

Direct Measurement of the Ciliary Sulcus Diameter by 35-Megahertz Ultrasound Biomicroscopy

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Purpose: To measure the ciliary sulcus diameters in 4 different axes and to determine the correlation with white-to-white distance.

Design: Cross-sectional observational study.

Participants: Fourteen normal volunteers with no evidence of ocular disease.

Methods: Twenty-eight eyes were scanned using a 35-megahertz (MHz) ultrasound biomicroscopy (UBM) in sequential meridional scan planes at 45° increments. Horizontal white-to-white distance was measured using Orbscan IIz (Bausch & Lomb-Orbtek, Inc., Salt Lake City, UT).

Main Outcome Measures: Ciliary sulcus diameter, anterior chamber diameter, white-to-white distance, and coefficient of variation.

Results: The coefficient of variation for 35-MHz UBM was 0.90%. The mean diameters \pm standard deviations of ciliary sulci were 11.55 \pm 0.38 mm at 45°, 11.99 \pm 0.36 mm at 90°, 11.54 \pm 0.36 mm at 135°, and 11.32 \pm 0.40 mm at 180°. In all eyes, vertical diameters were greater than horizontal diameters. The mean difference between vertical and horizontal diameters was 0.67 \pm 0.26 mm (range, 0.36–1.13 mm), and this was statistically significant ($P < 0.001$). Horizontal sulcus diameters and horizontal white-to-white distances were not correlated ($r = 0.006$; $P = 0.976$).

Conclusions: The posterior chamber appears to have a vertically oval shape. The white-to-white technique is inaccurate at predicting the horizontal diameter of the ciliary sulcus. The 35-MHz UBM may provide a good means of measuring the ciliary sulcus diameter for the implantation of a posterior chamber phakic intraocular lens. *Ophthalmology* 2007;114:1685–1688 © 2007 by the American Academy of Ophthalmology.

The implantation of phakic intraocular lenses (IOLs) has gained popularity for the treatment of high ametropia because their implantation can avoid some complications of corneal refractive surgeries and the loss of accommodation associated with clear lens extraction.¹ This procedure is also a good alternative for patients with a thin cornea that is insufficient for corneal refractive surgery.² Several authors have demonstrated excellent refractive results with this technique.^{3–5}

The Visian Implantable Collamer Lens (ICL; STAAR Surgical AG, Nidau, Switzerland) is a popular posterior chamber phakic IOL. It has many advantages such as a

lower risk of endothelial cell loss, minimal inflammation without angle-related complications, and the ability to be implanted through a small incision to maintain astigmatic neutrality and to minimize surgical trauma.⁶ However, the higher rate of postoperative cataract formation remains a clear disadvantage, and low vaulting is important with respect to postoperative cataract formation.⁷ An undersized ICL may result in low vaulting and can lead to cataract formation as a result of chronic crystalline lens touch.^{1,7–9} It also may cause free rotation because of insufficient sulcus support.¹⁰ However, an oversized ICL may induce excessive vaulting, leading to pigment dispersion and angle crowding, and introduces a potential for angle-closure glaucoma.¹¹ Therefore, accurate ICL sizing is critical for reducing complication rates because most ICL complications are the result of improper sizing.^{12,13}

Horizontal white-to-white measurement is an indirect method used to estimate the ciliary sulcus diameter. However, it was reported that there is no correlation between white-to-white distance and sulcus diameter.^{14–16} Ultrasound biomicroscopy (UBM) with a 50-megahertz (MHz) transducer has been used to measure ciliary sulcus diameter directly.¹⁶ However, some 50-MHz UBM instruments have an important limitation, namely, that 2 or 3 images have to be assembled to measure sulcus diameter, which has a high

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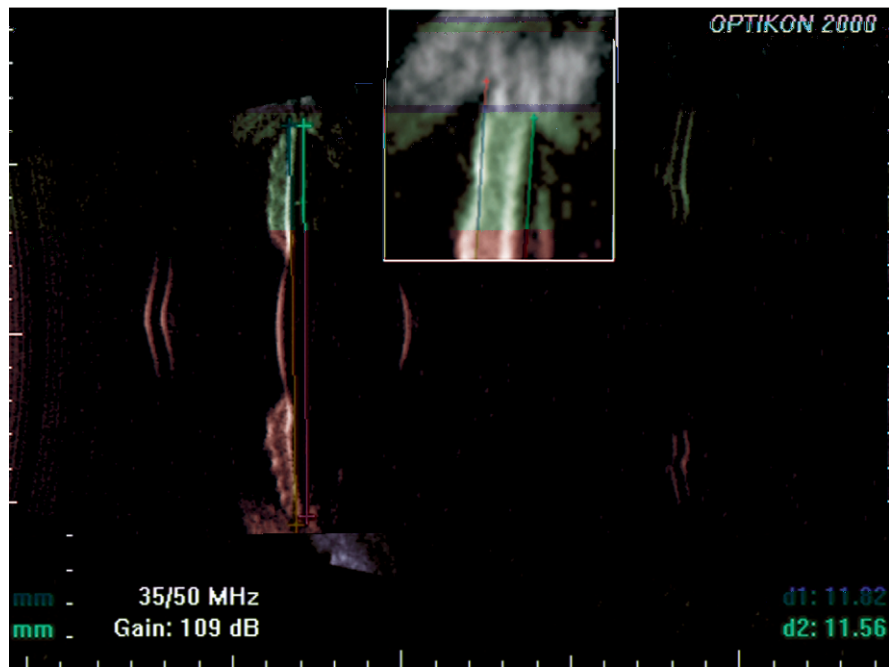


