

Improving the Predictability of Intraocular Lens Power Calculations

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● We reviewed the intraocular lens power calculations on 512 posterior chamber lens implantations and determined four ways to reduce the estimated 5% incidence of large postoperative refractive "surprises" (greater than 2 diopters [D]): First, preoperatively identify those patients who have greater than a 1-D difference between the theoretical and linear regression formulas. Second, repeat axial length and corneal power measurements in these patients to eliminate random error. Third, develop an individualized theoretical formula that accounts for constant bias. Fourth, encourage manufacturers to improve instrumentation for measuring corneal power and axial length. We also examined the disparity between the linear regression formula and the curvilinear theoretical formula.

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Cataract removal and intraocular lens (IOL) implantation is one of the most successful surgical procedures today.¹ Due to the success of this procedure, 840,826 IOLs were implanted in the United States during the past 12 months.²

One problem that still exists, however, is accurately predicting the necessary power of an IOL for a desired postoperative refraction. Although recent studies demonstrate that improved diagnostic and surgical techniques have reduced the number of refractive "surprises," 5% to 10% of the cases still result in an error of 2

diopters (D) or more.^{3,6} Refractions that vary by more than 2 D from the desired postoperative refraction often result in asthenopic symptoms. These symptoms are most commonly a result of binocular diplopia and altered depth perception. Sometimes these problems can be treated by slabbing off the spectacles or using asymmetrical bifocal segments, but, unfortunately, in some cases a second operation is required to exchange the IOL for one of a different power.

The purpose of this study is to present available techniques for reducing unwanted postoperative refractive errors and to suggest that manufacturers of ultrasonic A-scanners and keratometers further improve their instruments.

MATERIALS AND METHODS

We reviewed 512 extracapsular cataract extractions performed by three surgeons from January 1983 to June 1984, in which 10° angulated, Sinsky-style posterior chamber lenses were implanted. All patients underwent ultrasonic A-scanning (Sonometrics DBR 400) and keratometric readings (Bausch & Lomb keratometer). Intraocular lens power calculations were performed on all patients by using the Binkhorst theoretical formula and the Sanders-Retzlaff-Kraff (SRK) linear regression formula. The final refraction in each case was determined at least six months postoperatively and was not considered accurate unless the patient's best corrected visual acuity was better than 20/40. Twenty-six (5.1%) of the 512 patients were found to have final refractions that differed by more than 2 D from the preoperative target refraction, as indicated by one or both formulas. The average error of the 26 preoperative target refractions and the number of patients with errors greater than 2 D did not differ significantly between the two formulas

(Binkhorst average error, 3.4 D [N = 14]; SRK average error, 3.2 D [N = 16]). Each of these patients was asked to return for repeated keratometric readings, A-scanning, and anterior chamber depth (ACD) measurements. All remeasurements were performed independently by two of us (J.T.H., T.C.P.). The IOL power calculations were then repeated using the postoperative measurements.

RESULTS

Using the postoperative measurements, it was possible to determine for each parameter (keratometric measurements, axial length, and ACD) the average percentage of improvement in IOL prediction for all 26 patients with each formula (Table). (These percentages were calculated using the improvement in diopters of the predicted refraction with the postoperative measurements for each component compared with the total error in diopters using the preoperative data.)

It was expected that the repeated measurements would improve the accuracy in predicting the final refraction, since the postoperative corneal power and ACD could be measured, not just predicted, from the preoperative data. In addition, postoperative axial length measurements in pseudophakic eyes have been shown to be more accurate than in phakic eyes because the exact ultrasonic velocity and thickness of the IOL are known.⁷

Preoperative differences from the final corneal power accounted for 10% improvement in predictability for the Binkhorst formula and 11% for the SRK regression formula. Accurate axial length measurements improved the predictability by 54% and 32% for

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Average Improvement in Predictability for IOL Power Calculations With Use of Postoperative Measurements*		
Reason for Error	Improvement, %	
	Binkhorst Formula	SRK Formula
Keratometry	10	11
Axial length	54	32
ACD	3	...
Unexplained	33	57
Total	100	100

* All percentages are based on the 26 patients in whom the final refractions varied by more than 2 diopters from predictions based on preoperative data. IOL indicates intraocular lens; SRK, Sanders-Retzlaff-Kraff; and ACD, anterior chamber depth.

the Binkhorst and SRK formulas, respectively. This improvement due to axial length was the greatest contributor to improved IOL power predictability for both formulas.

