Relationship between ciliary sulcus diameter and anterior chamber diameter and corneal diameter

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PURPOSE: To evaluate the relationship between the horizontal ciliary sulcus diameter and anterior chamber diameter measured by 35 MHz ultrasound biomicroscopy (UBM) and the horizontal corneal diameter (white to white [WTW]) measured by scanning-slit topography and to assess the repeatability (intraexaminer difference) of the 2 methods.

SETTING: Department of Orthoptics and Visual Science, Kitasato University School, Sagamihara, Japan.

METHODS: The repeatability and agreement of UBM and scanning-slit topography were assessed using the intraclass correlation (ICC) and the Bland and Altman method (ie, mean difference and 95% limits of agreement [LoA]).

RESULTS: Thirty-one normal eyes of 31 subjects (mean age 22.6 years $\pm$ 4.8 [SD]) were evaluated. The mean differences between the repeated measurements were as follows: ciliary sulcus diameter, −0.05 mm (95% LoA, −0.38 to 0.28 mm); anterior chamber diameter, 0.02 mm (95% LoA, −0.42 to 0.45 mm); and WTW diameter, −0.02 mm (95% LoA, −0.18 to 0.13 mm). The agreement between ciliary sulcus diameter and WTW diameter was poor (ICC, 0.679). The mean difference was 0.41 mm (95% LoA, −0.46 to 1.28 mm). The agreement between the ciliary sulcus diameter and anterior chamber diameter was high (ICC, 0.918). The mean difference was 0.13 mm (95% LoA, −0.41 to 0.67 mm).

CONCLUSION: Results suggest that direct measurement of the ciliary sulcus by UBM would reduce the percentage of complications related to intraocular lens sizing over the percentage when sizing is based on WTW diameter.

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Posterior chamber phakic intraocular lenses (pIOLs) have many advantages in the treatment of refractive error, especially for moderate to high ametropia, because the correction amount is not limited by corneal thickness and accommodation is preserved.[1,2] However, posterior chamber pIOLs may lead to complications if the wrong IOL size is selected. An undersized posterior chamber pIOL can lead to a low vault (ie, distance from IOL to crystalline lens), which can cause cataract formation from chronic crystalline lens contact.[1,2] On the other hand, an oversized posterior chamber pIOL leads to a high vault, which can cause pigment dispersion and angle crowding and may result in angle-closure glaucoma.[2] Therefore, the sizing of posterior chamber pIOLs is important.

Traditionally, the horizontal corneal diameter (ie, white to white [WTW]) measured by calipers or scanning-slit topography has been used to estimate the diameter of the ciliary sulcus. For posterior chamber pIOLs, 0.5 mm or 1.0 mm is added to the horizontal WTW diameter.[3] This method is based on the

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hypothesis that the WTW diameter is correlated with and smaller than the ciliary sulcus diameter. However, some studies[4–7] found no correlation between WTW diameter and ciliary sulcus diameter, and others found a WTW diameter larger than the ciliary sulcus diameter.[5,8] Choi et al.[3] found high vault (>750 μm) and low vault (<250 μm) in 17.6% and 23.5% of eyes, respectively, when determining pIOL length using WTW diameter. These conflicting results could be due to individual variation in WTW diameter and ciliary sulcus diameter and the repeatability performance of the measuring device. These factors may affect the percentage of IOL complications related to sizing versus those when IOL sizing is based on WTW diameter.

To our knowledge, no published study has directly compared the within-rater and between-instrument measurements of WTW and ciliary sulcus diameters using these instruments concurrently. Although Oh et al.[5] found that anterior chamber diameter was more helpful than WTW diameter when estimating sulcus size, they did not report the repeatability of the WTW diameter and the limits of agreement (LoA) of the difference between the ciliary sulcus diameter and the anterior chamber and WTW diameters. Therefore, we studied the relationship between horizontal ciliary sulcus diameter and anterior chamber diameter measured by 35 MHz ultrasound biomicroscopy (UBM) and the horizontal WTW diameter measured by scanning-slit topography. We also assessed the repeatability (intraexaminer difference) of the 2 measurement methods.

