

# Preoperative biometric measurements with anterior segment optical coherence tomography and prediction of postoperative intraocular lens position

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## Abstract

The purpose of this study is to evaluate the biometric parameters of crystalline lens components and to find effective factors for predicting postoperative intraocular lens (IOL) position. This retrospective study included 97 eyes from 97 patients with a mean age of  $63.00 \pm 12.38$  (SD) years. The biometric measurements were performed by means of a 3-dimensional optical coherence tomography (3D-OCT) device. Specifically, anterior chamber depth (ACD), aqueous depth (AD), lens thickness (LT), lens meridian parameter (LMP), white-to-white diameters (WTW), anterior segment length (ASL), the anterior part of lens (aLT), and the posterior part of lens (pLT) were measured. Additionally, axial length (AL) and corneal radius (CR) were measured by the partial coherence interferometry. Ninety-seven eyes were divided into thin lens group (LT < 4.5 mm) and thick lens group (LT  $\geq$  4.5 mm). The differences between the above two groups were also analyzed. Postoperative IOL position was measured by 3D-OCT at 3 months postoperatively and regression formulas for predicting postoperative IOL position were developed by various combinations of preoperative factors. As lens thickened, ACD and AD became shallow (all  $P < .001$ ). AD, ACD, ASL, aLT, and pLT showed statistically significant differences between two subgroups classified on the basis of LT (all  $P < .001$ ). Meanwhile, the value obtained by subtracting aLT from pLT did not show any association with the other biometric measurements. The combination of ACD, aLT, pLT, AL, CR, and WTW showed the highest correlation with postoperative IOL position ( $R^2 = 0.536$ ,  $P < .001$ ). In conclusion, pLT–aLT was an independent factor not affected by any other variables and did not show significant difference between thin lens group and thick lens group. The subdivision of the lens structure using 3D-OCT helps to predict postoperative IOL position.

**Abbreviations:** 3D-OCT = 3-dimensional optical coherence tomography, ACD = anterior chamber depth, AD = aqueous depth, AL = axial length, aLT = anterior part of lens, AND = antenuclear distance, AS-OCT = anterior segment-optical coherence tomography, ASL = anterior segment length, CR = corneal radius, FLACS = femtosecond laser-assisted cataract surgery, hWTW = horizontal white-to-white diameters, IOL = intraocular lens, LMP = lens meridian parameter, LT = lens thickness, NT = nuclear thickness, OCT = optical coherence tomography, PCI = partial coherence interferometry, pLT = posterior part of lens, WTW = white-to-white diameters.

**Keywords:** cataract, intraocular lens, optical coherence tomography

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## 1. Introduction

Optical coherence tomography (OCT) is a non-invasive, high-resolution imaging technology that provides in vivo cross-sectional images of the ocular structures.<sup>[1,2]</sup> The use of OCT is progressively increasing as it provides accurate measures and is fast, safe, and comfortable for patients and operators. Recent studies have demonstrated that the application of anterior segment-optical coherence tomography (AS-OCT) is useful in preoperative planning for cataract surgery, including the delineation of the anterior chamber structure.<sup>[3–6]</sup>

In the last years, the interest in the thickness of the crystalline lens has grown. Preoperative anterior chamber depth (ACD) has shown a positive correlation with axial length (AL)<sup>[7–12]</sup> and a negative correlation with lens thickness (LT). LT increases with the aging process and formation of cataract. Jonas et al<sup>[13]</sup> concluded that the development of cataracts provokes a slight forward movement of the center of the crystalline lens. Furthermore, LT is considered in newly developed intraocular lens (IOL) calculation formulas such as the Barret-Universal II,<sup>[14]</sup> Holladay 2,<sup>[14]</sup> and Olsen<sup>[15]</sup> formulas.

In recent years, research results have been published in which the thickness of the cataractous lens is segmented by OCT to

predict postoperative IOL position. Shammass formula<sup>[16]</sup> introduced the combination of antenuclear distance (AND) and nuclear thickness (NT) measured by optical low-coherence reflectometry. Goto et al<sup>[17]</sup> also found that angle-to-angle depth measured by AS-OCT was a good predictor of postoperative ACD.

