Evaluation of the White-to-White Distance in 39,986 Chinese Cataractous Eyes

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PURPOSE. To investigate the distribution of white-to-white (WTW) distance and its associations with other biometric parameters in Chinese cataractous eyes.

METHODS. Data on 39,986 eyes from 23,627 Chinese cataract patients were analyzed. Ocular biometric parameters, including WTW distance, corneal curvature, anterior chamber depth (ACD), lens thickness (LT), central corneal thickness (CCT), and axial length (AL), were obtained using the ZEISS IOLMaster 700.

RESULTS. The mean age of patients was 63.7 ± 12.4 years, and 57.61% were female. The mean WTW distance was 11.69 ± 0.46 mm. The WTW distance was larger in male patients than in female patients for all age groups (all $P < 0.001$). The WTW distance was positively correlated with corneal curvature and ACD and negatively correlated with age, LT, and CCT (all $P < 0.001$). Multivariable analysis revealed that a larger WTW distance was associated with younger age; male gender; larger corneal curvature, ACD, and LT; and thinner CCT (all $P < 0.001$). Notably, the association between WTW distance and AL was not linear. As the AL increased, the WTW distance initially increased, reached a peak in the group with ALs of 24.5 to 26 mm, and then slowly decreased. However, all of the myopic eyes (AL > 24.5 mm) still had larger WTWs than the normal and short eyes (AL $\leq$ 24.5 mm).

CONCLUSIONS. In Chinese cataractous eyes, the WTW distance was larger in younger male patients with flatter corneas, deeper anterior chambers, thicker lenses, and thinner central corneas. The association between WTW distance and AL was not linear, and WTW distance was the largest in eyes with ALs of 24.5 to 26 mm.

Keywords: cataract, corneal diameter, ocular biometry, high myopia, white-to-white (WTW)

The white-to-white (WTW) distance is the horizontal corneal diameter, measured between the borders of the corneal limbus. The traditional clinical application of the WTW distance has been for the diagnosis and management of ocular conditions such as congenital glaucoma and micro- and megalocornea.[1] Currently, the WTW distance is also frequently considered during cataract surgeries. It is a variable used in intraocular lens (IOL) power calculation formulas, especially new generation formulas such as the Holladay 2,[2] Hill-RBF 2.0,[3] Olsen,[4] and Barrett Universal II formulas,[5] and is also considered to be a factor influencing corneal astigmatism after cataract surgery.[6] More importantly, it is now also included in surgical planning for refractive cataract procedures.[7]

Premium IOLs such as multifocal, accommodative, and toric IOLs have now become a patient preference.[8,9] Precise measurement and thorough evaluation of biometric parameters are essential when implanting these IOLs.[10,11] A previous study on postmortem eyes showed a correlation between the mean corneal diameter and mean lens diameter,[12] suggesting that investigation of WTW distance and

its associated anterior segment parameters might provide additional information for cataract surgeons aiming for ideal surgical planning.

Although some previous studies have tried to determine the distribution of WTW distance in healthy subjects,[13–18] they used relatively smaller sample sizes and were mostly conducted in Western and Middle Eastern countries. Moreover, as the prevalence of myopia is especially high in East Asia,[19] we assume that axial length (AL) elongation might also affect the structural characteristics of the anterior segment, including the WTW distance. However, studies analyzing WTW distance in Chinese populations or stratified by ALs are still rare.

In this study, using a large number of Chinese cataractous eyes, we aimed to investigate the distribution of WTW distance and its relationship with other ocular anatomical parameters, in addition to revealing the influence of AL on WTW distance, thereby improving the planning of cataract surgeries and possibly leading to more accurate IOL calculations for this specific population.

Methods

Ethics

This study was approved by the Ethics Committee of the Eye and ENT Hospital of Fudan University (Shanghai, China). All procedures adhered to the tenets of the Declaration of Helsinki, and signed informed consents for the use of their clinical data were obtained from all participants before cataract surgery.

