Anterior Chamber and Aqueous Depth Measurement in Pseudophakic Eyes: Agreement Between Ultrasound Biometry and Scheimpflug Imaging

Giacomo Savini, MD; Kenneth J. Hoffer, MD, FACS; Michele Carbonelli, MD

ABSTRACT

PURPOSE: To compare anterior chamber depth (ACD) and aqueous depth (AQD) measurements provided by a Scheimpflug camera combined with corneal topography to those obtained by immersion ultrasound (US) biometry when assessing the distance between the cornea and intraocular lens (IOL) in pseudophakic patients.

METHODS: In a sample of 40 consecutive patients, each patient underwent measurements of ACD and AQD by means of the two techniques. **AQ1**Scheimpflug measurements were obtained by manually tracing a line between the anterior surface of the IOL and the central cornea. Results were compared by *t* test. Agreement was evaluated by Bland–Altman plots with 95% limits of agreement (LoA).

RESULTS: There was no statistically significant difference between the AQD as measured by US (3.95 ± 0.34 mm; range: 3.39 to 4.74 mm) and the AQD as measured by Scheimpflug photography (3.96 ± 0.34 mm; range: 3.41 to 4.77 mm; *P* = .3187). The statistically (but not clinically) significant difference between the ACD as measured by US (4.54 ± 0.37 mm; range: 3.93 to 5.35 mm) and Scheimpflug photography (4.58 ± 0.34 mm; range: 4.03 to 5.36 mm; *P* = .0024) disappeared after setting the US speed for ACD at 1,545 m/sec (mean ACD: 4.58 ± 0.37 mm; range: 3.96 to 5.39 mm). The 95% LoA ranged between -0.15 and +0.18 mm for AQD and between -0.12 and +0.21 mm for ACD.

CONCLUSIONS: In pseudophakic eyes, the manual ACD and AQD measurements obtained from the Scheimpflug camera combined with corneal topography are not significantly different compared to those provided by US and therefore can be considered interchangeable with the latter.

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The position of the intraocular lens (IOL) relative to the central anterior corneal apex is a major factor affecting the refractive outcome of cataract surgery, especially in short eyes requiring high power IOLs.[1,2] When IOL power is calculated, this position has to be predicted by both theoretical thin lens formulas and thick lens methods such as ray tracing.[3-9]

Clinically, there is little need to routinely measure the IOL position postoperatively. However, this measurement can become important in several situations: (1) when a new method to predict the IOL position has to be validated in a sample of patients who had surgery, (2) when the behavior of an IOL in the bag is being assessed (eg, three-piece vs one-piece IOLs), (3) when the efficacy of accommodating IOLs has to be confirmed by evaluating the forward movement of their anterior surface, and (4) when the refractive outcome is different than expected and the surgeon needs to rule out a malpositioned IOL as the cause of the refractive error.

Postoperative measurements of the IOL position can be performed by several technologies. The first instruments to become available were optical pachymeters attached to Haag-Streit and Zeiss slit-lamps. These were used by Binkhorst in the 1970s to measure the movement of iris clip IOLs from the prone to supine position and later in the 1980s by Hoffer to establish the anatomical relationship between axial length and the postoperative IOL position.[10-12] Ultrasound (US) biometry was used later and has consequently been regarded by some as the benchmark for comparison.[9,13-17] More recently, several optical methods have been re-introduced: optical pachymetry,[16,18] Scheimpflug imaging,[16,17,19-21] scanning-slit topography,[16] partial coherence interferometry,[22-24] and optical coherence tomography.[24-26] Among these technologies, Scheimpflug imaging has gained wide popularity due to the

