

Original research

Adjustment formulae to improve the correlation of white-to-white measurement with direct measurement of the ciliary sulcus diameter by ultrasound biomicroscopy

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Abstract

Purpose: This study evaluates the correlation between horizontal white-to-white (WTW) distance using Caliper and Orbscan IIz with the ciliary sulcus diameter measured by high frequency ultrasound biomicroscopy (UBM) and presents an adjustment formula to improve the correlation.

Methods: We measured horizontal sulcus-to-sulcus (STS) dimension of 273 right eyes of 273 high myopic patients with 35 MHz UBM and horizontal WTW using Orbscan IIz and Caliper. Mean WTW diameter, differences, and the correlation of measurement methods were evaluated.

Results: The mean spherical equivalent was -8.79 ± 4.87 diopters. Mean horizontal STS dimension with UBM was 12.13 ± 0.45 mm (range, 10.81–13.42 mm). Mean WTW diameter in the Caliper method was 11.70 ± 0.40 mm (range, 10.6–12.8 mm) and 11.70 ± 0.40 mm (range, 10.5–13.1 mm) in the Orbscan method. Mean difference of UBM STS and WTW with Caliper was 0.48 ± 0.28 mm (range, -0.19 to 1.37 mm). Mean difference of UBM STS diameter and Orbscan WTW was 0.38 ± 0.31 mm (range, -0.64 to 1.29 mm). The Pearson correlations of WTW diameter measured by Caliper and Orbscan with UBM's STS diameter were 0.778 and 0.773, respectively. This difference diminished after adjustment. The 95% limit of agreement was almost the same in Caliper and Orbscan (-0.07 to 1.03 compared with -0.23 to 0.99).

Conclusion: There is a significant difference in measurements between STS diameter using UBM and WTW diameter utilizing Caliper and Orbscan. This difference diminished after our recommended adjustment.

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Keywords: Ultrasound biomicroscopy; Sulcus-to-sulcus diameter; White-to-white diameter; Phakic IOL; WTW adjustment formula

Introduction

Posterior chamber phakic intraocular lenses (pIOLs) are gaining popularity in the correction of moderate to high

ametropia^{1,2} up to 20 diopter. This is mainly due to the fact that this method is not dependent on the cornea ablation utilized in the laser vision correction. Therefore, it is able to correct high refractive errors without comprising the cornea integrity hence avoiding cornea ectasia.

Quality of vision in posterior chamber pIOLs may be better than corneal refractive surgery or anterior pIOLs due to its closer position to the nodal point of eye. This lens is folded and placed within the posterior chamber, behind the iris and anterior to crystalline lens in ciliary sulcus.

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It is necessary to measure the sulcus diameter for a proper pIOL fit. As the direct measurement of sulcus was technically impossible in the past, most surgeons used to measure the WTW with a Caliper or Orbscan and then adjust it by adding 0.5–1.00 mm for myopic eyes and subtracting 0.5 mm for hyperopic eyes.^{3,4}

One of the challenges in posterior chamber pIOLs surgery is the IOL sizing relying on sulcus-to-sulcus (STS) measurement. An undersized pIOL (low vault < 125 μ) results in the pIOLs rubbing against the natural crystalline lens, which may result in cataract development.¹ On the other hand, an oversized pIOL (high vault > 1000 μ) leads to iris pigment dispersion, angle crowding, peripheral anterior synechia and angle-closure glaucoma.¹

Correct pIOL size and vault are critical in proper implantation. The empirical methods for determining pIOLs length may not be reliable or reproducible since WTW horizontal corneal diameter does not always represent the STS diameter.^{5,6}

Visualizing the posterior chamber anatomy with ultrasound biomicroscopy (UBM) technology has facilitated the calculation of the STS diameter and pIOL size.

The availability of devices that can directly measure the dimensions of the posterior chamber may provide an opportunity to improve the predictability of the optimal size of pIOLs for implantation. A number of studies have been performed to investigate a possible correlation between WTW and STS diameters. All these studies have concluded that a direct measurement of sulcus diameter is more accurate when compared to using WTW measurement.^{7,8}

The aim of this study was to find an adjustment formula to improve the calculation of STS diameter and pIOL sizing. We assessed the correlation between two measurement methods of horizontal STS diameter with UBM and horizontal WTW distance with Caliper and Orbscan in a group of Iranian high myopic individuals presented for pIOL surgery.