Patients

This retrospective study analyzed ocular biometric data for 39,986 eyes from 23,627 cataractous patients acquired from March 2018 to March 2020 at the Eye and ENT Hospital of Fudan University, which is the largest tertiary specialty hospital with ophthalmic services in Shanghai and has the highest patient output and productivity in Shanghai and surrounding areas. Cataractous patients over 30 years old were included. The exclusion criteria were previous ocular trauma or surgeries, corneal opacity or disease, lens dislocations, glaucoma, other ocular surface and intraocular diseases that could affect the measurements, and a patient's inability to cooperate or fixate adequately during the measurement process.

Biometric Measurements

Ocular biometric data were obtained using the IOLMaster 700, software version 1.80 (Carl Zeiss Meditec, Jena, Germany). Swept-source optical coherence tomography technology was used to measure axial parameters including AL; corneal curvature; anterior chamber depth (ACD), as measured from the corneal endothelium to the lens; lens thickness (LT), as measured between anterior and posterior poles of the lens; and central corneal thickness (CCT), as measured from the corneal epithelium to the endothelium. WTW distance measurements were taken using a light-emitting diode based on iris configuration. The measurements were taken by experienced technical staff. Patients were asked to place their chin and forehead correctly on the rest, focus on the vision target, blink once, and keep their eyes wide open during the measurement acquisition. During each measurement, the patient's eye geometry and axis of the measurements were visually checked on the scan image of the entire eye, and correct fixation was ensured during the foveal scan. The device calculates the standard deviation of the measurements and warns the operator of low-quality results if the standard deviation is greater than 0.021 mm for ACD, 0.038 mm for LT, or 0.027 mm for AL.[20] If one of the standard deviations is above the maximum for any measurement, that measurement is repeated until reproducible readings are obtained. If the data cannot be corrected, the unreliable data are excluded from further analyses.

The distribution of the WTW distance was described using the biometric data, and the WTW distance was then compared for age, gender, and laterality. The patients were further divided into six AL groups (<22, 22–24.5, 24.5–26, 26–28, 28–30, and >30 mm). Eyes with AL < 22 mm were defined as short eyes,[21–23] AL 22 to 24.5 mm as normal eyes,[21,22] AL 24.5 to 26 mm as moderately myopic eyes,[21,22] AL 26 to 28 mm as highly myopic eyes,[24] and AL > 28 mm as extremely myopic eyes.[24]

Statistics

Absolute and relative frequencies were calculated for dichotomous variables, and continuous variables were described as the mean ± SD. Either the Mann–Whitney *U* test or the Kruskal–Wallis test was used to compare continuous data between two groups or among three or more groups. Pearson's correlation coefficient (*r*) and scatterplots were used for univariate associations among WTW distance and age, ACD, CCT, LT, or corneal curvature. Multivariable analysis was conducted, with WTW distance as the dependent parameter and all other parameters as independent variables.[25,26] Linear regression models with general estimating equations (GEEs) were used to assess associations. The GEE model could account for correlations between corresponding eyes and is the most statistically efficient method for performing bivariate association tests using both-eye data.[25] Non-standardized beta coefficients (β) were identified, and confidence intervals were determined. Scatterplots for WTW distance and the various AL groups were produced and then fitted with smooth lines using the LOESS method. Subgroup analyses were further conducted for the six AL groups. Statistical analysis was performed using a commercially available statistical software package (SPSS Statistics 20.0; IBM, Armonk, NY). All *P* values were two sided, and a *P* < 0.05 was considered statistically significant.

Results

Characteristics

A total of 39,986 eyes from 23,627 patients were included in the study. The mean age of the patients was 63.7 ± 12.4 years (range, 30–99 years), and 57.61% of the subjects were female. The mean value of WTW distance was 11.69 ± 0.46 mm for all patients. The WTW distance was larger in males than in females (11.83 ± 0.45 mm for males and 11.59 ± 0.43 mm for females; *P* < 0.001). The distribution of WTW distances in our study is shown in Figure 1.

