IOL Power Calculation With Customized Ray-Tracing Eye Models

The future of lens power prediction is already here.

BY CARMEN CANOVAS, MSc; AND PABLO ARTAL, PhD

A classic problem in cataract surgery is the a priori determination of the ideal power of the IOL to be implanted. After a long history of efforts by many practitioners and enthusiasts, current IOL power calculation methods provide reasonably good average accuracy. However, the price for this progress is an increasing number of formulas that must be considered and the steps necessary to choose the proper calculation procedure for each patient. For these reasons, the need for more deterministic models has been suggested.[1]

Most IOL power calculation procedures are based upon regression analysis. Therefore, it is common sense that these calculations are accurate on average but not as accurate as desired in a given individual. It was recently reported that biometry errors leading to wrong IOL powers were the second most frequent cause of malpractice claims.[2] This resulted in payment of damages in 62% of closed cases, according to an analysis of the causes of malpractice claims related specifically to cataract surgery in the National Health Service in England from 1995 to 2008.

It is well understood that, although current IOL power calculation procedures provide good outcomes on average, results on an individual scale still need improvement. This is especially evident in cases in which patients present some peculiarity, such as an abnormal cornea or extreme eye geometry.

New generations of IOLs designed to correct corneal aberrations will not achieve their maximum potential visual benefit if the IOL power is not accurately determined.[3-6] Blur associated with any significant residual refractive error would mask the visual advantage related to the correction of the aberrations. Another important and limiting point is the paraxial nature of most current IOL power calculations. Paraxial approaches might not be sufficient for higher levels of aberrations, such as those in post-LASIK eyes.[7]

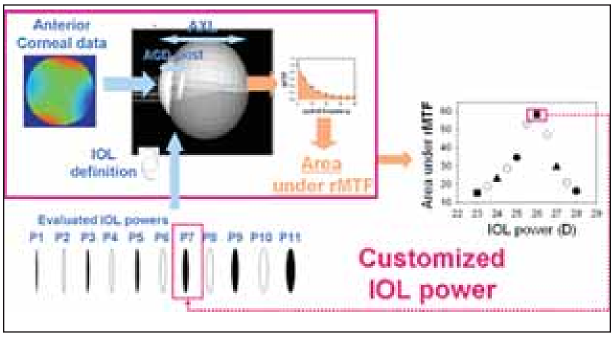

Figure 1. Schematic view of the customized IOL power calculation procedure.

The use in clinical practice of different instruments to accurately describe the eye, such as corneal topographers, may also be incorporated to improve the predictability of IOL power calculations.

CUSTOMIZED EYE MODEL

Although some attempts have been made to improve standard IOL power calculation procedures,[8-10] to the best of our knowledge a fully customized eye model that includes all of the patient's aberrations in combination with white-light (polychromatic) analysis has never been performed. We recently developed an approach using customized eye models to predict IOL power.[11] The approach is based on exact ray tracing and patient data. All pertinent aberrations, coming either from the cornea or the IOL, are considered in the calculation, together with biometric data.

Figure 1 shows schematically how the procedure works. For every patient, we build a corresponding cus-

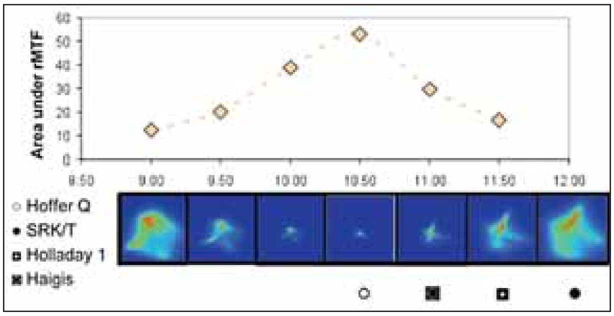

Figure 2. Overview of a patient with -8.50 D of myopia. (Top) Optic quality metric calculated with a customized model for a wide range of IOL powers. (Bottom) Symbols indicate the IOL power predicted for this patient by different standard calculations with the corresponding point spread function. The spread of the results among formulas shows the limitations of the current state-of-the-art formulas.

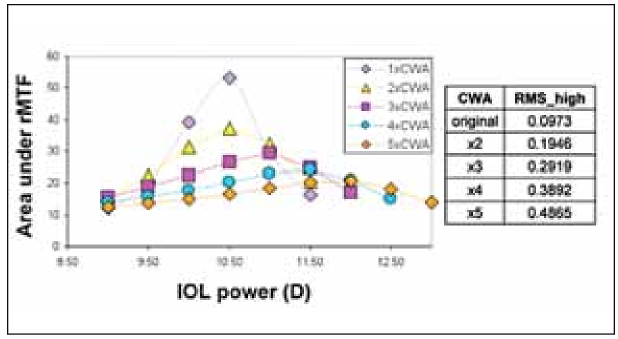

Figure 3. Optic quality metric with a customized procedure as a function of the IOL power for different amounts of corneal aberrations relative to a 4-mm pupil. Note that the predicted IOL power changes as the amount of aberrations increases. Paraxial formulas are blind to these changes.

tomized eye model. A description of the cornea is established by the introduction of corneal elevations obtained by a Placido disc-based corneal topographer (Atlas; Carl Zeiss Meditec, Jena, Germany). We determine the power of the posterior cornea by introducing an equivalent refractive index based on anatomic data.[12] IOL placement is predicted by the custom relationship found between the anterior chamber depth before surgery and the IOL position after surgery. The IOL's geometric design details (thickness, radius, and aspheric terms) and optical properties (refractive index and dispersion) are also introduced into the model. The retina is placed in a position corresponding to the patient's axial length, which is measured with optical biometry (IOL Master; Carl Zeiss Meditec).