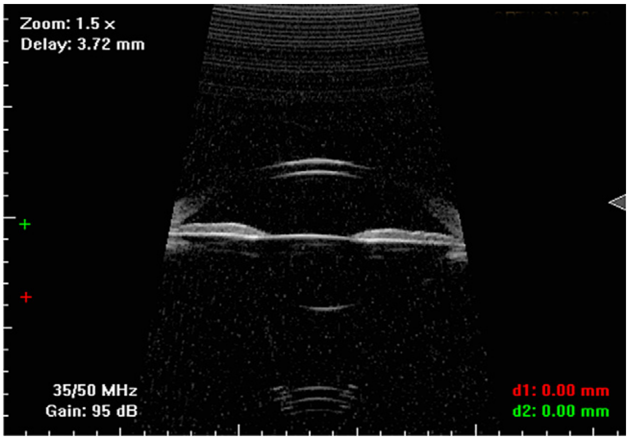

Figure 1. A typical 35 MHz UBM image.

SUBJECTS AND METHODS

This prospective nonrandomized study evaluated eyes with no known ocular abnormalities. Exclusion criteria included a corrected distance visual acuity (Snellen) worse than 20/20 in either eye. All subjects provided informed consent after receiving a thorough explanation of the nature of the study. The study followed the tenets of the Declaration of Helsinki.

The repeatability and agreement (correlation) between the ciliary sulcus diameter and the anterior chamber and WTW diameters were evaluated. Two measurements per eye were taken. All measurements were in the right eye. The objective refraction was measured using an OPD-Scan II device (Nidek, Inc.)

The WTW diameter was measured using an Orbscan II scanning-slit corneal topographer (version 3.12, Bausch & Lomb), a noncontact, 3-dimensional anterior segment system. The device uses digital image processing for WTW diameter measurement and detects the corneal limbus automatically from gray-scale steps between images of the sclera and images of the iris. The maximum resolution is 2 μm within the central corneal surface.

The horizontal ciliary sulcus diameter and anterior chamber diameter were measured by UBM using a HiScan ultrasound biometer equipped with a 35 MHz transducer (Optikon 2000). The axial and lateral resolutions of the 35 MHz transducer are 70 μm in the anterior segment with a 7.0 to 8.0 mm height. The same examiner performed all measurements using topical anesthesia of oxybuprocaine 0.4%. A 20.0 mm, 22.0 mm, or 24.0 mm eyecup was placed in 1 eye with the subject prone. The eyecup was filled with normal saline solution. Then, the subject was asked to fixate on a target on the ceiling while the other eye maintained fixation and accommodation.

The 35 MHz UBM system can measure the anterior segment in a motion video. The sampling rate was 8 frames per second, with the images captured in the video. The probe was scanned in the direction of a vertical

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Table 1. Results obtained from 35 MHz UBM and scanning-slit topography measured by the same examiner (n = 31).

	Mean (mm) ± SD				
Parameter	M1	M2	M1 and M2	Difference M1 and M2	95% LoA
Ciliary sulcus diameter	12.03 ± 0.55	12.08 ± 0.57	12.06 ± 0.55	−0.05 ± 0.17	−0.38 to 0.28
AC diameter	11.94 ± 0.43	11.92 ± 0.48	11.93 ± 0.44	0.02 ± 0.22	−0.42 to 0.45
WTW diameter	11.64 ± 0.32	11.66 ± 0.31	11.65 ± 0.32	−0.02 ± 0.08	−0.18 to 0.13

AC = anterior chamber; LoA = limits of agreement; M = measurement; WTW = white to white

meridian during each acquisition (Figure 1). Then, the images in the video were captured and analyzed with manual calipers. The horizontal cross-section was determined using the maximum pupil diameter from the captured images.

Statistical Analysis

The repeatability of the scanning-slit topographer and UBM system was assessed using the intraclass correlation (ICC)[9,10] and a method described by Bland and Altman[11] in which 95% of the differences, or LoA, lie between ±1.96 × the standard deviation of the mean difference. The ICC and Pearson correlation coefficient (*r*) tests can be used to assess the correlation, consistency, or conformity of a data set when it contains multiple groups. A 2-way random effects model was used for the ICC to ensure consistency of individual measurements. The ICC ranges from 0 to 1 and is commonly classified as follows: ICC <0.75, poor agreement; ICC 0.75 to 0.90, moderate agreement; ICC ≥0.90, high agreement.[9,10] The means of the 2 measurements were recorded and then compared.