Comparisons of WTW Distance, Stratified by Age, Gender, and Laterality

WTW distances stratified by age, gender, and laterality are shown in Table 1. For both males and females, the WTW distance decreased gradually with age (for the age groups ranging from <40 to 70–79 years; *P* < 0.001), but then showed no significant difference between the age groups of 70 to 79 years and >80 years (*P* > 0.05). The WTW distance was significantly larger in male eyes than in female eyes for all age groups (all *P* < 0.001). The trend was similar for right and left eyes, and no difference was observed in laterality (*P* > 0.05).

Associations Among WTW Distance and Age and Other Parameters of the Anterior Segment

The scatterplots for WTW distance and age, corneal curvature, ACD, LT, and CCT are shown in Figure 2. Pearson's correlation analysis revealed that WTW distance was positively correlated with corneal curvature (*r* = 0.468) and ACD (*r* = 0.346) and negatively correlated with age (*r* = –0.191), LT (*r* = –0.087), and CCT (*r* = –0.010) (all *P* < 0.001). Multivariable analysis using GEEs revealed that larger WTW distances were associated with younger age, male gender,
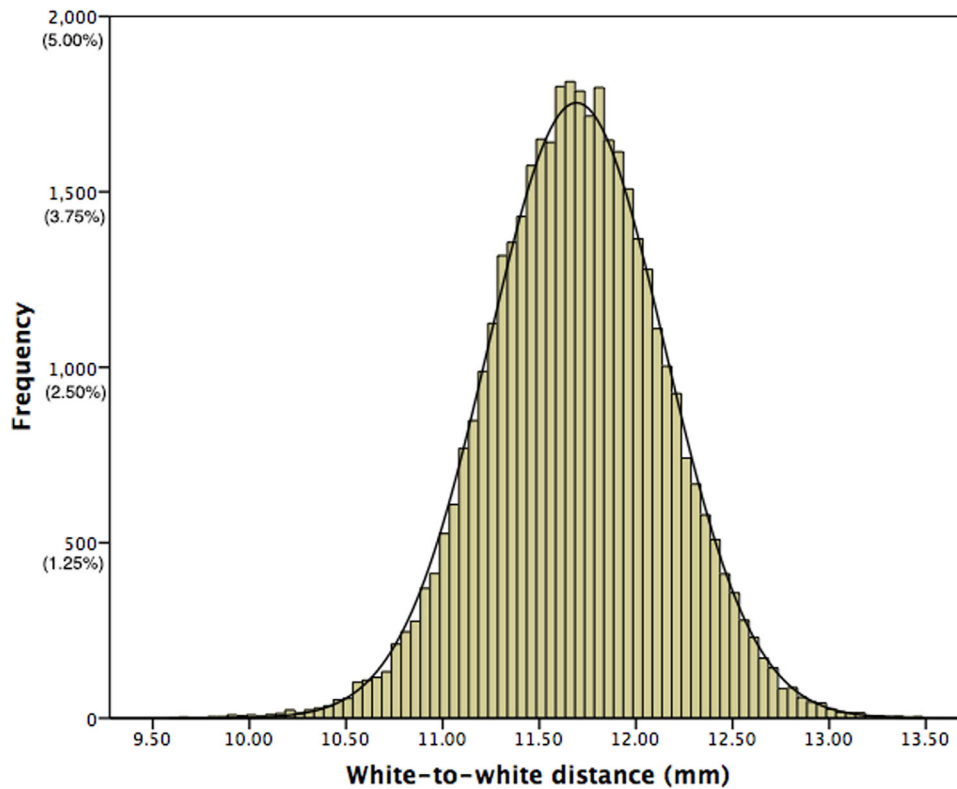
FIGURE 1. Distribution of WTW distance.