The detailed knowledge about the shape and thickness of the crystalline lens gets very important when femtosecond laser-assisted cataract surgery (FLACS) is considered. In fact, some advanced FLACS platforms include OCT based systems to identify and measure the lens structures. In particular, the Catalys Precision Laser System includes 3-dimensional OCT (3D-OCT) and measures axial and sagittal sectional scanned images. The scanned capsule provided by the built-in algorithm of the laser system is an imaginary line of the crystalline lens seen from the anterior and posterior capsule. A previous study showed that the scanned capsule center from preoperative crystalline lens was closest to the postoperative IOL center on the lens equatorial plane and thus, the best landmark for the crystalline lens was the scanned capsule center by Catalys 3D-OCT.<sup>[18]</sup>

The aim of this study is to evaluate the biometric parameters of the anterior segment structures of the eye using Catalys 3D-OCT and to verify that the measurement provided by 3D-OCT will be a better predictor for postoperative IOL position.

## 2. Methods

This retrospective study includes 97 eyes from 97 patients who were scheduled for FLACS from September 2016 to March 2017. Informed consent was obtained from all patients before study start, and the study adhered to the tenets of the Declaration of Helsinki for the use of human participants in biomedical research. The Institutional Review Board (IRB # KC13DISI0534) for Human Studies, Seoul St. Mary Hospital (Seoul, Republic of Korea), approved this study.

The exclusion criteria included previous ocular surgery, corneal diseases, pseudoexfoliation, insufficient pupil dilation to interfere with laser emission, zonular weakness, corneal astigmatism >1.00 diopters, glaucoma, macular disease, and amblyopia. Eyes in which laser pretreatment could not be completed because of unintentional loss of suction were also excluded.

After sufficient pupillary dilation was confirmed, the measurements were performed with the Catalys Precision Laser System (Abbott Medical Optics, Abbott Laboratories Inc., Abbott Park, IL). All procedures were performed under topical anesthesia with 0.5% proparacaine hydrochloride (Alcaine, Alcon Laboratories, Fort Worth, TX).

Figure 1 shows the biometric measurements provided by the 3D-OCT in Catalys Precision Laser System. 3D-OCT shows the scanned capsule which is an imaginary line of the crystalline lens seen from the anterior and posterior capsule, provided by the built-in algorithm of the laser system. The equator plane is a straight line connecting both ends of the imaginary lines. It measures ACD (the distance along the visual axis between the corneal epithelium and the anterior lens surface), aqueous depth (AD: as the distance from the corneal endothelium to the lens), LT, vertical/horizontal white-to-white diameters (WTW), and lens meridian parameter (LMP). The LMP is defined as the length from the anterior surface of central cornea to the crystalline lens equatorial plane. The equatorial lens plane was determined by two meridians of lens equator, which was estimated by the

imaginary line connecting the anterior and posterior capsule surface imaged with 3D-OCT in femtosecond laser machine for cataract surgery. The anterior segment length (ASL) was calculated by adding LT to ACD and we evaluated ASL. The anterior part of crystalline lens (aLT), the posterior part of crystalline lens (pLT), the ratio of posterior to anterior part (pLT/aLT) and the difference between anterior and posterior part (pLT – aLT) were calculated.

The AL and mean corneal radius (CR) was measured with an IOL Master optical biometry (version 5, Carl Zeiss Meditec, Germany). The changes in biometric measurements by 3D-OCT according to AL by partial coherence interferometry (PCI) and patient age were analyzed. We also investigated the relationship between LT and other biometric measurements. To understand the morphological characteristics of the crystalline lens more precisely, we analyzed the correlation between pLT/aLT or pLT – aLT value and other measurements.