Statistical analysis was performed using PASW Statistics software (version 17.0, SPSS, Inc.). A *P* value less than 0.05 was considered statistically significant.

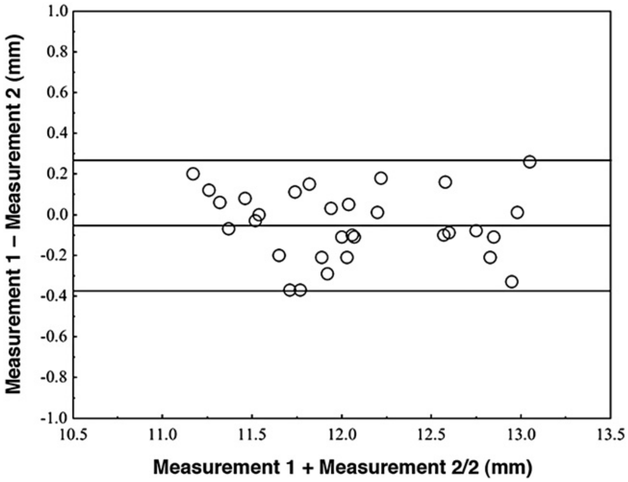

Figure 2. Repeatability of 35 MHz UBM measurements (within-rater) of ciliary sulcus diameter. The solid lines represent the mean difference and the 95% LoA.

RESULTS

The study evaluated 31 eyes of 31 subjects with a mean age of 22.6 years ± 4.8 (SD) (range 20 to 28 years). The mean sphere was −3.20 ± 2.61 diopters (D) (range +0.25 to −10.25 D); the mean cylinder, −0.51 ± 0.60 D (range 0.00 to −2.75 D); and the mean spherical equivalent refraction, −3.46 ± 2.72 D (range +0.13 to −10.25 D).

Table 1 shows the mean diameter measurement results as well as the mean difference and 95% LoA. The repeatability of ciliary sulcus diameter measurements by 35 MHz UBM is shown in Figure 2; of anterior chamber diameter measurements by 35 MHz UBM, in Figure 3; and of WTW diameter measurements by scanning-slit topography, in Figure 4. The ICC between repeated measurements was 0.984 (95% confidence interval [CI], 0.966-0.992) for WTW diameter, 0.938 (95% CI, 0.871-0.970) for anterior chamber diameter, and 0.976 (95% CI, 0.951-0.989) for ciliary sulcus diameter.

The agreement between ciliary sulcus diameter and WTW diameter was poor (ICC 0.679; 95% CI, 0.335-0.845 mm). The mean difference was 0.41 mm (95% LoA, −0.46 to 1.28 mm). There were statistically significant linear correlations and a weak overall correlation (r = .597, P < .001) (Figure 5). The agreement between ciliary sulcus diameter and anterior chamber diameter was high (ICC 0.918; 95% CI, 0.830-0.961 mm). The mean difference was 0.13 mm (95% LoA, −0.41 to 0.67 mm). There were statistically significant linear correlations and a high overall correlation (r = .869, P < .001) (Figure 6).

Figures comparing all 3 diameters between right eyes and left eyes are shown in Supplements A, B, and C (at www.jcrsjournal.org).

DISCUSSION

We studied the relationship between the horizontal ciliary sulcus diameter and anterior chamber diameter measured by 35 MHz UBM and the horizontal ciliary sulcus diameter and horizontal WTW diameter

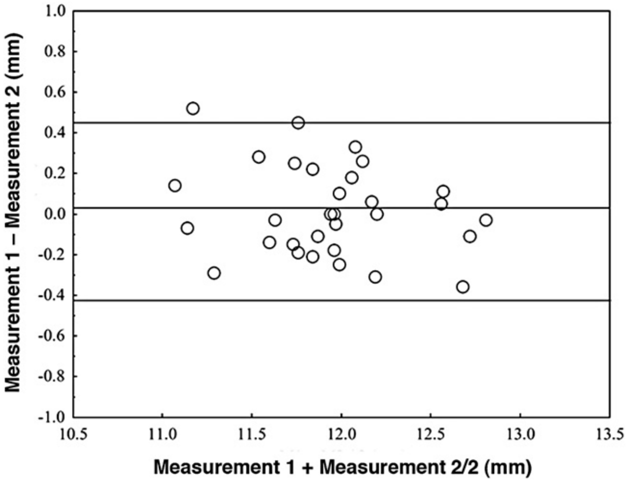

Figure 3. Repeatability of 35 MHz UBM measurements (within-rater) of anterior chamber diameter. The solid lines represent the mean difference and the 95% LoA.

