Scheimpflug imaging to determine intraocular lens power in vivo

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PURPOSE: To assess the feasibility of determining intraocular lens (IOL) power by measurement of the central optic thickness using clinically available Scheimpflug imaging (Pentacam, Oculus).

SETTING: King's College Hospital Ophthalmology Department, London, United Kingdom.

METHODS: Sixty-seven eyes were assessed 1 month after uneventful phacoemulsification with in-the-bag implantation of AcrySof MA60AC IOLs (Alcon). The correlation between IOL thickness measurement and IOL power was calculated. Repeatability of central optic thickness measurement was determined from 10 successive scans of 4 patients.

RESULTS: Within-subject standard deviation increased with the subject mean. The coefficient of variability was 1.4%. Measured lens thickness was highly correlated with lens power (R^2 = 0.94, P<.001). Over the measured range, 95% confidence intervals varied between ±0.83 diopters (D) and ±0.92 D.

CONCLUSIONS: Central IOL thickness measurements with the Pentacam Scheimpflug camera were highly repeatable and closely correlated with the known IOL power. The IOL power, calculated from a regression equation, is likely to be less than ±1.00 D away from the actual power. Approximate in vivo IOL power determination is feasible with clinically available Scheimpflug imaging. This could be applied clinically in cases of unexplained postoperative refractive error.

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Scheimpflug imaging allows a plane of sharp focus to be achieved that is not parallel to the film plane by forming an angle between the film and lens planes (Wheeler RE. Notes on View Camera Geometry, May 8, 2003 [online]. Available at: http://www.bobwheeler.com/photo/ViewCam.pdf. Accessed March 5, 2007). The technique was first patented in Vienna in 1904 by Captain Theodore Scheimpflug for use in aerial photography for military targeting when a wide focal range was needed. In the 1970s, Hockwin and collaborators in Germany developed Scheimpflug cameras for ophthalmic assessment of cataract density. The most recently commercially available device (Pentacam, Oculus) uses a rotating Scheimpflug camera to image the anterior segment of the eye. Clinical applications include corneal topography, pachymetry, anterior chamber depth (ACD) measurement, and lens densitometry.

Corneal pachymetry has shown agreement with measurements using optical low-coherence reflectometry or ultrasound pachymetry[1] and ACD measurement, which is reportedly comparable to scanning slit topography.[2,3] The central cornea is imaged many times during a scan, and anterior and posterior corneal powers are measured. Software for biometry after refractive surgery was recently developed (R. O'hEineachain, "ESCRS Congress Symposium Report: Anterior Segment Imaging," EuroTimes, November 2005, pages 24–27. Available at: http://www.escrs.org/Publications/Eurotimes/05November/Pdf/ESCRSSymposiumReport.pdf. Accessed March 5, 2007).

The purpose of the present study was to assess the feasibility of using current clinically available Scheimpflug imaging to measure intraocular lens (IOL) central optic thickness in an attempt to determine IOL power. The clinical applications of this would include the determination of IOL power in cases of unexplained refractive error postoperatively or when the IOL power in the first eye is not known when second eye surgery is needed. We assessed repeatability of the measurements and whether central optic thickness measurements correlated with known lens power and assessed whether this information could be used in a predictive way.

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PATIENTS AND METHODS

Consecutive patients returning for a 1-month follow-up after cataract surgery were scanned with the Pentacam device. Patients were invited to participate in the study if they had uneventful phacoemulsification with in-the-bag IOL implantation and there were no documented intraocular complications and no unexpected refractive outcomes, defined as postoperative autorefraction greater than ±0.50 diopters (D) spherical equivalent of that predicted by preoperative biometry using the IOLMaster (Zeiss). In the study, only AcrySof MA60AC IOLs (Alcon) were used. The MA60AC is a foldable, 3-piece, acrylic IOL with a 6.0 mm diameter and 10-degree vaulted haptics; the manufacturer describes the IOL as being anteriorly biconvex, having a smaller radius of curvature for the anterior lens surface. Available powers range from 6.0 to 30.0 D in 0.5 D increments.

Noncontact scans were performed by 2 operators after mydriasis with the patient seated and his or her chin on a chin rest and forehead against the forehead strap. The patient was asked to fixate ahead while the operator visualized a real-time image of the patient's eye. The instrument's automatic release mode was used; the operator had to align the camera with the joystick as instructed on the screen. In approximately 2 seconds, the camera rotated over 180 degrees, taking 25 slit images using monochromatic blue (475 nm/ultraviolet-free) light; each image contained 500 true elevation points. Patient eye movement was monitored and adjusted for, and only measurements with fewer than 0.6 mm decentration were included. Because central structures are imaged repeatedly, multiple images of central optic thickness were generated. Images were identified in which the optic diameter, measured using the on-screen caliper, was 6000 μm to ensure the image was in the central lens plane.