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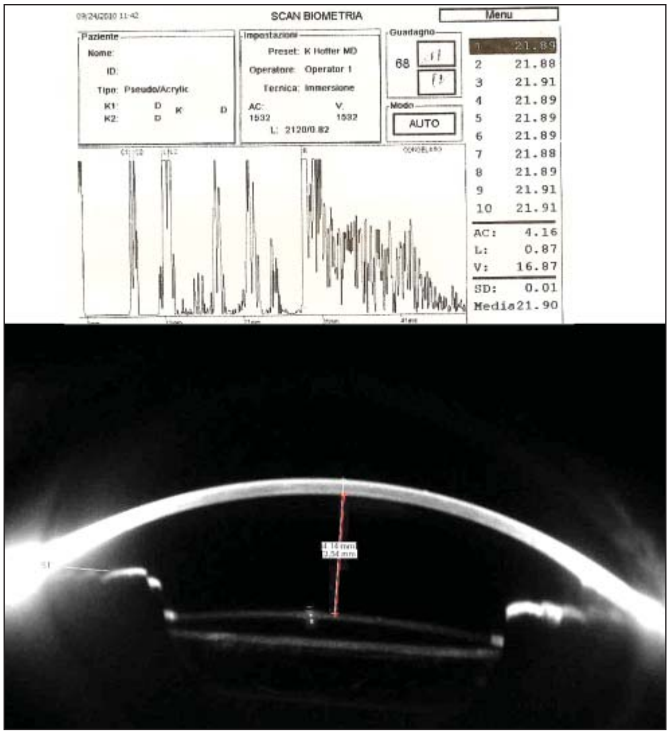

Figure 1. (Top) immersion ultrasound biometry shows a distance of 4.16 mm between the corneal epithelium (C1) and the anterior intraocular lens surface (L1). (Bottom) In the same eye, the caliper between the corneal epithelium and the anterior intraocular lens surface (white line) shows a distance of 4.14 mm, whereas the distance between the corneal endothelium and the lens is 3.54 mm (red line).

large variety of anterior segment measurements it can provide and constant advances in software and high measurement repeatability.[27] We have previously shown that Scheimpflug measurements, as provided by a single rotating Scheimpflug camera (Pentacam; Oculus Optikgerate GmbH, Wetzlar, Germany), can be considered interchangeable with those provided by US if the IOL position is manually measured.[28] Since that study was done, the number of commercially available Scheimpflug cameras has increased. One of the latest models is the Sirius (C.S.O., Firenze, Italy), which combines a rotating Scheimpflug camera and a Placido-disc corneal topographer. Anterior segment measurements by this device have already shown good repeatability.[29,30] The purpose of this study was to compare the measurements of this device to those obtained by immersion US biometry when assessing the distance between the cornea and IOL in patients who had undergone cataract surgery.

PATIENTS AND METHODS

A sample of consecutive patients undergoing routine postoperative ophthalmological examinations 6 or more months after cataract surgery was enrolled. The study was conducted in accordance with the ethical standards stated in the 1964 Declaration of Helsinki and approved by the local clinical research ethics committee with adequate informed consent obtained.

Each patient underwent measurement of the anterior chamber depth (ACD) (ie, the distance from the central corneal epithelium to the central anterior IOL surface) and aqueous depth (AQD) (ie, the distance from the central corneal endothelium to the central anterior IOL surface).[31] The measurements were made with the Sirius (software version 2.0) and immersion US biometry (Ocuscan; Alcon Laboratories, Fort Worth, TX). With both methods, the examination was performed under mydriasis to enable better visualization of the IOL optic, which can be difficult with a small pupil.

Measurements with the Sirius were performed according to the manufacturer's guidelines. The device was brought into focus and the patient's eye was aligned along the visual axis by means of a central fixation light. Patients were instructed to blink completely just before each measurement. The scanning process acquires a series of 25 Scheimpflug images (meridians) and one Placido top view image. The ACD and AQD measurements were manually performed by analyzing a single Scheimpflug image with the caliper tool included in the internal software (**Figure 1**). Because multiple images of the anterior chamber were generated for each eye, we arbitrarily selected one scan allowing visualization of the whole IOL optic (the horizontal scan was used in all cases). A line was traced between the anterior surface of the IOL and the central cornea. Automatic readings of ACD and AQD were discarded due to the risk of erroneous detection of the anterior IOL surface, as we have already observed to occur with the Pentacam.[28]

Immersion US biometry was performed, as previously described, by means of a 10-Mhz A-scan probe, with the US speed for the anterior chamber set at 1,532 m/sec.[28] In addition, because the value of 1,532 m/sec does not account for the US speed through the cornea, which is 1,641 m/sec,[32] we also calculated the ACD depth with the US speed set at 1,545 m/sec (see the **Appendix** for the formula leading to this speed).