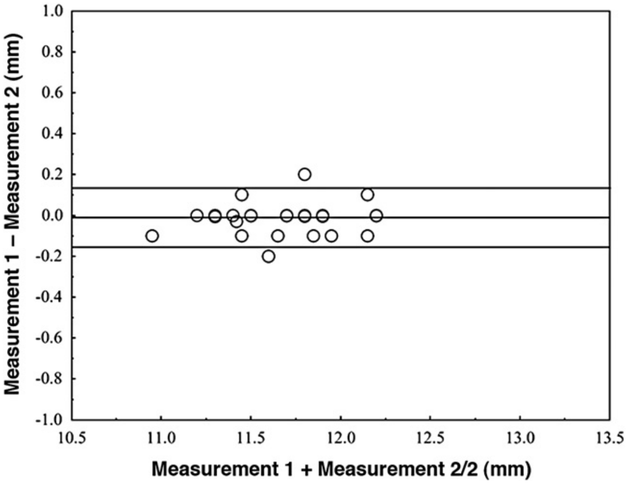

Figure 4. Repeatability of scanning-slit topography measurements (within-rater) of WTW diameter. Some plots (*thick circles*) overlap. The solid lines represent the mean difference and the 95% LoA.

measured by scanning-slit topography. We also evaluated the repeatability of the 2 methods.

To our knowledge, no published study has systematically assessed the repeatability of the methods used in our study. However, several studies have assessed scanning-slit topography or high-frequency UBM individually (Table 2).[4–6,12–15] Oh et al.[5] evaluated repeatability using the coefficient of variation (CV) for intraobserver sulcus diameter measurements by the UBM system used in our study. They found a mean CV value based on 5 repeated measurements of 0.90% $\pm$ 0.26%, showing that the measurement had high reliability. Reinstein et al.[13] found within-eye repeatability of 0.23 mm in sulcus diameter when measured using a very-high-frequency digital ultrasound arc scanner. Pinero et al.[12] found good intrasession repeatability scores for WTW diameter measured with scanning-slit topography; the mean CV of the repeated WTW diameter measurements was 0.40% $\pm$ 0.20%, and the ICC was 0.989. Wang and Auffarth[16] also found very accurate WTW

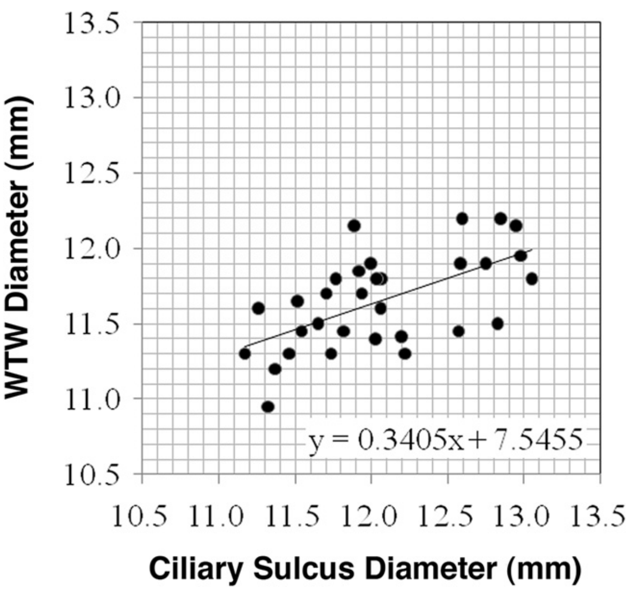

Figure 5. Scattergraph and the linear regression line of the relationship between ciliary sulcus diameter and WTW diameter (WTW = white to white).