TABLE 1. WTW Distance by Age, Gender, and Laterality

	Male		Female		
Age Group (y)	No. of Eyes	WTW Distance (mm), Mean ± SD	No. of Eyes	WTW Distance (mm), Mean ± SD	*P**
Right eyes					
<40	457	12.00 ± 0.45	315	11.80 ± 0.50	<0.001
40–49	960	11.93 ± 0.44	761	11.72 ± 0.45	<0.001
50–59	1648	11.86 ± 0.43	2124	11.64 ± 0.42	<0.001
60–69	2539	11.80 ± 0.44	4377	11.56 ± 0.42	<0.001
70–79	1957	11.71 ± 0.43	2836	11.50 ± 0.41	<0.001
>80	746	11.71 ± 0.42	941	11.52 ± 0.38	<0.001
All	8307	11.81 ± 0.44	11,354	11.57 ± 0.43	<0.001
Left eyes					
<40	480	12.04 ± 0.47	346	11.86 ± 0.44	<0.001
40–49	1010	11.99 ± 0.45	792	11.74 ± 0.43	<0.001
50–59	1754	11.89 ± 0.44	2227	11.67 ± 0.43	<0.001
60–69	2652	11.84 ± 0.45	4549	11.59 ± 0.43	<0.001
70–79	1958	11.75 ± 0.45	2813	11.54 ± 0.42	<0.001
>80	766	11.76 ± 0.44	978	11.54 ± 0.43	<0.001
All	8620	11.84 ± 0.46	11705	11.60 ± 0.43	<0.001
Both eyes	16,927	11.83 ± 0.45	23,059	11.59 ± 0.43	<0.001