Statistical Analysis

Because some patients had undergone surgery in both eyes, only one eye for each subject was used for statistical analysis (in the event of bilateral surgery, it was randomly chosen). The Gaussian distribution was assessed by the Kolmogorov–Smirnov test. Measurements were compared by a paired *t* test and linear regression was used to quantify how well the measurements varied together. Statistical analyses were performed using GraphPad InStat (Version 3a) for Macintosh (GraphPad Software, San Diego, CA).

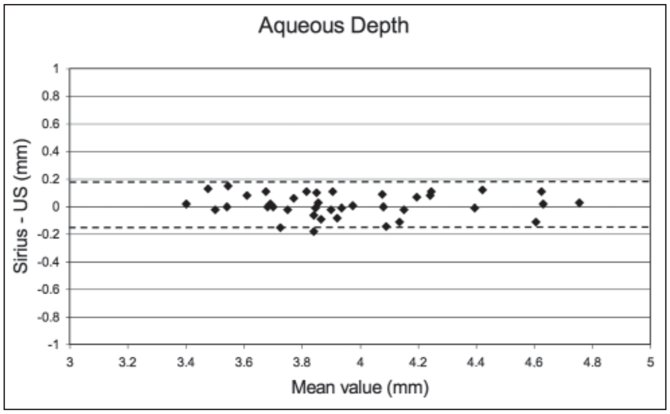

Figure 2. Bland–Altman plot showing the 95% limits of agreement (dotted lines) between Scheimpflug imaging and immersion ultrasound biometry (US) for aqueous depth measurements.

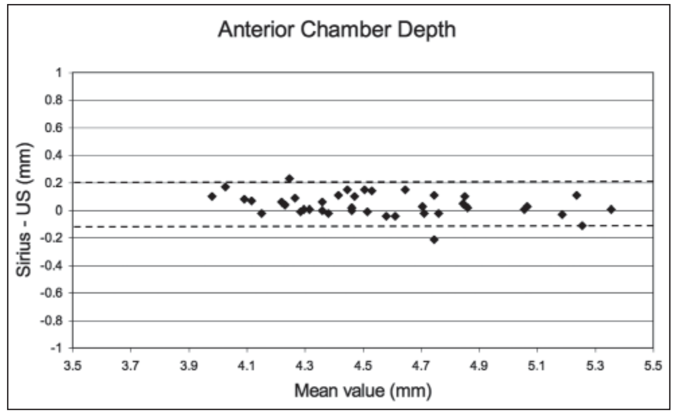

Figure 3. Bland–Altman plot showing the 95% limits of agreement (dotted lines) between Scheimpflug imaging and immersion ultrasound biometry (US) for anterior chamber depth measurements.

The relationship between pairs of measurements was also assessed by means of Bland–Altman analysis.[32]

Repeatability and Reproducibility

To further validate the ACD and AQD measurements provided by this rotating Scheimpflug camera, we also evaluated their intra-observer repeatability and inter-observer reproducibility. For this purpose, we enrolled a separate sample of 10 consecutive patients who had undergone phacoemulsification with implantation of the same IOL model. Three repeated consecutive measurements (under mydriasis) were taken by one examiner to assess intra-observer repeatability; one more measurement was taken by a second masked examiner and compared to the first measurement of examiner 1 to assess inter-observer reproducibility. The assessment of both repeatability and reproducibility was based on test–retest variability and the coefficient of variation (COV). Test–retest variability was calculated by multiplying the pooled within-subject standard deviation (s_w) by 2.77. We can expect that the difference between two measurements for the same patient will be less than 2.77 s_w for 95% of pairs of observations.[33] The COV was calculated as the s_w divided by the average of the measurements and was expressed as a percentage.