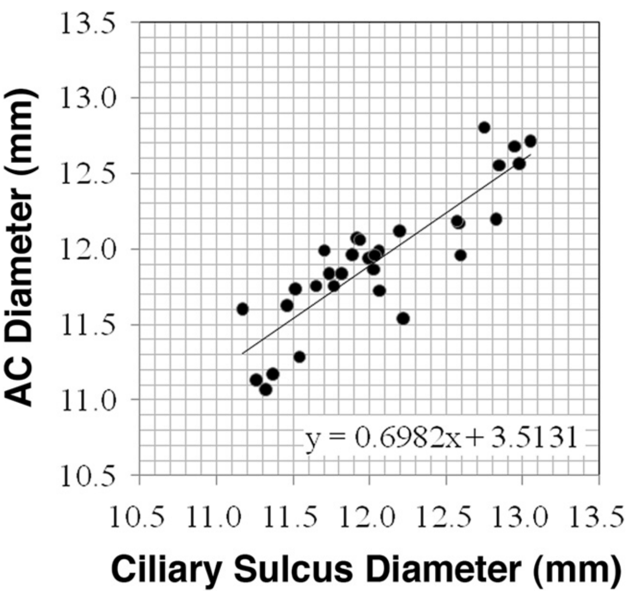

Figure 6. Scattergraph and linear regression line of the relationship between ciliary sulcus diameter and anterior chamber diameter (AC = anterior chamber).

Table 2. Comparison of the within-rater repeatability of the WTW distance, anterior chamber diameter, and the ciliary sulcus diameter (horizontal meridian section).

Study*	Eyes (n)	Patient Age (Y) Mean ± SD	Patient Age (Y) Range	Device	Measurement	Difference (mm) Between Repeated Measurements Mean	Difference (mm) Between Repeated Measurements 95% LoA	ICC Between Repeated Measurements Value	ICC Between Repeated Measurements 95% CI	Other Assessment
Present	31	23 ± 5	—	35 MHz UBM	Ciliary sulcus diameter	−0.05 ± 0.17	−0.38 to 0.28	0.976	0.951 to 0.989	—
				35 MHz UBM	AC diameter	0.02 ± 0.22	−0.42 to 0.45	0.938	0.871 to 0.970	—
				S-S topo	WTW diameter	−0.02 ± 0.08	−0.18 to 0.13	0.984	0.966 to 0.992	—
Pinero[12]	30	—	20–51	OCT	AC diameter	—	—	0.994	0.996 to 0.999	0.24 ± 0.14%[§]
				S-S topo	WTW diameter	—	—	0.989	0.980 to 0.994	0.40 ± 0.20%[§]
Fea[4]	10	—	20–79	MRI (1.5 tesla imager)	Ciliary sulcus diameter	0.28[†]	—	—	—	0.89[¶]
				S-S topo	WTW diameter	0.26[†]	—	—	—	0.91[¶]
Reinstein[13]	40	35 ± 7	—	50 MHz UBM	Ciliary sulcus diameter	—	—	—	—	0.23 mm[‖]
Oh[5]	12	—	23–37	35 MHz UBM	Ciliary sulcus diameter	—	—	—	—	0.90 ± 0.26%**
Rondeau[14]	28	—	24–40	50 MHz UBM (custom device)	Ciliary sulcus diameter	—	—	—	—	0.85%, 1.51%[††]
				50 MHz UBM (custom device)	AC diameter	—	—	—	—	0.94%, 1.06%[††]
Pop[6]	43	34 ± 6	—	50 MHz UBM	Ciliary sulcus diameter	—	—	0.79[‡]	—	—
Kohnen[15]	52	35 ± 8	—	OCT	AC diameter	—	—	—	—	P = .861[‡‡]
				S-S topo	WTW diameter	—	—	—	—	P = .799[‡‡]

AC = anterior chamber; CI = confidence interval; CV = coefficient of variation; ICC = interclass correlation; LoA = limits of agreement; MRI = magnetic resonance imaging; OCT = optical coherence tomography; S-S topo = Scanning-slit topography; UBM = ultrasound biomicroscopy; WTW = white to white
*First author
[†]Measurements taken masked fashion 10 days apart (intersession reliability)
[‡]ICC found while measuring the sulcus with 3 data sets (1 by first technician, 2 by second technician)
[§]Within-eye mean CV (±SD) of 3 repeated measurements
[¶]Spearman correlation
[‖]Variance of 10 measurements in each eye calculated for sulcus diameter and the within-eye repeatability calculated as square root of mean variance
**Measurements performed 5 times
[††]Within-eye CV of 10 repeated measurements (model-fit diameter, raw-data diameter)
[‡‡]Comparisons between first and second measurements (Kruskal-Wallis test)

diameter measurements with the scanning-slit topographer. Our results suggest that both scanning-slit topography and UBM have good within-rater repeatability.