Methods

This cross-sectional observational study evaluated 273 right eyes of 273 myopic patients assessed for posterior chamber pIOL surgery. All individuals with ocular comorbidities were excluded. The study was conducted according to the tenets of the Declaration of Helsinki. It was approved by the Ethical Committee of Eye Research Center, Rassoul Akram Hospital.

Horizontal WTW diameters were measured with Caliper and Orbscan Iiz (Bausch & Lomb Inc., Salt Lake City, USA). The STS diameters on horizontal meridian were measured with VuMax-II UBM with a 35-MHz transducer (Sonomed Inc. USA). Following capturing cross-sectional images at the horizontal meridian, STS diameters were measured using high zoom function by S.J.H. An example can be seen in Fig. 1.

Ultrasound biomicroscopy ciliary sulcus measurement

Topical tetracaine 0.5% was instilled to anesthetize the cornea before measurement. One of 3 available eyecups (18 mm, 20 mm or 22 mm) was placed over the eye depending

on the vertical palpebral aperture measurement. Then the individual was asked to fixate on a distant target with the other eye while the eyecup filled with sterile normal saline was fitted on the eye being examined.

The ciliary sulcus diameter was measured using VuMax-II UBM equipped with a 35-MHz transducer. In vivo, cross-sectional or transverse images can then be obtained detailing the cornea, iris, ciliary body, anterior chamber angle, and peripheral sclera to demonstrate structural relationships. Cross-sectional images were obtained at the horizontal meridians. Sulcus and anterior chamber (AC) diameters were measured in captured images using the zoom function to improve the accuracy of angle and sulcus measurements (Fig. 1).

All measurements were taken under normal light condition. Following capturing a video clip of eye, the clip was reevaluated, and the best captured image was selected (Fig. 1).

The selection criteria for best image were:

- 1) Horizontal capture
- 2) The capture that demonstrated the largest surface area of anterior and posterior surface of crystalline lens.
- 3) The capture that showed the best image of iris pigment epithelium.
- 4) The capture that recorded the best image of anterior chamber angle and angle to angle distance without any tilt.

To assess the reliability of the UBM measurements, 21 images were selected. Then they were unlabeled and randomly presented to S.J.H. for measurement on 5 different occasions. We used intra cluster correlation (ICC) to measure the repeatability of measurements. According to the Cicchetti (1994) ICC, any value more than 0.75 was considered an excellent reliability. ICC showed that measurements of STS by 35-MHz UBM were reliable as the ICC was 0.876 [95% confidence interval (CI): 0.787 to 0.940].

To measure the horizontal WTW diameter by Caliper, in all patients, the author (S.J.H.) used Asico Caliper RE 1500 with 1 mm unit. Under topical anesthesia, horizontal WTW diameters were measured 3 times and rechecked with a ruler under a slit-lamp microscope.

One expert operator took Orbscan Iiz (Bausch & Lomb Inc., Salt Lake City, USA) in all patients. Scans were taken in automatic release mode. If the system considered the measurement to be unreliable, the measurement was repeated.

The operator selected the best capture to determine the horizontal WTW diameter.

Statistical analysis

As can be seen from Table 1, the mean, standard deviation (SD), median and range were calculated. In order to check the normal distribution of differences between measurements, Kolmogorov-Smirnov test and Q-Q plot were utilized. Median, range, and 95% CI were calculated to assess the differences between the values of STS measured by UBM and WTW diameter measured by Orbscan II and Caliper. We also applied repeated measurements ANOVA to assess the