Figure 1. A typical scan of 35-megahertz ultrasound biomicroscopy. Angle-to-angle diameter and sulcus-to-sulcus diameter are depicted with the red line (d1) and green line (d2), respectively. **Inset,** Magnified image of the zoom function, which improves the accuracy of angle and sulcus measurements. dB = decibels.

risk of producing erroneous measurements.¹⁶ Recently, a 35-MHz UBM was developed, and this device seems to be more accurate than other methods because it can measure ciliary sulcus diameter from 1 image, even though the image resolution is not as good as that of 50-MHz UBM. In the present study, we measured ciliary sulcus diameters in 4 different axes using a 35-MHz UBM and evaluated the correlation with white-to-white distances.

Patients and Methods

This observational UBM study was conducted at the Department of Ophthalmology, Korea University College of Medicine. Informed consent was provided by the participants, and the principles outlined in the Declaration of Helsinki were followed in this study. At the time of obtaining the measurement, no approval by an institutional review board or ethical committee was required for this study in Korea.

We evaluated 28 eyes of 14 volunteers who had no evidence of ocular disease. The mean age \pm standard deviation of the 8 men and 6 women was 28.36 ± 3.66 years (range, 23–37 years). Horizontal white-to-white distances were measured by scanning slit topography using Orbscan IIz (Bausch & Lomb-Orbtek, Inc., Salt Lake City, UT).

Topical proparacaine 0.5% (Alcaine, Alcon, Fort Worth, TX) was instilled to anesthetize the cornea before measurement. One of 3 differently sized eyecups (20 mm, 22 mm, and 24 mm) was inserted depending on the ocular aperture size. An eyecup was filled with sterile normal saline and the subject was asked to fixate on a ceiling target with the fellow eye to maintain accommodation and fixation. Diameters of the ciliary sulcus were measured using a Hiscan UBM (Optikon, Roma, Italy) equipped with a 35-MHz transducer. The wide view probe of the 35-MHz transducer en-

ables up to $70 \mu\text{m}$ of axial and lateral resolution in the anterior segment with the penetration of 7 to 8 mm (Fig 1). Cross-sectional images were obtained on the 4 meridians: vertical (90°), horizontal (180°), temporal oblique (45°), and nasal oblique (135°). 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, inset). One experienced technician measured all eyes using this method. For 12 eyes of 6 subjects, measurements of sulcus diameter were performed 5 times to estimate the repeatability of this method using coefficients of variation.

The paired *t* test was used to analyze differences between vertical and horizontal diameters for the sulcus and AC diameters for all 28 eyes. The correlations between white-to-white distances and sulcus or AC diameters were assessed using Pearson's correlation analysis. *P* values less than 0.05 were considered to be statistically significant.

Results

The coefficient of variation for intraobserver sulcus diameter measurement for this UBM was 0.90% (± 0.26), demonstrating the high reliability of the 35-MHz UBM. The mean horizontal white-to-white distance measured using the Orbscan IIz was 11.74 ± 0.42 mm.

Mean diameters of ciliary sulci \pm standard deviations were 11.55 ± 0.38 mm at 45° , 11.99 ± 0.36 mm at 90° , 11.54 ± 0.36 mm at 135° , and 11.32 ± 0.40 mm at 180° . The mean vertical diameter was longest and the mean horizontal diameter was shortest. The mean diameters of 2 oblique meridians were almost same, and these were between the mean diameters of vertical and horizontal meridians. In all eyes, vertical diameters were longer than horizontal diameters, and vertical diameters were the longest among the 4 meridians. The mean difference between vertical and hori-

Table 1. The Relationship between Ciliary Sulcus Diameters and Anterior Chamber Diameters for the 4 Meridians

	Ciliary Sulcus Diameter (mm), Mean±Standard Deviation	Anterior Chamber Diameter (mm), Mean±Standard Deviation	Correlation Coefficient (P value)
45°	11.54±0.75	11.75±1.00	0.926 (0.000)
90°	11.99±0.73	12.00±1.02	0.840 (0.000)
135°	11.55±0.77	11.80±0.90	0.888 (0.000)
180°	11.32±0.72	11.55±0.88	0.924 (0.000)

zontal diameters was 0.67 ± 0.26 mm (range, 0.36–1.13 mm), and this difference was statistically significant ($P < 0.001$).