In a comparison of WTW and ciliary sulcus diameters, Oh et al.[5] found that the mean horizontal WTW diameter measured by scanning-slit topography was slightly larger than the mean horizontal ciliary sulcus diameter measured by 35 MHz UBM. The authors did not perform statistical analyses because a comparison between WTW and ciliary sulcus diameters was not the main purpose of the study. Reinstein et al.[13] found a mean difference between WTW diameter and sulcus diameter of −0.89 ± 0.57 mm, which was statistically significant. Pop et al.[6] found that the WTW diameter measured by a caliper was significantly lower than the ciliary sulcus diameter measured using 50 MHz UBM. Our results agree with those of Reinstein et al.[13] and Pop et al.[6], although the difference we observed was small (0.41 mm). Feldman et al. also found that the difference between the ciliary sulcus diameter by 35 MHz UBM and the manually measured WTW diameter was not statistically significant (E. Feldman, et al. IOVS 2008; 49:E-Abstract 2815).

We found poor agreement and a weak correlation between the horizontal WTW diameter and the ciliary sulcus diameter, although there were statistically significant linear correlations. Our results agree with those in several studies.[4–7,13] There is considerable variation in WTW diameter and ciliary sulcus diameter between studies (Table 3).[4–7,12–15] Although the reason for this variation is unclear, it may be related to the performance of the measurement device, the fact that some

Table 3. Comparison of studies evaluating the agreement between WTW distance and ciliary sulcus diameter (horizontal meridian section).

		Patient Age (Y)					Correlation with Sulcus Diameter	
Study*	Eyes (n)	Mean ± SD	Range	Device	Measurement	Mean (mm) ± SD	(r Value)	P Value
Present	31	23 ± 5	—	35 MHz UBM	C-S diameter	12.06 ± 0.55	—	—
				35 MHz UBM	AC diameter	11.93 ± 0.44	0.869[§]	.001
				S-S topo	WTW diameter	11.65 ± 0.32	0.597[§]	.001
Reinstein[13]	40	35 ± 7	—	50 MHz UBM	C-S diameter	12.85 ± 0.69	—	—
				S-S topo	WTW diameter	11.96 ± 0.37	0.568[§]	.001
Feldman[†]	6	—	—	35 MHz UBM	C-S diameter	12.28	—	—
				S-S topo	WTW diameter	12.17	—	—
Oh[5]	28	28 ± 4	—	35 MHz UBM	C-S diameter	11.32 ± 0.40	—	—
				OCT	AC diameter	11.55 ± 0.88	0.924[§]	.001
				S-S topo	WTW diameter	11.74 ± 0.42	0.006[§]	.98
Fea[4]	10	—	20–79	MRI (1.5 tesla imager)	C-S diameter	11.70 ± 0.40	—	—
				S-S topo	WTW diameter	11.69 ± 0.40	0.005[¶]	.97
Werner[7]	12[‡]	—	—	Digital metric ruler	C-S diameter	11.32 ± 0.34	—	—
				Digital metric ruler	AC diameter	11.88 ± 0.25	—	—
				Digital metric ruler	WTW diameter	11.75 ± 0.43	0.406[¶]	.19
Pop[6]	43	34 ± 6	—	50 MHz UBM	C-S diameter	12.39 ± 0.58	—	—
				Caliper	WTW diameter	11.87 ± 0.49	0.05[§]	.78
Rondeau[14]	28	—	24–40	50 MHz UBM (custom device)	C-S diameter	12.35 ± 0.42	—	—
				50 MHz UBM (custom device)	AC diameter	12.10 ± 0.31	—	—
Pinero[12]	30	—	20–51	OCT	AC diameter	11.76 ± 0.52	—	—
				S-S topo	WTW diameter	12.25 ± 0.49		—
Kohnen[15]	52	35 ± 8	—	OCT	AC diameter	12.45 ± 0.53	—	—
				S-S topo	WTW diameter	11.84 ± 0.41	—	—