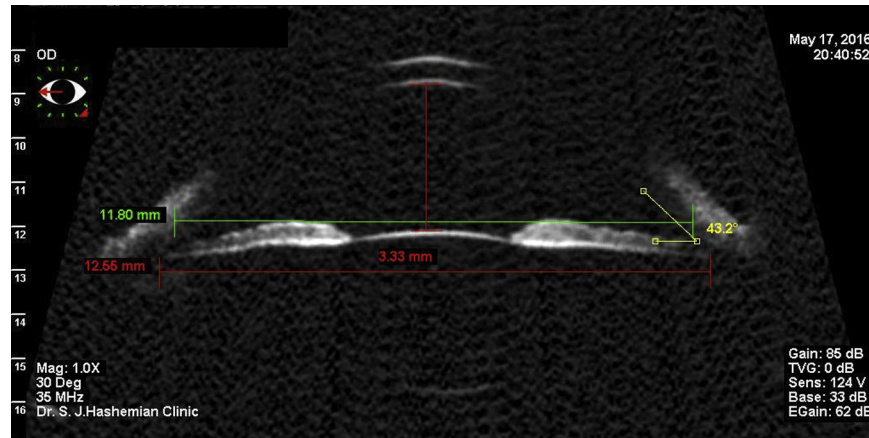


Fig. 1. An ultrasound biomicroscopy (UBM) image showing a ciliary sulcus measurement.

differences among the measurements. Then Bonferroni method was used to consider multiple comparisons in bivariate comparisons. Linear regression analysis was utilized to assess the partial correlation, ICC among these three methods. In addition, Bland-Altman, Scatter, and Folded cumulative distribution plots were used to evaluate the agreement between instruments in measuring WTW and STS diameter. Ninety-five percent limits of agreement (LoA) were also calculated as the mean \pm 1.96 SD of differences. We used regression analysis to suggest a correction factor for deriving accurate values of STS diameter from Orbscan II and Caliper system. In all estimations, the probable correlation of eyes was considered by cluster analysis. All statistical analyses were performed using PASW SPSS 17.0 (SPSS Inc., Chicago, IL). P values less than 0.05 were considered to be statistically significant.

Results

Two hundred and seventy-three subjects with the mean age of 28 ± 6.4 years (median: 26, range: 18 to 50) participated in this study. The mean sphere was -7.53 ± 4.94 diopter (median: -7 , range: -21 to 1), and mean cylinder was -2.53 ± 1.83 diopter (median: -2.5 , range: -7 to 0) which resulted in mean spherical equivalent of -8.79 ± 4.87 diopter (median: -7.9 , range: 22.75 to -1).

Table 1 shows the STS and WTW measurements measured with three methods. Based on these results, the UBM values were the highest, but the Caliper and Orbscan II measurements were noted to be more similar. STS values mean was 12.13 ± 0.45 (range, 10.81–13.42 mm). Mean WTW dimension with Caliper was 11.65 ± 0.37 mm (range, 10.6–12.8). Mean WTW dimension with Orbscan was 11.74 ± 0.42 mm (range, 10.5–13.1).

Mean difference of UBM STS diameter and Caliper WTW was 0.48 ± 0.28 mm (range, -0.19 to 1.37 mm). Mean difference of UBM STS diameter and Orbscan WTW was 0.38 ± 0.31 mm (range, -0.64 to 1.29 mm (Table 2)).

Mean differences of Orbscan WTW and Caliper WTW dimensions were 0.09 ± 0.17 mm (range, -0.30 – 1.10 mm).

In 37.1% of eyes, STS diameters and Caliper WTW distances were equal. In 37.1% of eyes, STS diameters were 0.5 mm larger than Caliper WTW distances. In 23% of eyes, STS diameters were 0.75–1.0 mm higher than Caliper WTW distances. In 2.8% of eyes, STS diameters were 1.25 mm greater than Caliper WTW distances.

Table 2 shows Pearson correlation of measurements of these methods before adjustments. The correlation of UBM STS, Caliper WTW and UBM STS and Orbscan WTW diameter was almost the same. Although their ICC was higher in Orbscan, both values were not significantly high (Table 2).

Using regression analysis, we obtained the corrected version of these measurements which were as: Adjusted Caliper WTW = $0.796 + 0.973 \times$ Caliper WTW and Adjusted Orbscan WTW = $2.288 + 0.838 \times$ Orbscan WTW. These adjustments improved the ICC to 0.775 and 0.700, respectively.

We found a statistically significant difference in measurements among Caliper WTW and Orbscan WTW with UBM STS diameter; however, this difference diminished after applying the proposed adjustment (Table 2).

