Refractive Power Calculations for Intraocular Lenses in the Phakic Eye

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To correct a severe refractive error and obviate thick spectacles or contact lenses, an intraocular lens can be placed in the anterior chamber in front of the normal crystalline lens as an alternative to keratorefractive procedures. The power of the intraocular lens may be determined from the recipient's spectacle correction, its vertex distance, and the corneal power in diopters. These measurements, combined with an intraocular lens constant based on its location within the anterior chamber, provide the appropriate power of the intraocular lens.

These formulas were applied to seven Baikoff anterior chamber lenses and three Momose anterior chamber lenses in phakic eyes. The mean absolute prediction error was 0.42 (standard deviation, ±0.60) for the Baikoff lenses and 0.57 (±0.64) for the Momose lenses. The accuracy of the measurements is limited by the accuracy of the preoperative refraction, the measurement of the corneal power, and the restoration of the preoperative refractive power of the cornea.

To CORRECT LARGE REFRACTIVE ERRORS, intraocular lenses are being placed in the anterior chamber in phakic eyes as an alternative to keratorefractive surgery to obviate contact lenses or thick spectacles.[1-17] Current surgery is primarily limited to myopia of more than 6.00 diopters. The accuracy in calculating the appropriate refractive power of the intraocular lens to achieve the desired postoperative refraction is just as important as the usual calculation in patients undergoing cataract extraction. The equations for determining the intraocular lens power in phakic eyes, however, are different from those used when a cataract is removed.

For the intraocular lens calculation in phakic eyes, the optical elements of the eye (cornea and crystalline lens) remain unchanged. These conditions allow direct calculation of the necessary intraocular lens power from the corneal power, preoperative refraction, and vertex distance. Knowledge of the ultrasonic axial length is not necessary. Because calculating the refraction assumes nothing about the thickness, refractive index, or principal planes of the crystalline lens, the calculation is limited only by the measurement accuracy of the corneal power, refraction, and spectacle vertex distance.

The appropriate formulas were derived for calculating the intraocular lens power from the refraction when the crystalline lens is not removed. The refraction predicted by these formulas were compared with the actual refractive results of the first two styles of high minus power anterior chamber lenses in phakic eyes. These formulas also are valid for plus power lenses used in phakic eyes with severe hyperopia and also may be used to determine the proper secondary lens implant power in aphakia from the refraction in aphakic eyes.

Material and Methods

The only measurements necessary for the calculation are the corneal power, the preoperative refraction, and the vertex distance of the refraction. The other variables necessary for the calculation are the desired postoperative refraction and the expected position of the intraocular lens with respect to the corneal vertex. If emmetropia is desired, the vergence of the rays entering the crystalline lens induced by the combination of the cornea and spectacle must equal the vergence of the rays entering the

crystalline lens by the combination of the cornea and intraocular lens. The following three formulas satisfy these conditions and yield the intraocular lens power that will produce the desired postoperative refraction:
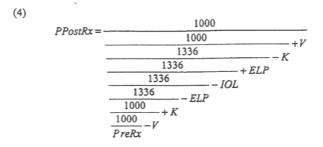
(1) $\quad AA = 3.74$

(2) $\quad ELP = AA + SF$

(3) $\quad IOL = \dfrac{1336}{\dfrac{1336}{\dfrac{1000}{PreRx} + K} - V} - ELP} - \dfrac{1336}{\dfrac{1336}{\dfrac{1000}{DPostRx} + K} - V} - ELP}$

where AA = anatomic anterior chamber depth in mm (distance from corneal vertex to plane of iris root), ELP = expected lens position in mm (distance from corneal vertex to principal plane of intraocular lens), SF = surgeon factor in mm (distance from plane of iris root to principal plane of lens, negative in anterior chamber), IOL = intraocular lens power in diopters, K = net corneal power in diopters, $PreRx$ = preoperative refraction in diopters, $DPostRx$ = desired postoperative refraction in diopters, and V = vertex distance in mm of refractions.

Multiplication of the measured keratometric reading by the fraction 1333/1337.5 is recommended to compensate for the steeper posterior curve of the cornea, which reduces the net power of the cornea by 0.25 to 0.50 diopter compared to its front surface power.[18] The calculation of the anatomic anterior chamber depth from the corneal vertex to the plane of the iris root has been described previously,[19] although it requires the measurement of axial length. The improved accuracy of performing this calculation vs using a constant value of 3.74 mm for the anatomic anterior chamber depth[19,20] is negligible for minus power anterior chamber intraocular lenses of 10.00 diopters or less in phakic eyes.

Because intraocular lens powers are only available in specific powers (usually in 0.5-diopter increments), equation 4 is given to calculate the predicted postoperative refraction ($PPostRx$) in diopters for a specific intraocular lens power.