AC = anterior chamber; C-S diameter = ciliary sulcus diameter; MRI = magnetic resonance imaging; OCT = optical coherence tomography; S-S topo = Scanning-slit topography; UBM = ultrasound biomicroscopy; WTW = white to white
*First author
[†]E. Feldman, et al. IOVS 2008; 49:E-Abstract 2815
[‡]Phakic human eyes obtained from eyes banks within 24 hours of death
[§]Pearson correlation
[¶]Spearman correlation

UBM images must be assembled to measure the entire sulcus diameter, the definition of the cross-section in ciliary sulcus diameter, the individual variation in WTW and ciliary sulcus diameters, and the difference in populations (eg, in refraction, age) between studies. Regarding the need to assemble UBM images, the horizontal ciliary sulcus diameter by UBM should be evaluated from 1 image rather than from an image created from several images. In addition, ciliary sulcus diameter should be measured in the horizontal cross-section as precisely as possible. If the recorded image were not a horizontal cross-section, the ciliary sulcus diameter would be underestimated.

The conventional algorithm for the WTW diameter or the regression model described by Reinstein et al.[13] and Kim et al.[8] may be sufficient to determine the proper pIOL size because the conventional algorithm of posterior chamber pIOL size would be accurate in most cases and most manufacturers provide a limited number of posterior chamber pIOL sizes. However, our results show that there is individual specificity in WTW and ciliary sulcus diameters. Fea et al.[4] found that the ciliary sulcus diameter and other anterior chamber structures change significantly with age, which could cause inaccuracies in posterior chamber pIOL sizing. Kamiya et al.[17] showed that pIOL vaulting is dependent on WTW diameter and patient age, although most of the variance remains unexplained. In addition, in a study by Choi et al.,[3] the posterior chamber pIOL vault determined by UBM was significantly better than that determined by the conventional WTW method. Choi et al. also found that UBM was better than the conventional method in predicting ciliary sulcus diameter in the determination of posterior chamber pIOL length.

Therefore, these studies may elucidate which methods are best suited for accurate determination of posterior chamber pIOL size.

Also, although the mean difference between the diameter WTW and sulcus diameter may be 0.5 or 1.0 mm, this offset is currently used in the sizing formula. The potential for sizing complications when using WTW-based estimates comes from the high degree of variability in the difference between WTW and sulcus diameters (ie, the standard deviation of the difference). The standard deviation of 0.44 mm in our study indicates that the difference between WTW and sulcus diameters deviated from the mean difference by more than 0.50 mm in 25.0% of eyes and by more than 1.00 mm in 2.3% of eyes (calculated assuming a normal distribution). Given that IOLs are sized to the nearest 0.50 mm, an error in IOL sizing is possible. This deviation can be compared with the potential for lens-sizing errors if direct sulcus measurements are used; this can be calculated from the repeatability of sulcus measurements. However, the reliability of sulcus measurements could be improved by using multiple measurements rather than 2 repeated measurements because 1 of the measurements could be an outlier that would distort the findings. Thus, our results may have had more robust repeatability had we taken 5 or more measurements.

We found that anterior chamber diameter has a stronger correlation with ciliary sulcus diameter. Our results agree with those of Oh et al.[5] In addition, Kohnen et al.[15] found that anterior chamber measurements using optical coherence tomography showed good repeatability. Therefore, it might be better to estimate sulcus diameter using anterior chamber diameter rather than WTW diameter as an alternative to measuring with a high-frequency UBM device.

Our study has several limitations. Although we used undilated pupils to define the cross-section, the pupil may fluctuate slightly, leading to inaccurate positioning of the meridian section of ciliary sulcus diameter. However, we measured normal eyes, in which such effects would not be significant because the sampling rate of the UBM device was high and subjects maintained fixation and accommodation. Based on our observations, we propose that the ciliary sulcus should be measured under physiologic conditions and not under mydriasis. In the future, the largest diameter of the posterior chamber dimension and its orientation should be evaluated for more precise sizing of posterior chamber pIOLs.[14] Also, we cannot make a strong claim about the relationship between horizontal ciliary sulcus diameter and anterior chamber and corneal diameters because the sample size in our study was small and the age distribution was narrow. Further studies are needed to clarify the effects of aging on these measurements and their reproducibility.

In conclusion, we believe that high-frequency UBM is an effective tool for accurately determining pIOL size and that direct measurement of the ciliary sulcus will decrease the percentage of IOL sizing–related complications compared with the percentage when IOL sizing is based on WTW diameter.

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