Measurements were excluded if there was visible lens tilt on the Scheimpflug image, the image was distorted due to movement artifact, or a central 6000 μm image was not obtained. Central optic thickness was measured from the zoomed image from the central anterior lens reflex to the innermost surface of the posterior lens surface–posterior capsular complex reflection. This decision was based on the variability in the appearance of the latter (Figure 1).

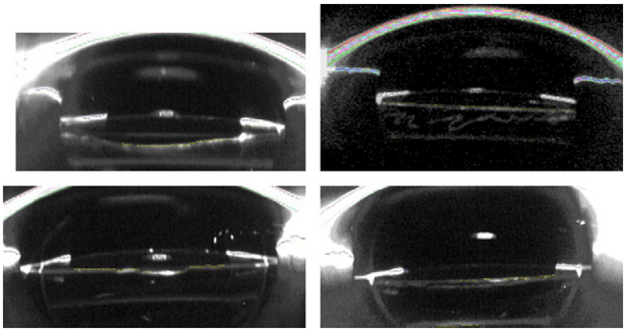

Figure 1. Scheimpflug images of 4 patients with various posterior lens surface–posterior capsular complex reflections (*clockwise from top left*: bowed, wrinkled, typical, thickened).

The first experiment, based on definitions adopted by the British Standards Institute as recommended by Bland and Altman,[4] involved 10 successive scans of 4 patients. The time between scans during software calculation was approximately 20 seconds, and the joystick was moved away from the patient between successive scans. Within subject standard deviations and means were determined.[5] The standard coefficient of repeatability for 95% confidence is twice the pooled within-subject standard deviation (ie, twice the standard deviation for repeated measurements of any 1 subject). In the second experiment, 67 eyes were imaged as outlined above. For each measurement, 4 readings were taken and averaged, with the operator unaware of the IOL power. A measure of repeatability was calculated, as were a linear regression equation, correlation coefficient, and confidence intervals (CIs) as detailed below. Net corneal power and ACD readings were also noted.

RESULTS

A plot of standard deviation against the mean for each patient in the study showed a clear relationship (Figure 2); the standard deviation increased with the mean. There are 2 well-known methods for approximating this: (1) logarithmically transforming the data and estimating the geometric coefficient of variation and (2) taking the root mean square of the coefficient of each subject. The latter method gives the larger result for these data at 1.4% of the measured value. Consistent with these calculations, precisely 38 of the 40 observations (95%) fell within these limits.

In the second experiment, data from 66 scans of 56 patients were analyzed as ACD measurement was not recorded by the instrument for 1 scan. The patients comprised 21 men and 35 women with a mean age 73.8 years (range 46 to 92 years). Corneal power (mean 43.3 D; range 39.9 to 46.9 D) and ACD (mean 4.46 mm; range 3.42 to 5.18 mm) were also included as variables. Ten scans were of insufficient quality for measurement because of poor clarity or no central lens scan being identifiable among the saved images. No scans were excluded on the basis of lens tilt. Known IOL powers

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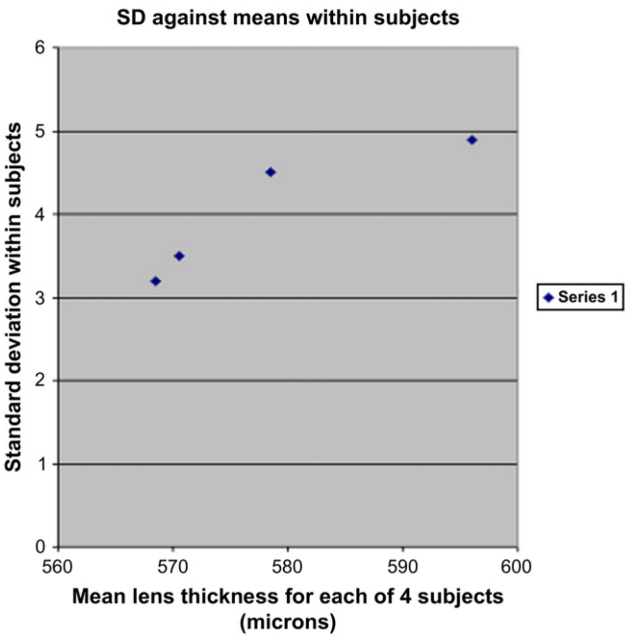

Figure 2. Plot of within-subject standard deviation against the mean.

ranged from 11.0 to 26.5 D. Lens thickness correlated significantly with lens power over this range ($R^2 = 0.94$, $P < .001$).

