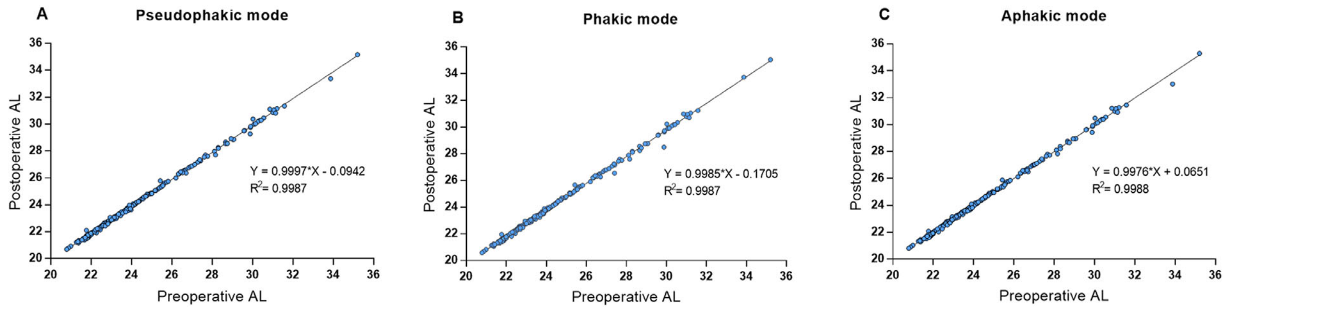

Figure 1. Scatterplots indicating the correlation between preoperative and postoperative axial length (AL) of three measurement modes: (A) pseudophakic mode; (B) phakic mode; and (C) aphakic mode.

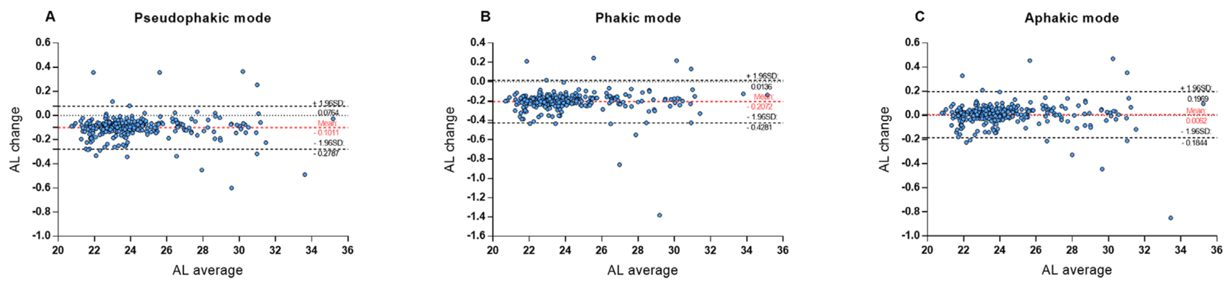

Figure 2. Bland-Altman plots indicating the agreement between preoperative and postoperative axial length (AL) of three measurement modes: (A) pseudophakic mode; (B) phakic mode; and (C) aphakic mode.

Table 3. Correction Factor of Axial Length Measurement for Pseudophakic Eye in Subgroups

IOL Type	Manufacturer	Material	Haptics	Refractive Index	Correction Factor Δ (mm)
509M	Carl Zeiss Meditec	Hydrophilic acrylic (25 %) with hydrophobic surface properties	Plate	1.46	0.11
PCB00	Abbott Medical Optics	Hydrophobic acrylic	C-loop	1.47	0.12
MX60	Bausch & Lomb	Hydrophobic acrylic	C-loop	1.53	0.10
SN60WF	Alcon	Hydrophobic acrylic	C-loop	1.55	0.08

IOL = intraocular lens.

all three measurement modes (r = 0.999, $P < 0.001$), the mean postoperative AL was 0.10 mm and 0.21 mm shorter than the preoperative AL utilizing pseudophakic and phakic mode ($P < 0.001$) in the operated eyes. No significant AL change was observed measured by aphakic mode in the operated eyes (-0.01 ± 0.10 mm, $P = 0.264$), and by phakic mode in the fellow eyes (0.002 ± 0.03 mm, $P = 0.305$).

Four types of IOLs, Asphina 509M, Tecnis PCB00, enVista MX60, and Acrysof SN60WF, were implanted in 51, 76, 83, and 95 eyes, respectively. The mean AL changes measured by pseudophakic mode ranged from -0.08 to -0.12 mm in 4 subgroups ($P < 0.001$; see Table 2). There were also significant AL changes ranging from -0.18 to -0.23 mm ($P < 0.001$) utilizing phakic mode in 4 subgroups. Although no significant AL change was observed utilizing aphakic mode in total ($P = 0.264$), a minor but statistically significant AL change (0.03 mm, $P < 0.001$) was found in the SN60WF IOL group.