(4)

$$PPostRx = \dfrac{1000}{\dfrac{1000}{\dfrac{1336}{\dfrac{1336}{\dfrac{1336}{\dfrac{1336}{\dfrac{1000}{\dfrac{1000}{PreRx} - V} + K} - ELP} - IOL} - ELP} + ELP} - K} + V}$$

Using this formula, a table can be created that enables the surgeon to choose an available lens power and see the predicted refraction.

Equations 5 through 11 yield the reverse solution for the lens position within the eye (surgeon factor), given the stabilized actual postoperative refraction ($APostRx$) and the actual power of the implanted intraocular lens. These seven equations allow the surgeon to determine the personalized surgeon factor (PSF) based on the experience with any style of lens after ten to 20 cases. Equation 10 includes a ± sign; the plus sign is used for myopic lenses and the minus sign is used for hyperopic lenses.

(5) $\qquad X = \dfrac{1336}{\dfrac{1000}{\dfrac{1000}{PreRx} - V} + K}$

(6) $\qquad Y = \dfrac{1336}{\dfrac{1000}{\dfrac{1000}{APostRx} - V} + K}$

(7) $\qquad A = IOL$

(8) $\qquad B = -IOL(X + Y)$

(9) $\qquad C = 1336(X - Y) + IOL\ X\ Y$

(10) $\qquad ELP = \dfrac{-B \pm \sqrt{B^2 - 4AC}}{2A}$

(11) $\qquad PSF = ELP - AA$

Personalizing the surgeon factor reduces prediction error.[19] Because lens constants are not currently available for these new intraocular lenses in phakic eyes, equations 5 through 11

were used to determine the surgeon factor for these two styles of lenses.

Results

The surgeon factor was −1.027 mm for the Baikoff lens and was −1.813 mm for the Momose lens. These values indicate that the principal plane of the Momose lens was 0.8 mm more anterior to the iris than the Baikoff lens. The method for converting the surgeon factor to the Binkhorst anterior chamber depth and the Sanders-Retzlaff-Kraff A-constant have been described previously.[19] The numeric values of equations 1 through 11 were determined for Patient 1 (Table).

The predicted refraction for each of the patients was determined by using equation 4. The difference in the predicted refraction and the actual postoperative spheroequivalent refraction yields the prediction error. The mean absolute prediction error was 0.42 diopter (standard deviation, ±0.60) for the Baikoff lens and 0.57 (standard deviation, ±0.64) diopter for the Momose lens.

Discussion

Calculation of intraocular lens power in phakic eyes requires measuring the corneal power, preoperative refraction, and the vertex distance. In these calculations, the preoperative refraction is the new measured variable that replaces axial length. Because the refraction requires no assumptions, such as crystalline lens thickness and presumed ultrasonic velocity, the prediction accuracy should exceed traditional intraocular lens power calculations when the cataractous lens is removed. The accuracy of these early results supports this contention.

The second factor that should reduce the prediction error with intraocular lenses in phakic eyes has to do with the lens location within the eye. A 1-mm error in the axial location of a posterior chamber lens results in approximately a 1.90-diopter error in the spectacle plane. A 1-mm error in the axial location of an anterior chamber lens results in approximately a 1.20-diopter error in the spectacle plane.[19] However, the average power of lenses

TABLE
CALCULATION VALUES FOR PATIENT 1

VARIABLE	INTRAOCULAR LENS CALCULATION	REFRACTION CALCULATION	PERSONALIZED SURGEON FACTOR
Preoperative refraction (D)	−8.25	−8.25	−8.25
Vertex distance of refraction (mm)	14	14	14
Desired postoperative refraction (D)	−0.50	—	—
Anatomic anterior chamber depth (mm)	3.74	3.74	3.74
Surgeon factor (mm)	−1.027	−1.027	—
Net corneal power (D)	44.12	44.12	44.12
Expected lens position (mm)	2.713	2.713	2.935331
Intraocular lens power (D)	−8.179859	−8.00	−8.00
Actual postoperative refraction (D)	—	—	−0.75
Predicted postoperative refraction (D)	—	−0.651874	—
Personalized surgeon factor (mm)	—	—	−0.804669

used after cataract extraction is approximately 20.00 diopters. Therefore, intraocular lenses in the anterior chamber that average 10.00 diopters in phakic eyes would be approximately one half this amount or 0.60 diopter of error per millimeter in axial location. Personalizing the surgeon factor for phakic lenses of 10.00 diopters or less therefore is not as critical as when using posterior chamber intraocular lenses in aphakic eyes.