* Mann–Whitney *U* test or Kruskal–Wallis test was used to compare continuous data between gender groups or among age groups within right or left eyes.

larger corneal curvature, larger ACD, larger LT, and thinner CCT (Table 2).

Analysis of WTW Distance Stratified by AL

The scatterplot of WTW distance against AL with a LOESS curve is shown in Figure 3, and it indicates that the relationship between WTW distance and AL is not linear. Thus,

Pearson's correlation analysis was not applied for WTW distance and AL for the whole group, but it was further conducted in various AL subgroups. Our results showed the WTW distance was negatively correlated with AL in the <22 mm ($r = -0.228$), 24.5 to 26 mm ($r = -0.055$), and 28 to 30 mm ($r = -0.109$) groups and was positively correlated with AL in the 22 to 24.5 mm ($r = 0.323$) and >30 mm ($r = 0.132$) groups (all $P < 0.001$). Additionally, we
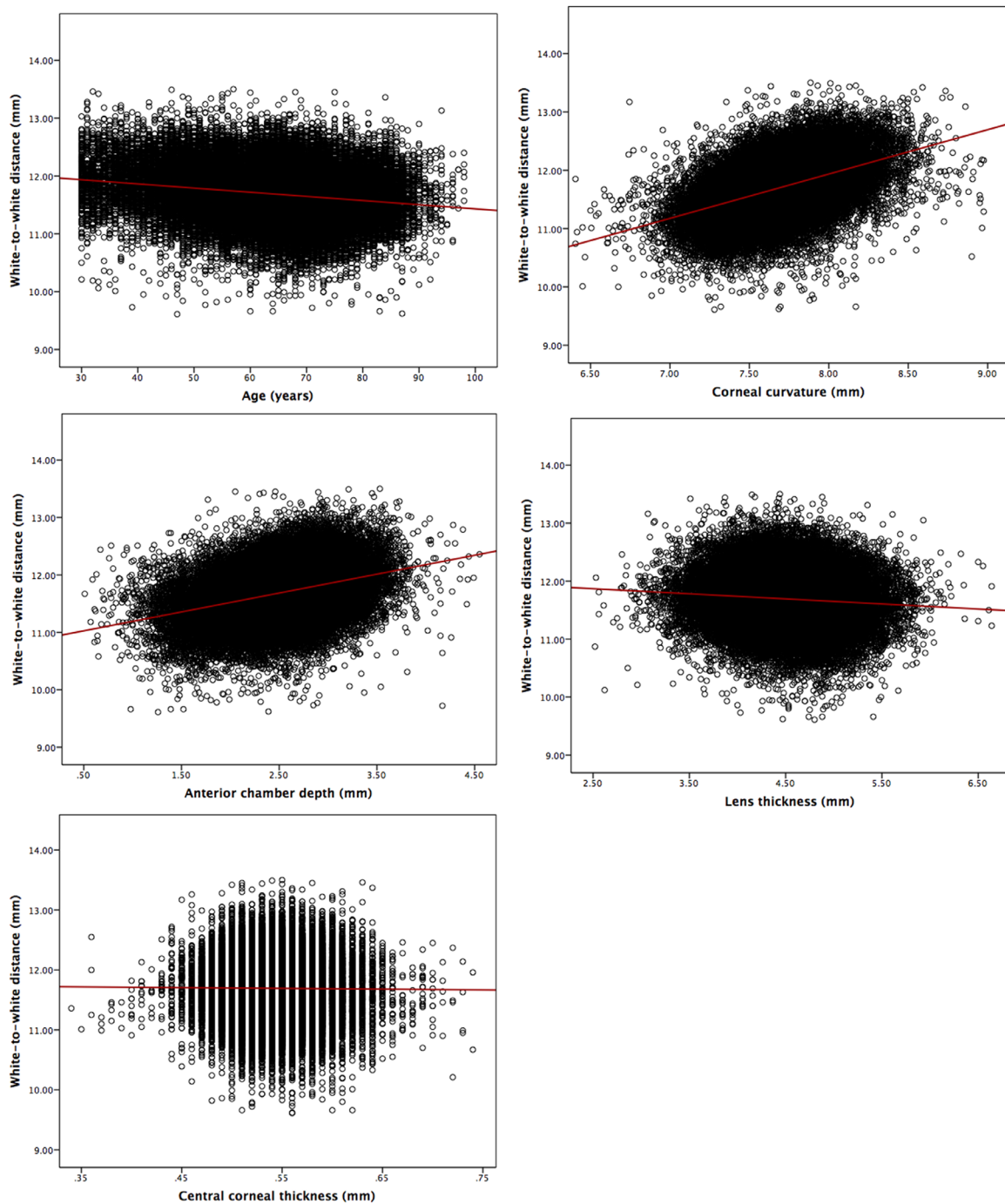
FIGURE 2. Correlations of WTW distance with age and other ocular biometric parameters.