Table 3 displays the correction factors Δ for pseudophakic eyes to obtain true postoperative axial lengths (AL_{true}) from AL results measured in the pseudophakic model ($AL_{pseudophakic}$) of the IOLMaster 700 according to $AL_{true} = AL_{pseudophakic} + \Delta$. The correction factor ranged from 0.08 to 0.12 mm in different types of IOLs, whereas no statistically significant difference was observed among 4 subgroups ($P = 0.365$).

The stepwise multivariate linear regression of potential associated factors and AL change measured by pseudophakic mode are shown in the

Supplementary Table. There were no statistically significant associations among AL change and cataract grade, lens thickness, pre-operative AL, or refractive index of IOL ($P > 0.05$).

Discussion

As far as we know, there are no published studies regarding the AL change in pseudophakic eyes based on swept source OCT-based biometry (IOLMaster 700). Our study demonstrated that AL of pseudophakic eyes remained a significant reduction ranging from 0.08 to 0.12 mm compared with pre-operative AL, even if the IOLMaster 700 was utilized. However, there was no significant AL change utilizing aphakic mode in pseudophakic eyes. No correlation was observed among the AL change and cataract grade, lens thickness, pre-operative AL, and refractive index of IOL.

The underlying cause of AL change after cataract surgery is controversial. There are two hypotheses to explain the AL difference. One could be that the reduction in the volume of the eye after natural lens extraction could flatten the corneal curvature and consequently reduce the AL.[17] However, the fact that no significant changes in corneal curvature after cataract surgery was observed in previous studies did not support this hypothesis.[17,18] At present, most researchers assumed the AL remained the same after cataract surgery, and the AL difference might result from the pre-operative or postoperative AL measurement error.[12,13,17,19–21]

Some authors speculated the AL change was related to the group refractive index used for the crystalline lens, which varied with cataract grade and led to the incorrect measurement of pre-operative AL.[13,21] In addition, AL change could be compensated by changing the pre-operative refractive index of the lens.[11,19] However, we did not find the correlation between cataract grade and the AL change, which was consistent with García López's study.[12] García López et al. reported that the AL change increased with the elongation of pre-operative AL. They assumed that the AL change was due to the poor reproducibility of IOLMaster (version 3) in extremely long eyes.[12] This correlation was not observed in the present study, and it perhaps was associated with the fixation examination of IOLmaster 700 and its high accuracy in AL measurement in long eyes.[22] Additionally, recent studies have proven that segmented-AL measurement using different refractive indices for each ocular medium was more accurate compared with traditional AL measurement using a single group refractive index.[23,24] Nonetheless, the difference between the pre-operatively measured AL and the real AL is being extremely reduced with the advancement in biometric instruments.

Most researchers considered the AL difference was due to the change in AL measurement mode from phakic to pseudophakic, which used inaccurate correction factor and was not sufficient to obtain the real AL. Haigis proposed pseudophakic correction factors based on IOL materials, which now have been built into the commercial version of the Zeiss IOLMaster.[14,17] However, the AL of pseudophakic eyes remained a significant reduction compared with pre-operative AL, both in IOLMaster 500 and IOLMaster 700. We found that the AL change showed a downward trend as the increasing of refractive index of IOL, but no correlation was discovered between them. Additionally, Chang et al. observed no significant difference in AL changes among IOLs with different chromophores.[3] Individual adjustment on IOLs with different refractive indices might help to measure AL in pseudophakic eyes more accurately in the future, but their impact on AL changes is relatively weak according to our study.

We found that the AL difference measured by aphakic mode of IOLMaster 700 was not statistically significant, which is consistent with a previous study based on IOLMaster 500.[17] Given that all IOL power calculation formulas are based on pre-operative biometric parameters, it is reasonable to assume that preoperative AL is closer to real AL. According to the present study, we suggest that a correction factor of 0.10 mm should be used for pseudophakic AL measurement in IOLMaster 700 before further improvement of AL measurement accuracy.

The results of the present study should be assessed within the context of its limitations. First, only four types of IOLs were included in the study. Whether the results can be applicable to other IOLs with different materials needs further studies. Second, the LOCS III lens grading system was subjective, and depended on graders' experience.[25] The swept source anterior segment OCT can evaluate the lens nuclear density objectively and quantitatively,[26] which might be an effective tool to evaluate the relationship between cataract grade and AL change in future studies.

Conclusions

This study demonstrated that the AL of pseudophakic eyes remained a significant reduction measured by IOLMaster 700, and the use of a correction factor of 0.10 mm can eliminate this AL measurement error in pseudophakic eyes. This finding is helpful to guide the accurate biometry for patients who need IOL exchange or a secondary piggyback IOL, and benefit monitoring AL and refractive development of special population after cataract surgery.