A definite advantage of the high minus power intraocular lens is the reduced minification compared to high minus power spectacles. For a −12.00-diopter intraocular lens in a phakic eye, the retinal image is approximately 25% larger than the image formed on the retina by the equivalent spectacle lens. A 25% larger image on the retina is equal to a one-line improvement in visual acuity. This benefit has been verified clinically.[11]

Prediction accuracy with intraocular lenses in phakic eyes will be limited primarily by the accuracy with which these lenses are labeled, the accuracy of the refraction, and the ability of the surgeon to leave the corneal power unchanged after the operation. The accuracy of calculating the intraocular lens power to correct refractive error in phakic eyes should be similar to that achieved with conventional spectacle lenses, that is, ± 0.25 diopter. To achieve this same prediction accuracy consistently with existing keratorefractive procedures, including excimer laser procedures, would be difficult, primarily because of unpredictable variation in patient healing.

References

1. Praeger, D. L.: Phakic myopic intraocular lens. An alternative to keratolenticulorefractive procedures. Ann. Ophthalmol. 20:246, 1988.

2. ————: Innovations and creativity in contemporary ophthalmology. Preliminary experience with the phakic myopic intraocular lens. Ann. Ophthalmol. 20:456, 1988.

3. Fechner, P. U., van der Heijde, G. L., and Worst, J. G.: Intraocular lens for the correction of myopia of the phakic eye. Klin. Monatsbl. Augenheilkd. 193:29, 1988.

4. Tchah, H., Duffey, R. J., Allarakhia, L., and Lindstrom, R. L.: Intraocular lens implantation in phakic rabbit eyes. J. Cataract Refract. Surg. 15:554, 1989.

5. Fechner, P. U., van der Heijde, G. L., and Worst, J. G.: The correction of myopia by lens implantation into phakic eyes. Am. J. Ophthalmol. 107:659, 1989.

6. Baikoff, G., and Colin, J.: Damage to the corneal endothelium using anterior chamber intraocular lenses for myopia (correspondence). Refract. Corneal Surg. 6:383, 1990.

7. Colin, J., Mimouni, F., Robinet, A., Conrad, H., and Mader, P.: The surgical treatment of high myopia. Comparison of epikeratoplasty, keratomileusis and minus power anterior chamber lenses. Refract. Corneal Surg. 6:245, 1990.

8. Fechner, P. U.: Intraocular lenses for the correction of myopia in phakic eyes. Short-term success and long-term caution. Refract. Corneal Surg. 6:242, 1990.

9. Baikoff, G., and Joly, P.: Comparison of minus power anterior chamber intraocular lenses and myopic epikeratoplasty in phakic eyes. Refract. Corneal Surg. 6:383, 1990.

10. Baikoff, G.: Phakic anterior chamber intraocular lenses. Int. Ophthalmol. Clin. 31:75, 1991.

11. Praeger, D. L., Momose, A., and Muroff, L. L.: Thirty-six month follow-up of a contemporary phakic intraocular lens for the surgical correction of myopia. Ann. Ophthalmol. 23:6, 1991.

12. Peiffer, R. L., Porter, D. P., Eifrig, D. E., and Boyd, J: Experimental evaluation of a phakic anterior chamber implant in a primate model. Part I. Clinical observations. J. Cataract Refract. Surg. 17:335, 1991.

13. Porter, D. P., Peiffer, R. L., Eifrig, D. E., and Boyd, J.: Experimental evaluation of a phakic anterior chamber implant in a primate model. Part II. Pathology. J. Cataract Refract. Surg. 17:342, 1991.

14. Bour, T., Piquot, X., Pospisil, A., and Montard, M.: Endothelial effects of the ZB anterior chamber myopic implant during the first year. Prospective study with statistical analysis. J. Fr. Ophtalmol. 14:633, 1991.

15. Saragoussi, J. J., Cotinat, J., Renard, G., Savoldelli, M., Abenhaim, A., and Pouliquen, Y.: Damage to the corneal endothelium by minus power anterior chamber intraocular lenses. Refract. Corneal Surg. 7:282, 1991.

16. Mimouni, F., Colin, J., Kiffi, V., and Bonnet, P.: Damage to the corneal endothelium from anterior chamber intraocular lenses in phakic myopic eyes. Refract. Corneal Surg. 7:277, 1991.

17. Waring, G. O.: Phakic intraocular lenses for the correction of myopia. Where do we go from here? Refract. Corneal Surg. 7:275, 1991.

18. Holladay, J. T.: Optics and topography of radial keratotomy. In Waring, G. O. (ed.): Refractive Keratotomy. St. Louis, Mosby-Year Book, Inc., 1992, pp. 62–63.

19. Holladay, J. T., Prager, T. C., Chandler, T. Y., Musgrove, K. H., Lewis, J. W., and Ruiz, R. S.: A three-part system for refining intraocular lens power calculations. J. Cataract Refract. Surg. 13:17, 1988.

20. Hoffer, K. J.: Biometry of 7,500 cataractous eyes. Am. J. Ophthalmol. 90:360, 1980.