Calculating the s_w allowed us to calculate the sample size needed for this study. Using PS version 3.0.12 (http://biostat.mc.vanderbilt.edu/twiki/bin/view/Main/PowerSampleSize, checked on August 22, 2012), a sample size of 4 eyes per group was estimated to detect a difference in ACD of 0.1 mm with a standard deviation of ±0.04 mm and a power of 90% at a significance level of 5%.

RESULTS

Forty consecutive patients (25 women and 15 men) who had undergone uneventful phacoemulsification and IOL implantation in the capsular bag were enrolled. Their mean age was 76.1 ± 6.4 years. Surgery had been performed a mean of 34.5 ± 27.3 months earlier (range: 6 to 105 months). All eyes received an AcrySof MA60AC IOL (Alcon Laboratories) with a mean power of 21.0 ± 4.5 D (range: 7 to 29 D). Twenty-four right eyes and 16 left eyes were analyzed.

There was no statistically significant difference between the AQD as measured by US biometry (3.95 ± 0.34 mm; range: 3.39 to 4.74 mm) and the AQD as measured by Scheimpflug photography (3.96 ± 0.34 mm; range: 3.41 to 4.77 mm; P = .3187). A statistically (but not clinically) significant difference was detected between the ACD as measured by US biometry (4.54 ± 0.37 mm; range: 3.93 to 5.35 mm) and the ACD as measured by Scheimpflug photography (4.58 ± 0.34 mm; range: 4.03 to 5.36 mm; P = .0024). A statistically significant correlation between the measurements of the two technologies was observed for both AQD (r = 0.97, r^2 = 0.94, P < .0001) and ACD (r = 0.98, r^2 = 0.96, P < .0001). The difference between ACD measurements was no more statistically significant (P = .4762) when the US speed was set at 1,545 m/sec (4.58 ± 0.37 mm; range: 3.96 to 5.39 mm).

Bland–Altman analysis revealed excellent agreement between the two technologies, with low 95% limits of agreement (LoA), as shown by **Figures 2** and **3**. The difference between Scheimpflug images and US biometry generated a 95% LoA ranging between -0.15 and +0.18 mm for AQD and between -0.12 and +0.21 mm for ACD. After setting the US speed at 1,545 m/sec, the 95% LoA for ACD ranged between -0.16 and +0.17 mm.

Intra-observer repeatability was high for measurements of both AQD (COV = 0.6%, test–retest variability = 0.069 mm) and ACD (COV = 0.84%, test–retest variability = 0.112 mm). Inter-observer reproducibility yielded similar results for AQD (COV = 0.66%, test–

retest variability = 0.082 mm) and ACD (COV = 0.91%, test–retest variability = 0.122 mm).

DISCUSSION

In our era of premium IOLs, achieving the desired postoperative refractive outcome after cataract surgery is of utmost importance. Several steps are necessary to achieve the required precision: accurate measurements of the axial length and corneal power, entry of the data into the most accurate IOL power formulas, and constant optimization to produce a zero mean prediction error. Nevertheless, refractive errors are still possible and ACD prediction is one of the most important factors leading to inaccuracy in IOL power calculation. The relative contribution of ACD prediction to refractive error has been estimated to range between 20% and 40%.[1,2] Recent approaches based on ray-tracing for IOL power calculation, such as those developed by Norrby and Olsen, allow us to predict the geometrical distance of the IOL from the cornea rather than the effective lens position, which is a fictitious distance typical of thin lens formulas.[8,9] Because the importance and popularity of ray-tracing for IOL power calculation are likely to increase in the future, measuring the distance between the cornea and the IOL will become a fundamental step when the predicted value has to be confirmed after surgery.