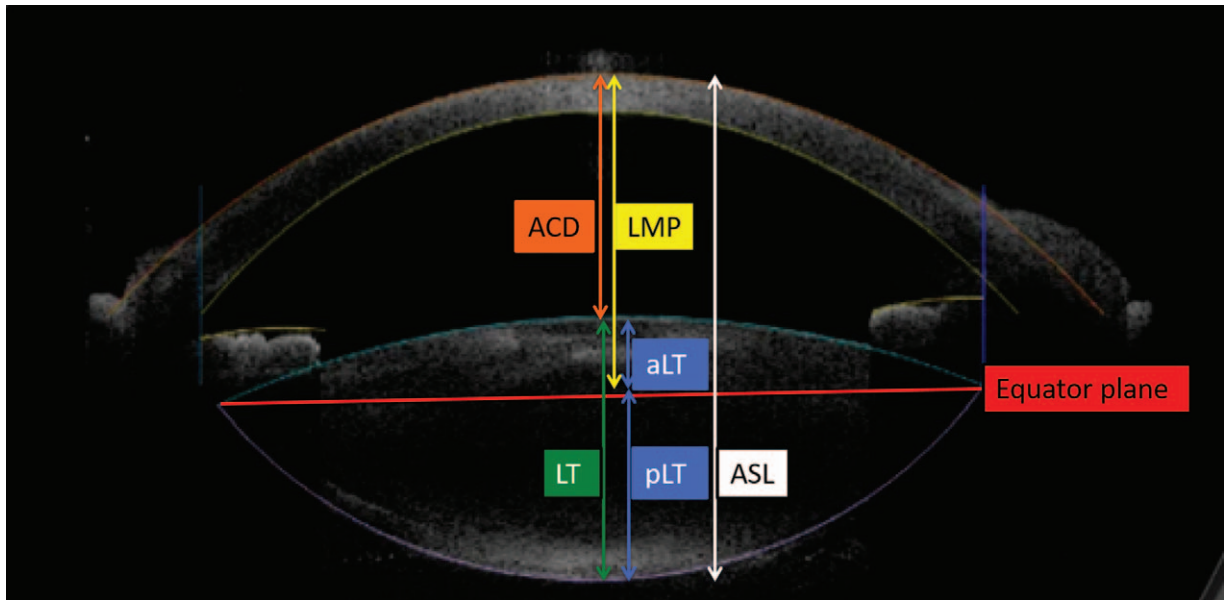
After completion of the laser emission procedure, the vacuum interface was removed and the patient was transported to a day-surgery operation room and cataract surgery was performed by one surgeon (CKJ). All of the cataract surgeries were performed using the Ozil torsional hand piece with the Infiniti Vision System (Alcon). Following phacoemulsification, 1 type of IOL (ZCB00, Johnson & Johnson) was inserted into the capsular bag. No intraoperative complications occurred. Figure 2 shows Postoperative IOL position or postoperative ACD. It was measured with the same 3D-OCT at 3 months postoperatively and defined as the distance along the visual axis between the corneal epithelium and the anterior surface of IOL center. The disposable vacuum interface was fixed to the globe using a suction ring and the laser aperture was engaged with the vacuum interface-globe complex.

Postoperative ACD was measured after complete connection. Preoperative measurements were divided into two groups; external measurements (AL, CR, horizontal WTW), internal measurements (ACD [by PCI], ACD [by 3D-OCT], LMP, ASL, LT, aLT, and pLT). We developed various combinations of regression equations based on preoperative biometric measurements for predicting postoperative ACD.