performed multivariable analyses using GEEs within each AL group (Table 3). A larger WTW distance was consistently associated with younger age, male gender, larger corneal curvature, larger ACD, larger LT, and thinner CCT within all AL groups (all $P < 0.001$).

Comparisons of WTW distances for the various AL groups are provided in Table 4. In comparison to the AL 22 to ~24.5 mm group, the WTW distance was statistically smaller for the AL < 22 mm group ($\beta = -0.201$, $P < 0.001$) and larger for the AL 24.5 to ~26 mm ($\beta = 0.110$, $P < 0.001$), AL

26 to ~28 mm ($\beta = 0.089$, $P < 0.001$), AL 28 to ~30 mm ($\beta = 0.060$, $P < 0.001$), and AL > 30 mm ($\beta = 0.016$, $P < 0.001$) groups. We see, therefore, that as AL increased, the corresponding WTW distance was lowest in the short eyes group (smallest mean WTW distance, 11.33 ± 0.45 mm; $P < 0.001$), increasing and reaching a peak in the moderately myopic eyes group (highest mean WTW distance, 11.86 ± 0.44 mm; $P < 0.001$) and then slowly decreasing in the highly and extremely myopic eye groups. However, when compared to normal eyes, the WTW distance was still larger
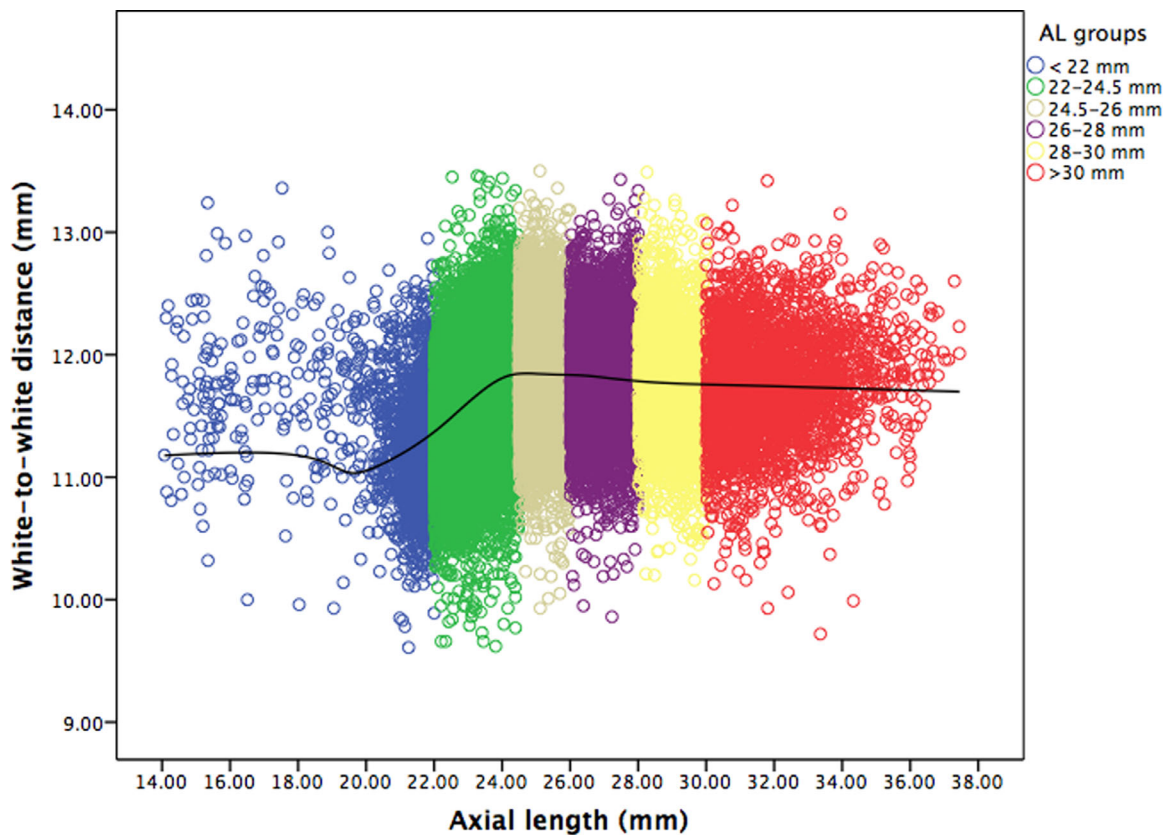
FIGURE 3. Scatterplots with LOESS curve of WTW distance versus AL for the various AL groups.

TABLE 2. WTW Distance Multivariable Analysis

Variable	β Coefficient[*]	95% CI	P
Age (y)	−0.004	−0.005 to −0.004	<0.001
Sex, male/female	0.083	0.073–0.092	<0.001
Corneal curvature (mm)	0.640	0.621–0.658	<0.001
ACD (mm)	0.367	0.353–0.381	<0.001
LT (mm)	0.226	0.212–0.239	<0.001
CCT (mm)	−0.901	−1.038 to −0.765	<0.001

[*] Generalized estimating equations were used to control for correlations between right and left eyes.

in all moderately, highly, and extremely myopic eyes, as revealed by multivariable analyses using GEEs, after adjustment for age and sex ($\beta > 0$, all $P < 0.001$).

DISCUSSION

Today, the IOLMaster has become a standard for measuring ocular biometry because it is considered to be less operator dependent and more accurate than other machines.[27] The IOLMaster can easily measure the biometric parameters of the anterior segment, such as WTW distance and LT, simplifying investigations into relationships among the variables. However, previous analyses of WTW distance distributions and associations with other biometric parameters used relatively smaller sample sizes (reported $N = 4787$,[14] 974,[13] 410,[15] 390,[16] or 61[17]), and very few have looked at Chinese populations, which have a higher incidence of myopia. In this study, based on the biometrics of a large number

of Chinese cataractous eyes gathered using the IOLMaster 700, we found that WTW distance was greater in younger, male patients with larger corneal curvature, deeper ACD, larger LT, and thinner CCT. As the AL increased, we found that WTW distance was lowest in the short eyes group; it increased and reached a peak in the moderately myopic eyes group (AL 24.5–26 mm) and then slowly decreased in the highly and extremely myopic eye groups. However, when compared to normal eyes, the WTW distance was still larger in myopic eyes.