The 95% LoA was almost the same in Caliper and Orbscan (-0.07 to 1.03 in comparison with -0.23 to 0.99 , Table 2). This similarity remained after the adjustment (Table 2). The folded cumulative distribution plots also suggest the similarity of their agreement with UBM (Figs. 1–3).

Table 1
Descriptive data of different measurements.

	Mean	SD	Minimum	Percentile 25	Median	Percentile 75	Maximum
UBM STS	12.13	0.45	10.81	11.85	12.14	12.42	13.42
Caliper WTW	11.65	0.37	10.60	11.50	11.70	12.00	12.80
Orbscan WTW	11.74	0.42	10.50	11.50	11.70	12.00	13.10

SD: Standard deviation; UBM: Ultrasound biomicroscopy; STS: Sulcus-to-sulcus; WTW: White-to-White.

Table 2
The Pearson partial correlation, intra cluster correlation (ICC) and limits of agreement (LoA) of three modalities.

	UBM STS – Caliper WTW	UBM STS – Orbscan WTW	UBM STS – Adjusted Caliper WTW ^a	UBM STS – Adjusted Orbscan WTW ^b
Pearson partial correlation	0.778	0.773	0.778	0.773
ICC	0.454	0.517	0.775	0.700
ΔMean ± SD (mm)	0.48 ± 0.28	0.38 ± 0.31	−0.01 ± 0.28	0 ± 0.31
95% CI	0.44 to 0.52	0.34 to 0.42	−0.05 to 0.03	−0.04 to 0.04
P-Value ^c	<0.001	<0.001	>0.99	>0.99
Δ Median (range)	0.46 (−0.19 to 1.37)	0.39 (−0.64 to 1.29)	−0.02 (−0.69 to 0.9)	0 (−0.84 to 0.93)
95% LoA	−0.07 to 1.03	−0.23 to 0.99	−0.56 to 0.54	−0.61 to 0.61

UBM: Ultrasound biomicroscopy; STS: Sulcus-to-sulcus; WTW: White-to-White; ICC: Intra cluster correlation; Δ: Inter device difference; SD: Standard deviation; CI: Confidence interval; LoA: Limits of agreement.

^a Adjusted Caliper WTW = $0.796 + 0.973 \times \text{Caliper WTW}$.

^b Adjusted Orbscan WTW = $2.288 + 0.838 \times \text{Orbscan WTW}$.

^c Based post hoc analysis on a repeated measure ANOVA, multiple comparison considered by Bonferroni method.

Discussion

The pIOL implantation has gained more popularity as an alternative option for correcting refractive errors in particular high myopia. UBM is the only device that directly measures the ciliary sulcus diameter; however, due to its high cost, it is not widely available at many surgical centers. Therefore, WTW measurements with Caliper and Orbscan have been used to estimate STS diameters. Undoubtedly, these measurements have not been demonstrating the precise measurements of STS, hence resulting in errors (Fig. 4).

Having evaluated WTW measurements using Caliper and Orbscan and STS diameter using 35 MHz UBM and assessed their correlation in myopic patients, our study proposed a formula to improve the correlations of these measurement methods.

In our study, the mean horizontal STS diameter using 35 MHz UBM was 12.13 mm, and the mean horizontal WTW diameter measured by Caliper and Orbscan were 11.65 mm and 11.74 mm, respectively. Mean difference of UBM STS diameter and Caliper and Orbscan WTW were 0.48 mm and 0.38 mm, respectively. We found there was no statistically significant correlation between STS diameter and horizontal

WTW diameter measured by Caliper and Orbscan. The Pearson's correlation between UBM STS and Caliper WTW was 0.778 and 0.773 between UBM STS and Orbscan WTW. This correlation was stronger between Caliper WTW and UBM STS diameter. We found a statistically significant difference in measurements among Caliper WTW and Orbscan WTW with UBM STS; however, this difference diminished after adjustment.

The 95% LoA was almost the same in Caliper and Orbscan −0.07 to 1.03 compared with −0.23 to 0.99 (Table 2). This similarity remained after the adjustment (Table 2). According to the LoA between devices, we can conclude that even after adjustment, there is no agreement between measurements.