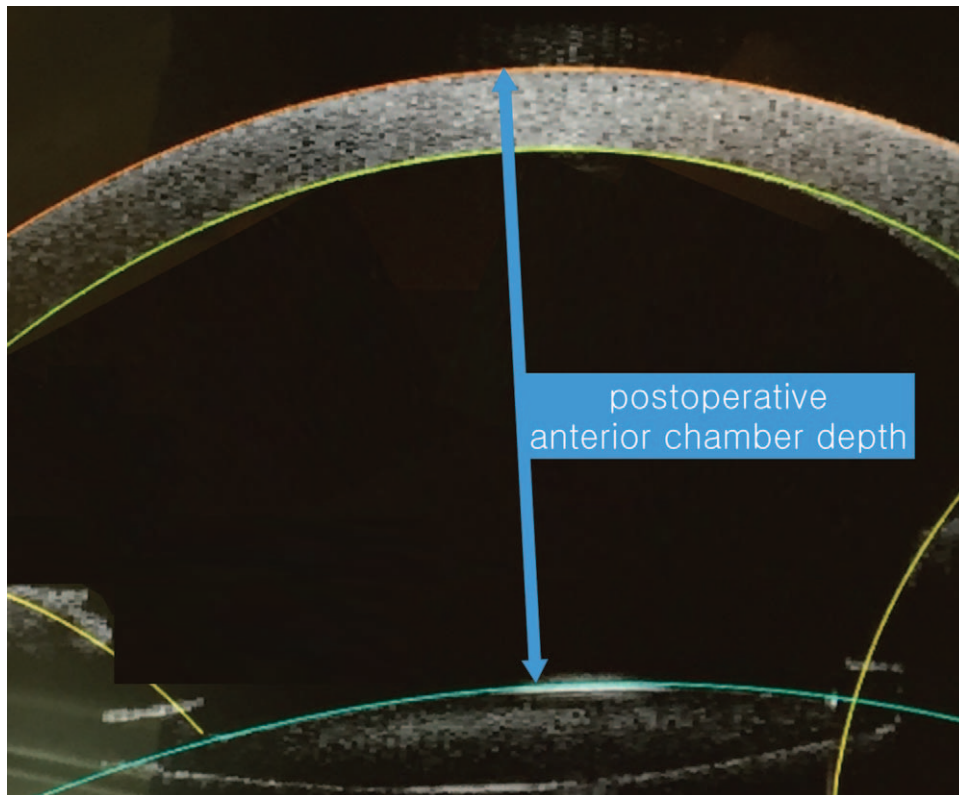
Statistical analysis was performed using SPSS statistical software (version 20.0, SPSS, Inc., Chicago, IL). The Pearson correlation coefficient ( $r$ ) was used to evaluate each correlation statistically. Ninety-seven eyes were divided into thin lens group ( $LT < 4.5$  mm) and thick lens group ( $LT \geq 4.5$  mm) and we determined the significance of the biometric measurements between two subgroups according to LT with the Mann-Whitney  $U$  test. Multiple linear regression was used to determine which combination was most accurate in predicting postoperative ACD. The level of significance was set at 0.05.

## 3. Results

Mean patient age was  $63.00 \pm 12.38$  (SD) years (range: 38–87 years); 59 (60.1%) were women and 38 (39.9%) were men. Table 1 shows the biometric measurements by 3D-OCT and AL by PCI. The changes in biometric measurements with age, AL, and LT are given in Table 2. AL was negatively correlated with age ( $r = -0.316$ ,  $P < .001$ ). On the contrary, age was negatively correlated with AD, ACD, LMP, horizontal/vertical WTW, and positively correlated with LT (all  $P < .001$ ). ASL did not show statistical correlation with age or AL ( $r = -0.060$ ,  $P = .560$ ;  $r = 0.179$ ,  $P = .079$ ). As the crystalline lens thickened, AD and ACD became shallow (all  $P < .001$ ). Correlation coefficients with the



**Figure 1.** Biometric measurements provided by 3D-OCT. 3D-OCT shows the scanned capsule, which is an imaginary line of the crystalline lens seen from the anterior and posterior capsule, provided by the built-in algorithm of the laser system. The equator plane is a straight line connecting both ends of the imaginary lines. Anterior chamber depth (ACD) is determined by calculating the distance along the visual axis between the corneal epithelium and the anterior lens surface by OCT while aqueous depth (AD) is defined as the distance from the corneal endothelium to the lens. Lens meridian parameter (LMP) is the vertical distance from the corneal apex to the equator plane of the crystalline lens. The anterior segment length (ASL) was calculated by adding LT to ACD. The crystalline lens was analyzed by dividing it into anterior part (aLT) and posterior part (pLT), bordered by the equator plane.



**Figure 2.** Postoperative intraocular lens (IOL) position or anterior chamber depth.

**Table 1**  
Demographic data.

	Mean	Min.	Max.
Age	63.00 ± 12.38	38	87
Sex (female)	59 (60.1%)		
AD	2.84 ± 0.48	1.5	4.5
ACD	3.40 ± 0.49	2.1	5.0
LMP	4.90 ± 0.39	4.0	6.7
LT	4.50 ± 0.47	3.4	5.6
ASL	7.89 ± 0.42	6.9	9.8
aLT	1.51 ± 0.28	0.9	2.3
pLT	2.99 ± 0.29	2.3	3.8
pLT/aLT	2.04 ± 0.40	1.22	3.50
pLT – aLT	1.47 ± 0.34	0.50	2.50
Vertical WTW	11.00 ± 0.40	10.1	11.9
Horizontal WTW	11.25 ± 0.41	10.3	12.3
Axial length (by PCI)	24.25 ± 1.93	21.07	31.93

ACD=anterior chamber depth, AD=aqueous depth, aLT=anterior part of lens, ASL=anterior segment length, LMP=lens meridian parameter, LT=lens thickness, PCI=partial coherence interferometry, pLT=posterior part of lens, WTW=white-to-white diameters.

anterior and posterior part of the lens were 0.806 and 0.816 (all  $P=.000$ ), respectively. ASL was positively correlated with LT ( $r=0.404$ ,  $P<.001$ ).