Previously, WTW distance was mainly used for the diagnosis of micro- or megalocornea; however, it has recently become a more important consideration when planning cataract surgeries. Some of the newer generation formulas, such as the Holladay 2,[2,28] Hill-RBF 2.0,[3] Olsen,[4] and Barrett Universal II formulas, which demonstrate better predictability, recommend use of WTW distance as an input variable.[5,29] In a recent study by Darcy et al.,[30] a good outcome was also achieved among a large population with a mean AL of 23.65 ± 1.34 mm using the Barrett formula without WTW distance as an input variable. However, for highly myopic cases with relatively unsatisfactory calculation accuracy, especially for extremely long eyes (AL > 30 mm), inputting more anterior segment variables might help to improve accuracy. Also, recent studies have revealed that capsular bag compatibility is important when using premium IOLs.[31–33] For myopic eyes with large capsular bags, some C-loop IOL implants might be particularly unstable and thus affect surgical outcomes, especially for premium IOLs.[10,11] However, the direct evaluation of capsular bag size remains difficult and inconvenient, as no reliable measuring apparatus is available. A

TABLE 3. Multivariable Analysis of the WTW Distance Within Each AL Group

AL Group	Age (y)	Sex, Male/Female	Corneal Curvature (mm)	ACD (mm)	LT (mm)	CCT (mm)
<22 mm						
β^*	−0.005	0.068	0.599	0.362	0.255	−1.165
95% CI	−0.007 to −0.004	0.022–0.114	0.532–0.667	0.304–0.420	0.200–0.310	−1.655 to −0.676
P	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001
22∼24.5 mm						
β^*	−0.005	0.051	0.661	0.452	0.284	−1.26
95% CI	−0.006 to −0.005	0.039–0.063	0.631–0.691	0.427–0.477	0.265–0.302	−1.430 to −1.090
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
24.5∼26 mm						
β^*	−0.004	0.081	0.707	0.45	0.242	−1.102
95% CI	−0.005 to −0.003	0.056–0.105	0.662–0.752	0.403–0.496	0.202–0.281	−1.441 to −0.764
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
26∼28 mm						
β^*	−0.004	0.097	0.707	0.482	0.262	−1.173
95% CI	−0.006 to −0.003	0.069–0.125	0.649–0.765	0.423–0.541	0.213–0.312	−1.554 to −0.792
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
28∼30 mm						
β^*	−0.007	0.092	0.716	0.505	0.285	−1.675
95% CI	−0.008 to −0.005	0.057–0.127	0.656–0.776	0.445–0.565	0.235–0.335	−2.137 to −1.212
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
>30 mm						
β^*	−0.007	0.051	0.611	0.486	0.237	−1.128
95% CI	−0.009 to −0.005	0.016–0.086	0.539–0.684	0.425–0.546	0.184–0.291	−1.713 to −0.542
P	<0.001	<0.05	<0.001	<0.001	<0.001	<0.001

*Generalized estimating equations were used to control for correlations between right and left eyes.

TABLE 4. Comparisons of WTW Distances in Different AL Groups

AL Group	No. of Eyes (%)	WTW Distance (mm), Mean ± SD	β Coefficient*	95% CI	P
<22 mm	2467 (6.17)	11.33 ± 0.45	−0.201	−0.221 to −0.18	<0.001
22∼24.5 mm	23081 (57.73)	11.66 ± 0.43	Ref.	Ref.	NA
24.5∼26 mm	5218 (13.05)	11.86 ± 0.44	0.110	0.097–0.122	<0.001
26∼28 mm	3980 (9.95)	11.82 ± 0.45	0.089	0.074–0.103	<0.001
28∼30 mm	2489 (6.23)	11.76 ± 0.47	0.060	0.043–0.077	<0.001
>30 mm	2748 (6.87)	11.74 ± 0.45	0.034	0.016–0.052	<0.001

*Generalized estimating equations were used to control for correlations between right and left eyes. Models were adjusted for sex and age.

previous study on postmortem eyes revealed some correlation between mean corneal diameter and mean lens diameter.[12] Thus, describing the relationships among anatomical parameters might help clinicians to better determine the anterior segment dimensions of candidates for surgery or to make better lens diameter predictions. Preoperative communications would be improved, and patient surgical decision making might be better informed.