There have been several studies that measured WTW and ciliary sulcus diameters and evaluated their correlations. The measurement results were very variable. Some studies found no statistical correlation between WTW and STS diameter^{5,7,9}; however, some others showed a relative but weak correlation between STS and WTW.^{7,9–11}

We believe this variability in results may be related to the device type, technical variation, different parameters definition, and particularly variations in study populations in terms of age, refraction, and race.

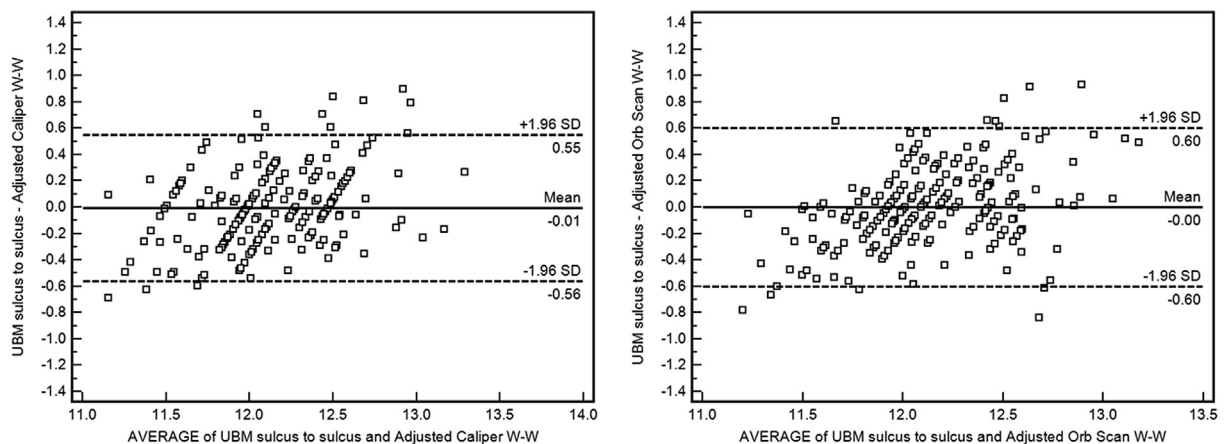


Fig. 2. The Bland Altman plot demonstrating the agreement between the raw measurement of Caliper and Orbscan compared to ultrasound biomicroscopy (UBM) measurements.

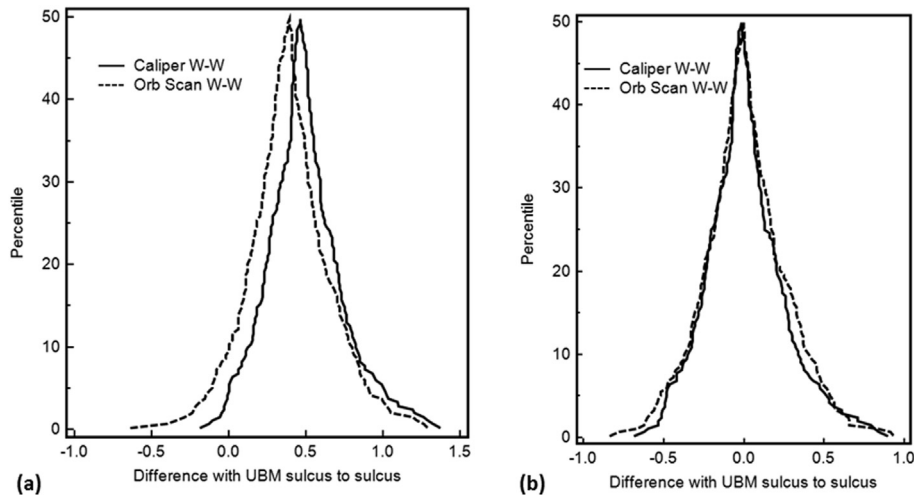


Fig. 3. The Bland Altman plot demonstrating the agreement between the adjusted measurement of Caliper and Orbscan compared to ultrasound biomicroscopy (UBM) measurements.