Table 3 shows the measurements of the two subgroups according to the LT. AD, ACD, ASL, anterior and posterior part of the lens showed statistically significant differences between subgroups with regard to LT (all  $P<.001$ ). The pLT/aLT ratio was different between the two subgroups, with the thicker lens showing a lower pLT/aLT ratio. In contrast, the thicker lens group did not show statistically significant differences compared to the thinner lens group regarding LMP, pLT – aLT, as well as horizontal and vertical WTW diameters ( $P=.399$ ,  $.826$ ,  $.236$ , and  $.246$ , respectively).

Table 4 shows that the pLT/aLT ratio was positively correlated with AD and ACD ( $r=0.400$ ,  $P<.001$ ;  $r=0.412$ ,  $P<.001$ ) and negatively correlated with LT and the anterior part of the lens ( $r=-0.404$ ,  $P<.001$ ;  $r=-0.843$ ,  $P<.001$ ). The pLT – aLT did not show any association with the other biometric measurements.

Mean postoperative ACD was 5.02 mm (standard deviation; 0.25 mm) and multiple linear regression equations for predicting

**Table 3**  
A total of 97 eyes were stratified by lens thickness (LT).

	<4.5 mm	≥4.5 mm	$P^*$
Number of eyes	49	48	
AD	3.07 ± 0.35	2.64 ± 0.50	<.001
ACD	3.62 ± 0.36	3.18 ± 0.50	<.001
LMP	4.94 ± 0.28	4.87 ± 0.46	.399
LT	4.10 ± 0.25	4.86 ± 0.29	<.001
ASL	7.72 ± 0.28	8.04 ± 0.48	<.001
aLT	1.32 ± 0.20	1.69 ± 0.23	<.001
pLT	2.78 ± 0.18	3.17 ± 0.25	<.001
pLT/aLT ratio	2.16 ± 0.38	1.92 ± 0.37	.002
pLT – aLT	1.47 ± 0.28	1.48 ± 0.38	.826
Vertical WTW	11.05 ± 0.35	10.96 ± 0.44	.246
Horizontal WTW	11.30 ± 0.36	11.21 ± 0.44	.236
Axial length	25.05 ± 2.21	23.54 ± 1.29	<.001
Age	58.47 ± 12.07	67.36 ± 11.01	<.001

ACD=anterior chamber depth, AD=aqueous depth, aLT=anterior part of lens thickness, ASL=anterior segment length, LMP=lens meridian parameter, pLT=posterior part of lens thickness, WTW=corneal diameter.

\*  $P$  value by Mann–Whitney  $U$  test.

postoperative IOL position are listed in Table 5. All of the equations statistically significant (all  $P<.001$ ) while, the results of regression equations adopting LMP as a variable showed greater value of  $R^2$  than those when ACD was included as a variable. In addition, when the two internal variables were used, the combination of LMP and pLT was more predictive than the combination of ACD and LT. The best results were obtained when three internal variables (ACD by 3D-OCT, aLT, and pLT) were used ( $R^2=0.470$  for ACD by 3D-OCT, aLT, pLT, and AL;  $0.510$  for ACD by 3D-OCT, aLT, pLT, AL, and CR;  $0.536$  for ACD by 3D-OCT, aLT, pLT, AL, CR, and horizontal WTW).

#### 4. Discussion

In this study, we evaluated the biometric measurements provided by 3D-OCT and confirmed that the analysis of the LT by the 3D-OCT-based segmentation is helpful in predicting the postoperative lens position. Especially, when the cataractous lens was divided into two parts based on the equator line and analyzed with the ACD, the predictive accuracy was the highest.