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References

1. Lansingh VC, Carter MJ, Martens M. Global cost-effectiveness of cataract surgery. *Ophthalmology*. 2007;114(9):1670–1678.
2. Pizzarello L, Abiose A, Ffytche T, et al. VISION 2020: The Right to Sight: a global initiative to eliminate avoidable blindness. *Arch Ophthalmol*. 2004;122(4):615–620.
3. Chang SW, Yu CY, Chen DP. Comparison of intraocular lens power calculation by the IOLMaster in phakic and eyes with hydrophobic acrylic lenses. *Ophthalmology*. 2009;116(7):1336–1342.
4. Abdalla Elsayed MEA, Ahmad K, Al-Abdullah AA, et al. Incidence of intraocular lens exchange after cataract surgery. *Sci Rep*. 2019;9(1):12877.
5. Tartarella MB, Carani JC, Scarpi MJ. The change in axial length in the pseudophakic eye compared to the unoperated fellow eye in children with bilateral cataracts. *J AAPOS*. 2014;18(2):173–177.
6. Leiba H, Springer A, Pollack A. Ocular axial length changes in pseudophakic children after traumatic and congenital cataract surgery. *J AAPOS*. 2006;10(5):460–463.
7. Seven E, Tekin S, Batur M, Artuç T, Yaşar T. Evaluation of changes in axial length after congenital cataract surgery. *J Cataract Refract Surg*. 2019;45(4):470–474.
8. Lee MW, Lee SE, Lim HB, Kim JY. Longitudinal changes in axial length in high myopia: a 4-year prospective study. *Br J Ophthalmol*. 2020;104(5):600–603.
9. Holladay JT, Prager TC. Accurate ultrasonic biometry in pseudophakia. *Am J Ophthalmol*. 1989;107(2):189–190.
10. Freudiger H, Artaria L, Niesel P. Influence of intraocular lenses on ultrasound axial length measurement: in vitro and in vivo studies. *J Am Intraocul Implant Soc*. 1984;10(1):29–34.
11. Naeser K, Naeser A, Boberg-Ans J, Bargum R. Axial length following implantation of posterior chamber lenses. *J Cataract Refract Surg*. 1989;15(6):673–675.
12. López CG, López VG, Juan V, Martin R. Change in axial length pre and post cataract surgery measured with IOL Master. *J Clin Exp Ophthalmol*. 2016;7(2):544.
13. Prinz A, Neumayer T, Buehl W, et al. Influence of severity of nuclear cataract on optical biometry. *J Cataract Refract Surg*. 2006;32(7):1161–1165.
14. Haigis W. Pseudophakic correction factors for optical biometry. *Graefe's Arch Clin Exp Ophthalmol*. 2001;239(8):589–598.
15. Akman A, Asena L, Güngör SG. Evaluation and comparison of the new swept source OCT-based IOLMaster 700 with the IOLMaster 500. *Br J Ophthalmol*. 2016;100(9):1201–1205.
16. Siik S, Chylack LT, Friend J, et al. Lens autofluorescence and light scatter in relation to the lens opacities classification system, LOCS III. *Acta Ophthalmol Scand*. 1999;77(5):509–514.
17. De Bernardo M, Salerno G, Cornetta P, Rosa N. Axial length shortening after cataract surgery: new approach to solve the question. *Transl Vis Sci Technol*. 2018;7(6):34.
18. Klijn S, Sicam VA, Reus NJ. Long-term changes in intraocular lens position and corneal curvature after cataract surgery and their effect on refraction. *J Cataract Refract Surg*. 2016;42(1):35–43.
19. Olsen T, Thorwest M. Calibration of axial length measurements with the Zeiss IOLMaster. *J Cataract Refract Surg*. 2005;31(7):1345–1350.
20. Rajan MS, Keilhorn I, Bell JA. Partial coherence laser interferometry vs conventional ultrasound biometry in intraocular lens power calculations. *Eye (Lond)*. 2002;16(5):552–556.
21. Drexler W, Findl O, Menapace R, et al. Partial coherence interferometry: a novel approach to

biometry in cataract surgery. *Am J Ophthalmol*. 1998;126(4):524–534.

22. Yang JY, Kim HK, Kim SS. Axial length measurements: Comparison of a new swept-source optical coherence tomography–based biometer and partial coherence interferometry in myopia. *J Cataract Refract Surg*. 2017;43(3):328–332.
23. Wang L, Cao D, Weikert MP, Koch DD. Calculation of axial length using a single group refractive index versus using different refractive indices for each ocular segment: theoretical study and refractive outcomes. *Ophthalmology*. 2019;126(5):663–670.
24. Cooke DL, Cooke TL. A comparison of two methods to calculate axial length. *J Cataract Refract Surg*. 2019;45(3):284–292.
25. Tan AC, Loon SC, Choi H, Thean L. Lens Opacities Classification System III: cataract grading variability between junior and senior staff at a Singapore hospital. *J Cataract Refract Surg*. 2008;34(11):1948–1952.
26. Panthier C, Burgos J, Rouger H, Saad A, Gatinel D. New objective lens density quantification method using swept-source optical coherence tomography technology: Comparison with existing methods. *J Cataract Refract Surg*. 2017;43(12):1575–1581.