For each customized model, an exact polychromatic ray tracing is generated to predict the realistic retinal image quality. To determine the optimum IOL power, we sequentially introduce different IOL powers into the model and calculate an optical quality metric, the area under the modulation transfer function (MTF), for each case. At the end of the procedure, the IOL power providing the highest image quality (ie, highest value of the selected metric) is chosen as the optimum power.

USE IN CLINCAL PRACTICE

Figures 2 and 3 illustrate the potential for use of this approach in clinical practice. Figure 2 shows a patient with high myopia (-8.50 D). The IOL power selected by our procedure is the one that maximizes the optical quality parameter, in this case 10.50 D. Retinal images of a point source for the IOL powers considered are displayed. The results provided by some of the commonly used paraxial formulas[13-16] are also shown. The values provided by the standard calculations present significant dispersion in this case, showing their potential for inaccuracy in highly ametropic patients.

Figure 3 emphasizes the importance of considering corneal aberrations in IOL power calculation. In this case, we repeated the calculations for the patient in Figure 2 but added up to five times the degree of corneal aberrations. This shows the difference in the impact of IOL selection on normal corneas as compared with aberrated corneas. The maximum of the optic quality metric is displaced as the degree of aberrations increases, indicating that the optimum IOL power differs depending on the degree of corneal aberrations.

Highly aberrated corneas such as these could be seen in a LASIK patient. This aberration would not be detected by standard formulas that do not consider aberrations, and such formulas would provide exactly the same IOL value for eyes with the same biometric data but different corneal aberrations.

CONCLUSION

These two cases show the potential value of this customized ray-tracing procedure and the possible limitations of standard IOL power prediction approaches in similar cases. Future routine use of ray-tracing procedures could

TAKE-HOME MESSAGE

- Using a customized eye model to predict IOL power, the surgeon can sequentially introduce different IOL powers into the model to calculate an optical quality metric.
- Ray tracing is generated to predict realistic retinal quality.
- The optimum IOL power depends on the degree of corneal aberrations.

In the future, standard regression paraxial formulas could be replaced by personalized ray-tracing calculations.

significantly improve refractive outcomes in cataract surgery, particularly in patients with certain features.

Of course, IOL power calculations will always be limited by the quality of biometric data, but more precise and accurate optical calculations should be preferred in the future. We envision a future in which standard regression paraxial formulas will be replaced by personalized ray-tracing calculations, similar to the way keratometry is currently being replaced by topography. ■

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1. Dupps W. Intraocular lens calculations: Call for more deterministic models. *J Cataract Refract Surg.* 2010;36(9):1447-1448.
2. Ali N, Little BC. Causes of cataract surgery malpractice claims in England 1995–2008. *Br J Ophthalmol.* 2011;95(4):490-492.
3. Guirao A, Redondo M, Geraghty E, Piers P, Norrby S, Artal P. Corneal optical aberrations and retinal image quality in patients in whom monofocal intraocular lenses were implanted. *Arch Ophthalmol.* 2002;120(9):1143-1151.
4. Artal P. History of IOLs that correct spherical aberration. *J Cataract Refract Surg.* 2009;35(6):962-963.
5. Holladay JT, Piers PA, Koranyi G, van der Mooren M, Norrby NE. A new intraocular lens design to reduce spherical aberration of pseudophakic eyes. *J Refract Surg.* 2002;18(6):683-691.
6. Tabernero J, Piers PA, Artal P. Intraocular lens to correct corneal coma. *Opt Lett.* 2007;32(4):406-408.
7. Benito A, Redondo M, Artal P. Laser in situ keratomileusis disrupts the aberration compensation mechanism of the human eye. *Am J Ophthalmol.* 2009;147(3):424-431.
8. Olsen T. The Olsen formula. In: Shammas J, ed. Intraocular Lens Power Calculations. Thorofare, NJ; Slack Incorporated; 2004.
9. Norrby S. The Dubbelman eye model analyzed by ray tracing through aspheric surfaces. *Ophthalmic Physiol Opt.* 2005;25(2):153-161.
10. Preussner PR, Wahl J, Weitzel D. Topography-based intraocular lens power selection. *J Cataract Refract Surg.* 2005;31(3):525-533.
11. Canovas C, Artal P. Customized eye models for determining optimized intraocular lenses power. *Biomed Opt Express.* 2011;2(6):1649-1662.
12. Dubbelman M, Sicam VA, Van der Heijde GL. The shape of the anterior and posterior surface of the aging human cornea. *Vision Res.* 2006;46(6-7):993-1001.
13. Haigis W. The Haigis formula. In: Shammas J, ed. Intraocular Lens Power Calculations. Thorofare, NJ; Slack Incorporated; 2004.
14. Hoffer KJ. The Hoffer Q formula: a comparison of theoretic and regression formulas. *J Cataract Refract Surg.* 1993;19(6):700-712.
15. Holladay JT, Prager TC, Chandler TY, Musgrove KH, Lewis JW, Ruiz RS. A three-part system for refining intraocular lens power calculations. *J Cataract Refract Surg.* 1988;14(1):17-24.
16. Retzlaff JA, Sanders DR, Kraff MC. Development of the SRK/T intraocular lens implant power calculation formula. *J Cataract Refract Surg.* 1990;16(3):333-340.