**Table 2**  
Pearson correlation coefficient between each parameter and patient age.

	Correlation with age		Correlation with axial length		Correlation with lens thickness	
	Coefficient	$P^*$	Coefficient	$P^*$	Coefficient	$P^*$
AD	-0.496	<.001	0.508	<.001	-0.606	.000
ACD	-0.500	<.001	0.505	<.001	-0.605	.000
LMP	-0.367	<.001	0.381	<.001	-0.171	.094
LT	0.468	<.001	-0.365	<.001		
ASL	-0.060	.560	0.179	.079	0.404	.000
aLT	0.360	<.001	-0.349	<.001	0.806	.000
pLT	0.400	<.001	-0.245	.016	0.816	.000
pLT/aLT	-0.153	.135	0.224	.028	-0.404	.000
pLT – aLT	0.042	.685	0.083	.416	0.025	.806
Vertical WTW	-0.268	.008	0.312	.002	-0.192	.060
Horizontal WTW	-0.341	.001	0.326	.001	-0.245	.016
Axial length	-0.316	.002			-0.365	<.001

ACD=anterior chamber depth, AD=aqueous depth, aLT=anterior part of lens thickness, ASL=anterior segment length, LMP=lens meridian parameter, LT=lens thickness, pLT=posterior part of lens thickness, WTW=corneal diameter.

\*  $P$  value by Pearson correlation test.



**Table 4**  
**Pearson correlation coefficient between each parameter the ratio of posterior to anterior part (pLT/aLT) and the difference between anterior and posterior part (pLT – aLT).**

	Correlation with pLT/aLT		Correlation with pLT – aLT	
	Coefficient	P*	Coefficient	P*
AD	0.400	<.001	0.186	.068
ACD	0.412	<.001	0.196	.054
LMP	-0.100	.331	-0.173	.091
LT	-0.404	<.001	0.025	.806
ASL	0.030	.771	0.253	.012
aLT	-0.843	<.001	-0.571	<.001
pLT	0.176	.084	0.598	<.001
Vertical WTW	0.149	.144	0.050	.629
Horizontal WTW	0.137	.180	0.021	.838
Age	-0.153	.135	0.042	.685
Axial length	0.224	.028	0.083	.416

ACD= anterior chamber depth, AD=aqueous depth, aLT=anterior part of lens thickness, ASL=anterior segment length, LMP=lens meridian parameter, LT=lens thickness, pLT=posterior part of lens thickness, WTW=corneal diameter.

\* P value by Pearson correlation test.

ACD and LT change with patient age.<sup>[13,18-20]</sup> As shown in prior studies, our study also demonstrated that both AD and ACD decreased with the aging process. In contrast to AD and ACD, the crystalline lens was thicker in older patients. LT showed an inverse relationship with ACD and increased with age. Our findings were similar to the results of a study using optical low-coherence reflectometry with an 820-μm super luminescent diode.<sup>[21]</sup> ASL did not show a statistically significant correlation with age. Koretz et al<sup>[22]</sup> had the same conclusion using Scheimpflug photography and magnetic resonance imaging. Although Dubbelman et al<sup>[23]</sup> and Jonas et al<sup>[13]</sup> demonstrated

controversial results using Scheimpflug photography combined with optical AL measurements and ultrasound, differences in the correlation might be due to the study population.

In contrast, AL showed positive correlations with AD/ACD and a negative correlation with LT, which may have two reasons. First, AL was negatively correlated with age in the population of this study. This association might be explained by genetic and environmental factors<sup>[24]</sup> and is similar to the results of a study of a southern Chinese population.<sup>[25]</sup> The authors relate these results to the rapidly increasing prevalence of myopia in East Asian people.<sup>[26]</sup> Secondly, longer eyes can have thinner lenses. In

**Table 5**  
**Multiple linear regression analysis for predicting postoperative anterior chamber depth after the implantation of one-piece intraocular lens (IOL).**