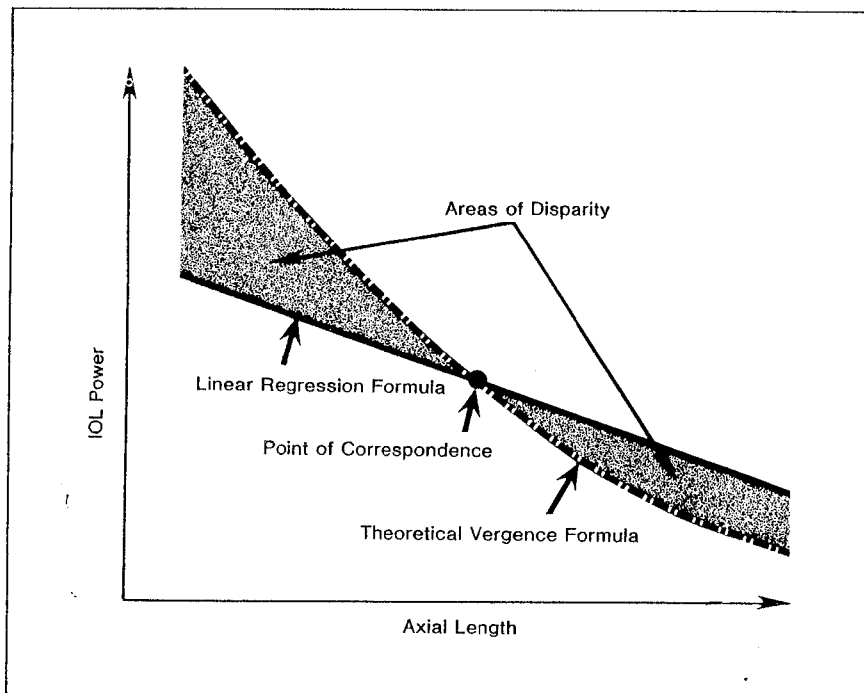
The improvement in predictability using the actual postoperative ACD was 3% for the Binkhorst formula and could not be calculated for the SRK, since ACD is not a part of the equation. This minimal gain of 3% explains why ACD has been dismissed from most linear regression formulas. The remaining percentage (Binkhorst, 33%; SRK, 57%) was considered to be unexplainable error using present techniques.

The percentages of improvements for the components of each formula (keratometric measurements, axial length, and ACD), shown in the Table, denote the increased accuracy using the corrected measurements. The higher the combined percentages of explained improvements, the more accurate the formula. This also implies that the lower the remaining unexplained error, the better the predictability of the formula. These conclusions are valid in our study, since the preoperative inaccuracy of the two formulas were equivalent.

In our study, if the measured and predicted factors had been as accurate as the postoperative values, then the Binkhorst vergence formula (or any of the equivalent theoretical formulas: Fyodorov, Vander Heijde, Colenbrander, Hoffer, Thijssen)⁸ would have been a better predictor by a margin of 24% over the SRK linear regression formula (the difference in the unexplained errors). The Binkhorst formula's 22% greater improvement due to axial length was the major factor explaining this superiority.

COMMENT

A historical review of more than 30 articles⁹ on the accuracy of IOL power



Theoretical and linear regression formulas have "point of correspondence" near average axial length and average emmetropic intraocular lens (IOL) power. With more unusual axial lengths, disparity between powers predicted by formulas is greater.

calculations reveals three important facts. First, an investigator who has developed a formula always achieves better results with that formula than with any other formula tested, whether theoretical or regression.³ Second, studies evaluating formula accuracy performed by investigators who have not developed a formula are almost equally divided between the theoretical and regression formulas.³ Third, the average percentage of patients with postoperative errors greater than 2 D was 10% in studies before 1980 and 5% in those after 1980.^{3,5} Indeed, the controversy over the best formula still flourishes, leaving the ophthalmic surgeon in a dilemma, even though our overall accuracy appears to be improving.