Some studies have investigated the distribution of WTW distance in Middle Eastern and Western countries. One Iranian study that utilized the Orbscan corneal topography system (Bausch & Lomb, Rochester, NY) reported a mean WTW distance of 11.65 mm.[13] A Tehran eye study reported mean WTW distance of 11.68 mm,[15] a German study reported 11.71 mm,[16] and a Spanish study reported 11.9 mm.[18] Moreover, an Iranian study utilizing the Lenstar (Haig-Streit, Köniz, Switzerland) reported a WTW distance of 11.80 mm,[14] and a Canadian study that used the IOLMaster 500 reported 11.97 mm.[17] However, these sample sizes were relatively small, and analyses among Chinese populations, which have a higher incidence of myopia, have still been rare. In our study, based on 39,986 eyes from 23,627 Chinese cataract patients, we found that the distri-

bution of WTW distance in cataractous patients was more like a normal distribution, with a mean value of 11.69 ± 0.46 mm. That result is similar to mean values from the aforementioned Middle Eastern studies[13,15] but slightly smaller than what was found in the studies from Western countries,[16–18] a disparity that might stem from ethnic differences. Although our findings regarding WTW distance distribution in genders differed from those of Fu et al.,[34] our data are consistent with other previous reports,[14,15,35] in which the male gender was associated with larger WTW distances. Furthermore, we observed a significant negative correlation between WTW distance and age, which is consistent with some of the previous reports,[13,14,36] although other studies have reported no significant correlation between WTW distance and age.[15,16,37] By multivariable analysis, we also found that a larger WTW distance was associated with a flatter cornea, deeper anterior chamber, thicker lens, and thinner central cornea, suggesting that the horizontal enlargement is usually accompanied by sagittal elongations of the anterior segment and central cornea attenuation in the eyes of cataract patients.

We paid particular attention to how the WTW distance changed as the AL changed. Of note, the relationship

between WTW distance and AL was not linear. As eyes elongated, the WTW distance first increased, reached a peak (mean, 11.86 ± 0.44 mm) in the group with AL of 24.5 to 26 mm, and then slowly decreased in the groups with AL > 26 mm. Yet, when compared to the normal eyes, the WTW distance was still larger in all myopic eyes and smaller in all short eyes.

Our results suggest that the horizontal WTW distance might be the largest among moderately myopic eyes, not among highly or extremely myopic eyes. Another German study, conducted using a fourth-order polynomial regression model, also reported a nonlinear association between WTW distance and AL.[35] However, that work included only relatively small proportions of long or extremely long eyes, which might be due to the lower prevalence of myopia in European countries,[35] and so does not help us answer our research question. Our study, with its large sample of Chinese cataractous patients, might provide valuable information for cataract surgeons who deal with myopic eyes.[35] Coincidentally, the phenomenon of inferior decentration of multifocal IOLs reported in our previous research was found in myopic eyes (reported mean AL of 25.44 ± 1.04 mm),[11] which means that the phenomenon might be more salient in eyes having peak WTW distances (ALs of 24.5–26 mm). Therefore, to some extent, measurement of the WTW distance and other anterior segment parameters could prove useful for cataract surgeons performing premium IOL implantations in highly myopic eyes by improving IOL calculations and estimations of anterior segment dimensions.

In conclusion, by examining a large number of Chinese cataractous eyes, we found that a larger WTW distance was associated with younger age, male gender, flatter cornea, deeper anterior chamber, thicker lens, and thinner central cornea. Notably, the association between WTW distance and AL was not linear, as eyes with ALs of 24.5 to 26 mm showed the largest WTW distances. Our research should provide valuable information to those planning refractive cataract surgeries.

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