Mean AC diameters \pm standard deviations were 11.75 ± 1.00 mm at 45°, 12.00 ± 1.02 mm at 90°, 11.80 ± 0.90 mm at 135°, and 11.55 ± 0.88 mm at 180°. The mean difference between vertical and horizontal diameters was 0.45 ± 0.50 mm (range, -0.32 to 1.10 mm), and this was statistically significant ($P < 0.001$). For AC diameters, the vertical diameter was longer than the horizontal diameter in 75% of eyes. The longest axis was vertical in 57.1%, horizontal in 10.7%, at 45° in 14.3%, and at 135° in 17.9% of the observed eyes.

No correlation was found between horizontal sulcus diameters and horizontal white-to-white distances ($r = 0.006$; $P = 0.976$) or between horizontal AC diameters and horizontal white-to-white distances ($r = 0.143$; $P = 0.467$). However, the relationship between ciliary sulcus diameters and AC diameters was significantly correlated for all 4 meridians (Table 1).

Discussion

Diameters of ciliary sulci were evaluated in human postmortem eyes to determine the range of haptic size for the sulcus fixation of posterior chamber IOL in the past.^{17–20} However at present, the sulcus diameter can be measured directly in living subjects by UBM and is considered an important determinant for posterior chamber phakic IOL implantation.

In this study, we used a 35-MHz UBM to measure sulcus diameters rather than a 50-MHz UBM. This method allows the measurement of sulcus diameters using a single image and showed good repeatability in the present study. The mean vertical diameter was greatest and the mean horizontal diameter was smallest among the 4 different meridians. Furthermore, in all eyes, vertical diameters were longer than horizontal diameters and vertical diameters were the longest. These results imply that the posterior chamber has a vertically oval shape, which may influence the stability of an implanted ICL. Stability is more important for toric ICLs. Although these ICLs can correct both myopia and astigmatism, if a toric ICL were rotated, it would induce visual impairment. Therefore, the prevention of ICL rotation is necessary for toric ICLs, and the placement of a toric ICL in the vertical meridian, which is the longest axis, may reduce the risk of rotation usefully.

Posterior chamber dimensions are the subject of continued debate. The mean vertical diameter of the ciliary sulcus was reported to be longer than the mean horizontal diameter

in the studies on human postmortem eyes, in which sulcus diameters were measured by caliper after fixation in a 4% formalin solution.^{19,20} However, Rondeau et al²¹ measured sulcus diameters in living subjects using a 50-MHz UBM and reported that the largest diameter was in the horizontal meridian. Although some 50-MHz UBM machines have a limitation that the sulcus diameter must be measured after assembling 2 or 3 separate images,¹⁶ the 50-MHz very high-frequency UBM used by Rondeau et al can produce a single image from sulcus to sulcus through arc scanning and digital processing. This machine seems to be less subject to errors. At present, we do not know the exact reasons for the differences between our study and the study by Rondeau et al. However, one of the possible reasons for the differences is sampling bias. Sampling bias might have occurred in either study because of small sample size: both studies evaluated only 28 eyes of 14 subjects. Different UBM systems or different races of the subjects may be another reason for the differences.

Regarding AC diameters, Baikoff et al²² evaluated in vivo AC dimensions using an optical coherence tomographer prototype and reported that in 74% of observed eyes, the vertical diameter was larger than the horizontal diameter by at least $100 \mu\text{m}$. Werner et al¹⁴ also demonstrated that the vertical axis generally was greater than the horizontal axis in cadaver eyes. In the present study, it was found that vertical AC diameters were longer than horizontal diameters in 75% of eyes and that the longest AC meridian was vertical in 57.1%, horizontal in 10.7%, at 45° in 14.3%, and at 135° in 17.9% of the observed eyes. Although it is not possible to explain why these differences exist between sulci and AC diameters, the degrees of angle apposition in the 4 different AC meridians may affect precise measurements and thus may influence the results of AC diameters. This also may explain the higher standard deviations observed in AC measurements compared with sulcus measurements.

Traditional estimations of sulcus size using horizontal white-to-white distance are inadequate because limbal size alone cannot predict sulcus size.¹⁶ Several authors have reported no correlation between horizontal white-to-white distance and sulcus diameter,^{14–16} and the present study concurs with this finding. However, strong positive correlations between AC diameter and sulcus diameter were observed in all 4 meridians. Therefore, AC diameter seems to be helpful for estimating sulcus sizes in situations where sulcus diameters cannot be measured directly with UBM.

The present study has limitations. For example, the sample size was relatively small, the subject's age range was narrow, and the effect of accommodation was not considered, although its status may influence sulcus diameter measurements. Especially because of the limitation of the relatively small sample size, we can not make a strong claim in this study.

In conclusion, the posterior chamber appears to have a vertically oval shape. Horizontal white-to-white distance was not correlated with horizontal sulcus diameter. The 35-MHz UBM may be a satisfactory method for measuring sulcus diameters accurately for ICL sizing.

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