The regression equation is as follows: Lens power = (0.045 × lens thickness in microns) − 6.549. For example, a lens thickness measured at 600 μm would predict an IOL power of approximately (0.045 × 600 − 6.549); that is, 20.451 D. Ninety-five percent CIs were generated for each prediction: CI width = square root [0.695 + (lens thickness in μm − 615.27)^2/274971]. For example, for a measured IOL thickness of 600 nm, a CI of ±0.83 was generated; that is, one could be 95% confident that the IOL power fell within ±0.83 of the predicted value (20.451 D), between 19.6 D and 21.3 D.

The CIs slightly increased the farther the IOL thickness was from the mean of the data (615.3 μm). The CIs formed a bow-tie shape around the regression line as inaccuracy in estimation of slope had a bigger effect farther from the mean. For an IOL thickness between 400 μm and 750 μm, the CIs did not exceed ±0.92 D. The CI was minimized at a lens thickness of 615 μm at ±0.83 D. There was no significant semipartial correlation between ACD or corneal power and unpredicted variation in IOL power (largest $r^2 = 0.14$).

Figure 3 shows that the lowest and highest data points are underneath the regression line, which is characteristic of a nonlinear contribution to the relationship. A variety of alternative predictors (using the cube, logarithm or reciprocal, of the IOL thickness) all provided a marginally better fit and more uniform residuals. The best fit was produced by reciprocals ($R^2 = 0.97$, $P < .001$).Therefore, these data could not be used to statistically predict values outside this range as the data did not allow determination of the exact relationship. Figure 4 shows the relationship between calculated and labelled IOL powers in this sample.

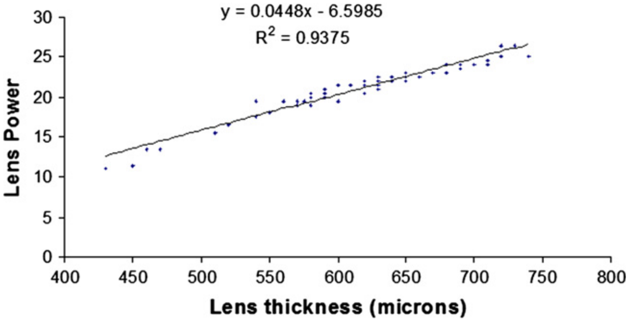

Figure 3. Plot of lens power (diopters) against central optic thickness measurement (microns).

DISCUSSION

We used the Pentacam Scheimpflug camera to measure the central optic thickness of the AcrySof MA60AC IOL in 67 eyes and found these measurements were highly repeatable and correlated significantly with known IOL power. This study indicates that IOL central optic thickness measurement with this instrument is feasible and that when measuring IOL thickness with the Pentacam over this range, we can be 95% confident that the predicted value will be less than 1.0 D from the true IOL power. Neither net corneal power nor ACD significantly increased the ability to predict the IOL power.

This was a relatively small feasibility study. Not all IOL power increments in the range were imaged, and multiple patients were not imaged in all subgroups. Statistically, extrapolation beyond the range is not

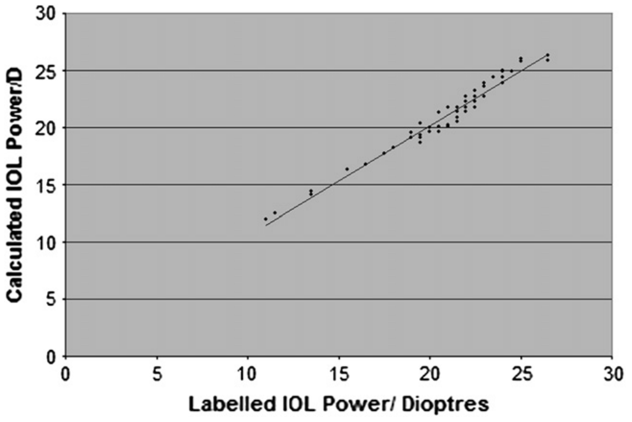

Figure 4. Plot of labeled IOL power against IOL power calculated using the regression equation for the patients.

possible without a larger sample size to precisely determine the nature of the relationship with IOL power. The results are likely to be valid only for the IOL type used in the study; however, it is one of the most commonly used IOLs in the United Kingdom at present and similar conversions for others IOL types are rapidly repeatable.

We conclude that clinically available Scheimpflug imaging allows the assessment of IOL power in vivo. We present the correction factor for this IOL type in the form of a regression equation and propose this is as a new clinical application for the Pentacam.

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