This study shows that the Sirius is able to accurately measure the position of the IOL relative to the cornea, with no clinical differences compared to immersion US biometry, which is still the benchmark method. Both the ACD and AQD measurements obtained with this Scheimpflug camera can be considered interchangeable with the respective US measurements. The slightly higher mean ACD overestimation by the Sirius (just 0.04 mm), although statistically significant, cannot be considered clinically important. This discrepancy is related to the fact that the US device used in this study does not allow the operator to set the sound speed of the cornea to 1,641 m/s,[34] but only allows setting the sound speed of the anterior chamber, lens, and vitreous. This leads to a lower accuracy of immersion US biometry in measuring the corneal thickness using the speed of 1,532 m/sec, which is correct for the aqueous but is too slow for the cornea. However, recalculating the corneal thickness by using a US speed of 1,545 m/sec made the statistical difference no more significant.

Our findings are in agreement with our own previous investigation that evaluated the same parameters as measured by another Scheimpflug camera, the Pentacam, whose ACD manual measurements were found to be interchangeable with those achieved by immersion US biometry.[28] As expected, the mean ACD value obtained by the Sirius (4.58 ± 0.34 mm) was close to that obtained by the Pentacam (4.65 ± 0.38 mm) with the same IOL model.

Previous studies comparing ACD measurements performed in pseudophakic eyes using US biometry and optical methods have yielded contradictory results. Some authors found that the Scheimpflug camera provided larger measurements than US biometry,[16,17] whereas others reported opposite results.[19] All of these investigations were affected by the same source of error, that of using contact US biometry, which is well known to give arbitrarily shallower ACD measurements due to corneal indentation by the probe. In addition, one of these studies analyzed only the automatic ACD values provided by the Pentacam and we have previously shown that these are frequently erroneous because of inaccurate detection of the anterior surface of the IOL by the software.[30] Several other optical methods for assessing the pseudophakic ACD have been investigated, but no comparison to immersion US biometry was performed. However, good agreement among them has been reported.[16]

This study is limited by the fact that only acrylic IOLs were evaluated and the results may differ for IOLs made from different materials, whose anterior surface may be more difficult to visualize by means of Scheimpflug photography.

This study shows that in pseudophakic eyes the manual ACD and AQD measurements obtained from the Sirius are not significantly different compared to those provided by immersion US biometry and can be therefore considered interchangeable with the latter. The Sirius represents a valid option for obtaining noncontact measurements of the ACD and AQD after cataract surgery and can be employed to develop new algorithms of ACD prediction to improve the refractive outcome in IOL implantation.

APPENDIX

To calculate the US speed (m/sec) through the entire ACD (= corneal thickness + AQD), we have to average the US speed through the cornea and the ACD. Given that the US speed through the AQD is 1,532 m/s,[32] the time required by US to travel from the corneal endothelium to the IOL (in average eye with an AQD depth of 3.95 mm)[28] can be calculated to be 2.5783 msec (or 0.0025783 sec). Given that the US speed through the cornea is 1,641 m/s,[32] the time required by US to travel from the corneal epithelium to the corneal endothelium (in average eye with a corneal thickness of 0.55 mm) can be calculated to be 0.3351 msec (or 0.0003351 sec).

The US speed through the whole ACD can be calculated by the formula: (1) ACD US speed = (AQD_{mm}/1,000

+ $Cornea_{mm}$/1,000) / (AQD_{sec} + $Cornea_{sec}$), where AQD_{mm} is the AQD depth in millimeters, $Cornea_{mm}$ is the corneal thickness in millimeters, AQD_{sec} is the time in seconds required by US to go from the corneal endothelium to the lens and $Cornea_{sec}$ is the time in seconds required by US to go from the corneal epithelium to the endothelium. By introducing the measured and the calculated values, formula (1) reads as: ACD US speed = (0.00395 + 0.00055) / (0.0025783 + 0.0003351) = 0.0045 / 0.00291349 = 1,545 m/s

AUTHOR CONTRIBUTIONS

Study concept and design (KJH, GS); data collection (MC, GS); analysis and interpretation of data (MC, GS); drafting of the manuscript (MC, KJH, GS); statistical expertise (KJH, GS)

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AUTHOR QUERIES

AQ1 - Please list the specific Scheimpflug device used.