Internal measurement	External measurement	Equation	Adj. R <sup>2</sup> value
ACD by PCI	AL	2.487 + 0.082AL + 0.183ACD	0.366
	AL, CR	3.631 + 0.120AL + 0.137ACD - 0.247CR	0.415
	AL, CR, hWTW	2.765 + 0.134AL + 0.180hWTW - 0.392CR + 0.014ACD	0.464
ACD by 3D-OCT	AL	2.412 + 0.089AL + 0.151ACD	0.361
	AL, CR	3.576 + 0.126AL + 0.108ACD - 0.249CR	0.410
	AL, CR, hWTW	2.730 + 0.137AL + 0.187hWTW - 0.401CR - 0.004ACD	0.464
LMP	AL	1.583 + 0.087AL + 0.282LMP	0.433
	AL, CR	2.814 + 0.118AL + 0.254LMP - 0.238CR	0.480
	AL, CR, hWTW	2.466 + 0.117AL + 0.117hWTW - 0.320CR + 0.188ASL	0.513
ASL	AL	0.411 + 0.104AL + 0.271ASL	0.418
	AL, CR	1.751 + 0.132AL + 0.240ASL - 0.230CR	0.475
	AL, CR, hWTW	1.504 + 0.125AL + 0.137hWTW - 0.324CR + 0.188ASL	0.510
ACD, aLT	AL	1.529 + 0.089AL + 0.277ACD + 0.295aLT	0.433
	AL, CR	2.700 + 0.127AL + 0.234ACD + 0.297aLT - 0.252CR	0.484
	AL, CR, hWTW	2.117 + 0.136AL + 0.127ACD + 0.260aLT - 0.252CR + 0.153hWTW	0.518
ACD, LT	AL	0.711 + 0.088AL + 0.330ACD + 0.244LT	0.443
	AL, CR	1.846 + 0.120AL + 0.279ACD + 0.225LT - 0.214CR	0.479
	AL, CR, hWTW	1.437 + 0.130AL + 0.165ACD + 0.191LT - 0.340CR + 0.148hWTW	0.511
LMP, pLT	AL	0.600 + 0.088AL + 0.369LMP + 0.179pLT	0.470
	AL, CR	1.838 + 0.115AL + 0.333LMP + 0.157pLT - 0.215CR	0.507
	AL, CR, hWTW	1.628 + 0.115AL + 0.268LMP + 0.141pLT - 0.290CR + 0.103hWTW	0.525
ACD, aLT, pLT	AL	0.574 + 0.089AL + 0.367ACD + 0.376aLT + 0.179pLT	0.470
	AL, CR	1.767 + 0.123AL + 0.315ACD + 0.367aLT + 0.153pLT - 0.227CR	0.510
	AL, CR, hWTW	1.401 + 0.132AL + 0.208ACD + 0.323aLT + 0.129pLT - 0.341CR + 0.135hWTW	0.536

3D-OCT=3-dimensional optical coherence tomography, ACD=anterior chamber depth, AL=axial length, aLT=anterior part of lens thickness, ASL=anterior segment length, CR=corneal radius, hWTW=horizontal white-to-white diameters, LMP=lens meridian parameter, LT=lens thickness, PCI=partial coherence interferometry, pLT=posterior part of lens thickness.

this study, we also measured WTW and analyzed the relationship with the other measurements. Both horizontal and vertical WTW showed a negative correlation with patient age and a positive correlation with AL. WTW was proven to be negatively correlated with corneal steepness,<sup>[27]</sup> and corneal power has been reported to be negatively correlated with AL.<sup>[8,24,28]</sup> Cui et al<sup>[25]</sup> also found that horizontal WTW was significantly correlated with age and AL in 6750 eyes of cataract candidates. This may be attributed to the interaction between the optical elements. Although it was traditionally accepted that the differences in refractive error were caused by differences in AL and the refractive power of cornea and lens was supposed to be constant,<sup>[27]</sup> since the mid-twentieth century many studies demonstrated that coordinated interactions between the ocular components of refraction lead to a higher prevalence of emmetropia than the expected value based only on AL.<sup>[29,30]</sup> Consequently, a longer eye has a less powerful lens and a flatter cornea, while a shorter eye has a more powerful lens and a steeper cornea. In our study, horizontal WTW was negatively correlated with LT which can be explained by the same conclusion.

Prior studies investigating LT or ASL used magnetic resonance imaging,<sup>[31]</sup> ultrasound,<sup>[8,13]</sup> and optical reflectometer,<sup>[21]</sup> while we used OCT and measured directly via images. 3D-OCT in our study obtained images with a wavelength of 830 nm and provided axial and lateral resolutions of 30 and 15  $\mu\text{m}$ , respectively. This technique has the advantage of showing each structure covered by a liquid optic interface with a clear aperture of 13.5 mm. OCT scans from the corneal epithelium to the posterior capsule of lens can be viewed on one image due to a greater depth of field.