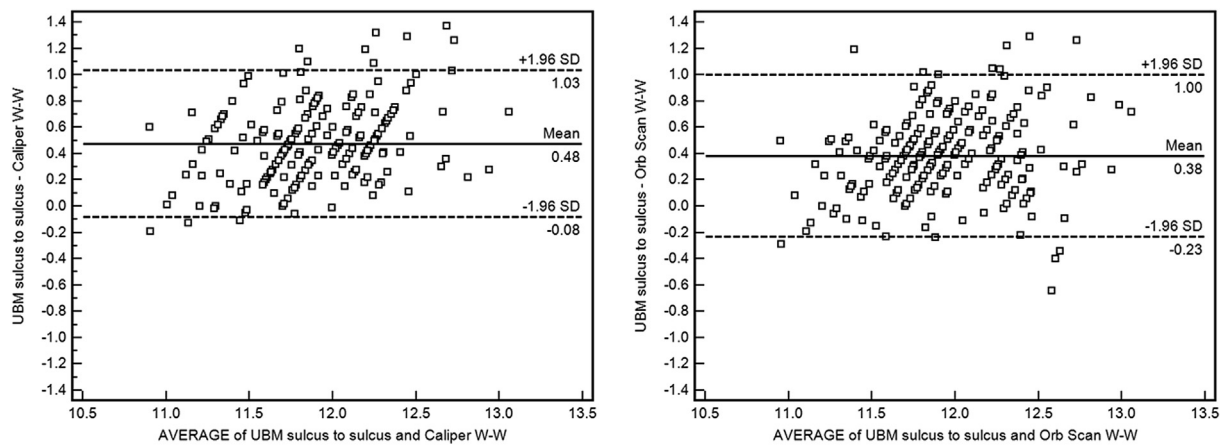


Fig. 4. The folded cumulative distribution plots demonstrating the discrepancy of Caliper and Orbscan measurements compared to ultrasound biomicroscopy (UBM) measurements before (a) and after (b) adjustment.

Werner et al.¹⁰ who found no correlation between horizontal WTW and STS diameters, only evaluated 12 cadaver eyes. In Reinstein et al.⁹ study, they evaluated 40 eyes of 20 patients with high myopia who were relatively similar to our study population. At their study, the mean horizontal STS diameter was 12.85 mm using 50 MHz UBM, and the mean Orbscan WTW diameter was 11.96 mm. Their mean difference between STS and WTW diameter was -0.89 mm. They also found a statistically significant correlation between WTW and STS diameters ($P < 0.001$) and a Pearson's correlation coefficient of 0.323, a relatively weak clinical correlation.

In Pop et al.⁵ study, the WTW diameter measured with Caliper was significantly lower than STS diameter measured by 50 MHz UBM which were 11.87 and 12.39, respectively. Kawamori⁷ studied 29 myopic eyes with a mean spherical equivalent refraction of -3.46 . Among these eyes, the mean WTW measured by Orbscan was 11.65, and STS diameter measured by 35 MHz UBM was 12.06 with a mean difference of 0.41 mm. They found a relative poor agreement between ciliary sulcus and WTW diameters (ICC, 0.679; 95% CI), which

demonstrated a statistically significant linear correlation and a weak overall correlation between STS and WTW diameters ($r = 0.597$, $P < 0.001$).

In Feldman et al.'s¹² study the mean STS diameter using 35 MHz UBM was noted to be 12.28 mm, which was very close to the mean WTW diameter of 12.17 mm using Orbscan II. They also found that the difference between STS and WTW diameter was not statistically significant, but the major limitation of their study was their small sample size of only 6 eyes.

Oh et al.¹³ evaluated 28 eyes and found that the Orbscan horizontal WTW diameter was slightly larger than horizontal STS diameter measured by 35 MHz UBM. The correlation between them was not significant. In contrast, our study demonstrated the mean measurement in the UBM group was higher than the Orbscan group. In general, measurements of WTW and STS do not correlate highly,^{9,10,14} although some authors have found varying degrees of correlation.¹⁵

We acknowledge this study has a few limitations. Our study did not include hypermetropic or emmetropic individuals. We did not study or analyze the finding according to age and sex.

To our knowledge, our study has been the largest one evaluating the measurements of STS and WTW diameter in high myopic patients with UBM, Caliper, and Orbscan, respectively. Based on our findings, there is a statistically significant difference in measurements among Caliper WTW and Orbscan WTW diameter with UBM STS diameter. We used regression analysis to suggest a correction factor for deriving accurate values of STS diameter from Orbscan II and Caliper system. This difference diminished after adjustment.

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