In 24 (92%) of our 26 patients with greater than 2-D errors, the theoretical and linear regression formula calculations differed by more than 1.00 D. In contrast, in only nine (1.9%) of the remaining 486 patients with errors less than 2 D did calculations differ by more than 1 D. Therefore, the majority (92%) of our refractive surprises could have been identified preoperatively if both formulas had been calculated. Only a small number (1.9%) of patients would have been falsely identified.

When a difference of 1 D or more in calculated emmetropic IOL power exists between the theoretical and

regression formulas, the corneal power and axial length should be remeasured by an independent observer with no knowledge of the previous measurements. Repeating the measurements will identify any random error, such as nonaxial alignment or compression with the ultrasonic transducer probe. Once random error has been eliminated and a 1-D difference still exists between the two formulas, the choice of which formula will be more accurate can vary.

This variation is a result of two factors. First, the actual improvement in predictability due to linear regression is a function of the amount of constant error. Some sources of constant errors that can be reduced by linear regression would include an A-scan instrument that measures 0.2 mm too long, a keratometer that is calibrated 0.50 D too flat, a technician who uses an applanation probe incorrectly and consistently shortens the eye during the measurement, an IOL that is labeled by posterior vertex power rather than equivalent power, or a surgeon who uses absorbable sutures that consistently result in a flatter, less powerful postoperative cornea. The theoretical formula assumes that all consistent biases have been eliminated prior to the calculation.

The second factor is the inaccuracy introduced by using a linear formula

to approximate the actual curvilinear IOL power relationship, as shown in the Figure. These two factors explain the apparent contradictory results of previous investigators when using linear regression and theoretical formulas.

It should be noted that the nonlinearity of the IOL power relationship is almost totally a result of axial length, since the other two factors, corneal power and ACD, each have a nearly linear relationship with the change in IOL power. This is supported in our study by the large difference in the average percentage improvement due to axial length and the negligible differences due to keratometric measurements and ACD (Table). This point has been further validated empirically by the emergence of a new generation of nonlinear regression formulas, which are only nonlinear in their axial length component.^{9,10} These new formulas are designed for unusually long or short eyes, in which the linear and theoretical formulas will have the greatest areas of disparity (Figure).

The linear estimation for axial length also becomes increasingly more inaccurate the higher the tar-

geted ametropia, because the linear equation was optimized for the emmetropic zone (plano to -1.00 D).¹¹⁻¹³ When targeting for high ametropias, the linear formulas typically result in an IOL power for a posterior chamber lens approximately 25% nearer the average emmetropic value of $+17.65$ D than that calculated by the theoretical formulas.

Our future efforts should be directed toward individualizing the theoretical formulas by compensating for any consistent dioptric error as is done when determining a specific A-constant for the SRK. An individualized theoretical formula has both the advantages of statistical analysis to eliminate constant bias and the accuracy of the nonlinear vergence relationship.

Finally, when repeated postoperative measurements were taken and their accuracy was confirmed, 33% of the errors were still unexplainable with the theoretical formula. These "unexplainable errors" are partly a result of limitations in current instrumentation. For example, most A-scan instruments use a constant value for the crystalline lens thickness and ultrasonic velocity, as well as retinal

thickness.¹⁴⁻¹⁷ Keratometers are calibrated using a spherical steel ball, not an aspherical cornea. These and other physiological variations can result in significant errors.

Avoiding these unexplained errors is possible given current ultrasonic and keratometric technology. The lack of general understanding regarding these problems has made manufacturers reluctant to invest the time and funds necessary to avoid the individual "minor errors" that can add up to major ones. We hope that more studies in which the IOL power is recalculated using postoperative measurements will demonstrate that previously unexplained errors are due to the inadequacies in current instrumentation and that these findings will require manufacturers to upgrade instrument quality to its full potential.

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