In our sample, the thickness of the posterior part of the crystalline lens was 2.04 times the thickness of the anterior part, and the pLT/aLT ratio was inversely correlated with LT. As the crystalline lens thickened, a relative portion of the posterior part became thinner. Only pLT – aLT was independent of other indicators. Although the difference in LT between thinner lenses and thicker lenses was 0.76 mm, the difference in pLT – aLT was 0.01 mm in the subgroup analysis based on LT. This means that the increment in thickness of the anterior part was identical to the increment in thickness of the posterior part.

Preoperative OCT measurements would be helpful for improving the predictive accuracy of IOL power. Tang et al<sup>[32]</sup> concluded that OCT-based IOL power calculation produced the least mean absolute error and the highest predictive accuracy. The accurate measurement of ACD is essential for the prediction of IOL position.<sup>[33,34]</sup> Many studies have shown that postoperative ACD is related to preoperative ACD and the Haigis formula<sup>[35]</sup> considers preoperative ACD for the prediction of effective lens position. However, it is insufficient to consider ACD only. As demonstrated in this study, ACD was negatively correlated with LT. As both ACD and LT changed with age, an age-related predictive error might occur. Consequently, the importance of LT has been highlighted in recent studies.<sup>[15,16]</sup> The Olsen formula includes the concept of the C constant. The C constant is related to the IOL type, determined as the mean value calculated from representative samples. A new formula proposed by Shammas considers the distance from the corneal apex to the anterior surface of lens nucleus and the thickness of the lens nucleus measured with optical low-coherence reflectometry. As discussed above, the lens shape did not show a constant pLT/aLT ratio due to the progression of cataract or thickening of the lens. LMP provided by 3D-OCT showed higher predictability than

ACD when combined with external measurements including AL, CR, and horizontal white-to-white diameters (hWTW). Even when two internal measurements were combined, the combination of LMP and PT was more predictive than the combination of ACD and LT regardless of external measurements. The highest correlation was obtained when ACD, aLT, pLT, and all the external measurements were considered. The new IOL formulas considering LMP and lens shape should help to improve the prediction of IOL power in the future study.

Our study has some limitations. First, non-cataractous lenses were not included in this study. Shammas<sup>[21]</sup> analyzed two lens spikes and two additional spikes indicating the anterior and the posterior surfaces of the nucleus measured by optical low-coherence reflectometry and concluded that the cataractous lens showed a statistically significant difference only in the anterior cortical space compared with the clear lens. In contrast, LT showed a statistically positive correlation with both anterior cortical space and posterior cortical space. A population-based cross sectional study or follow-up cohort study would be helpful for investigating the aging process of the crystalline lens more precisely. Second, we did not consider the differences in sex and ethnicity. In general, mean AL in males is known to be longer than in females.<sup>[18–20,36]</sup> LT and ASL are also greater in males.<sup>[13]</sup> Classification according to the gender will enhance the predictability for lens shape. As the prevalence of myopia in East Asian people is increasing, age may be a confounding factor for analyzing the relationship between AL and LT. Comparative studies with other ethnicities are needed to investigate the association between AL and LT more accurately. Third, we did not evaluate the grade of cataract. Cataract density may have a stronger impact on the ACD than age, as it is correlated to the age. Future studies will need to classify cataract by grade and analyze. Finally, we did not evaluate the repeatability of measurement by 3D-OCT. Due to the fact that the lens parameters are calculated by proprietary software built into the laser system, repeatability and accuracy of the measurements are unknown. However, since the measurement is made only after the perfect fixation of the disposable vacuum interface to the globe using a suction ring, the accuracy is expected to be high, and further verification will be needed in the future.

In conclusion, the present study determined the biometric parameters of the anterior segment of the eye and correlations between the parameters. Elder patients had thicker preoperative lenses, shorter AL, and shallower AD and ACD. When the LT was divided into two parts around the equator line, the difference between the posterior part and the anterior part was the only factor that was not significantly affected by other variables. In addition, when the anterior segment structure was subdivided into the anterior chamber, anterior part of lens (aLT), posterior part of lens (pLT), and the variables were assigned, the postoperative IOL position could be predicted most accurately.

## Author contributions

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