REVIEW

Updated practical intraocular lens power calculation after refractive surgery

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Purpose of review

Since its introduction in the 1980s, more than 40 million people worldwide have undergone some form of kerato-refractive surgery. Many of these individuals are now candidates for cataract surgery and pose the challenge of attaining first-rate refractive outcomes in nonvirgin eyes. Numerous approaches have been developed to estimate intraocular lens (IOL) power in eyes postrefractive surgery. This review highlights the most practical, relevant options for accurate IOL power determination in these cases.

Recent findings

With refined techniques and advances in instrumentation, more accurate assessments of true corneal power and thus, IOL power, are possible in postrefractive eyes. Optical coherence tomography and other corneal tomography instruments have markedly improved accuracy in this process. However, when expensive, modern equipments are not readily available, and online IOL calculators such as the American Society of Cataract and Refractive Surgery (ASCRS) calculator have become efficient, reliable options. Recent evidence confirms the accuracy of these online calculators.

Summary

Emerging literature supports the use of methods that do not rely on prior refractive data in IOL power determination. Online IOL calculators provide user-friendly, efficient options that greatly facilitate accurate IOL power determination for cataract surgery in eyes that have undergone prior kerato-refractive surgery.

Keywords

intraocular lens power calculation, laser-assisted in-situ keratomileusis, photorefractive keratectomy, refractive surgery, radial keratotomy

INTRODUCTION

The accurate prediction of refractive outcomes in eyes that have undergone corneal refractive surgery is more challenging than in virgin eyes [1,2]. Numerous methods have been devised to aid in accurate intraocular lens (IOL) power calculation post-refractive surgery. However, despite a variety of approaches, the reliability of predicting refractive outcomes in these eyes has been less than that in virgin eyes [3].

IOL power errors in these eyes can be attributed primarily to two factors: inaccurate determination of the true corneal refractive power and incorrect estimation of the effective lens position (ELP) by the third or fourth-generation IOL power calculation formulas when the postoperative corneal powers are used [4].

Online IOL calculators have become the preferred options for determining appropriate IOL power for cataract surgery due to their ease of use, ready availability and relative accuracy. Two commonly used calculators are the American Society of Cataract and Refractive Surgery (ASCRS) IOL Calculator [5] and the Ocular MD IOL Calculator [6].

This review will elucidate the factors causing the IOL power errors, latest methods and techniques available to improve the accuracy of the IOL power calculation and clinical pearls in selecting IOL power in these challenging cases.

SOURCES OF ERROR

There are three main sources of error in IOL calculation after refractive surgery: the radius

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KEY POINTS

- The accurate prediction of refractive outcomes in eyes that have undergone corneal refractive surgery is more challenging than in virgin eyes because it is difficult to ascertain the true corneal power and estimate the ELP.
- The safest, most reliable methods of determining IOL power postrefractive surgery do not rely on historical data, which may be inaccurate or unavailable.
- OCT, slit-scanning tomography and Scheimpflug-based instruments allow for direct measurement of posterior corneal curvature, obviating a lot of past errors.
- Online IOL calculators have become the preferred options for determining appropriate IOL power for cataract surgery due to their ease of use, ready availability and relative accuracy.

measurement error, the keratometer index error and the IOL formula error. The refractive power of the cornea is an important input parameter for the calculation of IOL power [7]. Currently, there is no instrument to directly measure corneal power in diopters (D). Keratometry or topography derives corneal power (K) from the radius of corneal curvature. Most keratometers measure central corneal radius of curvature in the paracentral 2.5–3.2 mm zone and assume a sphero-cylindrical cornea, an assumption that is incorrect after myopic refractive surgery [8,9]. Depending on the optical zone of the ablation, this measurement will likely be steeper than the centre. Thus, corneal power will be overestimated, IOL power underestimated and the patient will have uncorrected hyperopia. This is most relevant after myopic laser vision correction (LVC).

The keratometer index error stems from the fact that in classical keratometry or corneal topography, the corneal power is derived from a measurement of the anterior corneal surface alone without knowledge of the properties of the posterior corneal surface [7]. The keratometer index (1.3375) assumes a fixed ratio between anterior and posterior corneal curvatures. Refractive surgery alters this relationship and the constant is no longer applicable, leading to unreliable K values.

The IOL formula error applies to third-generation and fourth-generation formulas (Hoffer Q, Holladay, SRK/T), which predict the postoperative location of the lens or ELP on the basis of the corneal power. Postmyopic LVC, if postoperative corneal power is used to calculate the ELP, the calculated lens position will be more anterior than will likely occur [4]. That is, the predicted ELP or anterior chamber depth based on the flatter corneal radius is falsely shallow. This will cause the formula to select an IOL of insufficient power, resulting in postoperative hyperopia.

PRIOR RADIAL KERATOTOMY

In eyes with prior radial keratotomy, unlike post-laser-assisted in-situ keratomileusis (LASIK)/photorefractive keratectomy (PRK) eyes, posterior corneal curvature also changes, presumably more closely preserving the ratio between the anterior and posterior corneal surface [8]. Compared with post-LASIK/PRK eyes, refractive outcomes after cataract surgery in postradial keratotomy eyes are less predictable. This may be partly due to greater variability in anterior and posterior corneal curvature changes that deviate from those estimated by using the standardized refractive index [9]. In addition, it has been reported that 20–50% of radial keratotomy eyes have a gradual hyperopic shift [10].

IMPROVING ACCURACY

Important elements to consider when determining accuracy of IOL formulae are mean IOL prediction error, variance in that error and the percentage of eyes within a certain refractive prediction error [11▪]. The ideal formula would be one that best combines these different elements.

Many methods to improve the accuracy of IOL power selection for post-LVC eyes have been proposed. Some methods rely entirely on historical data, some rely on historical data and current measurements, and others rely solely on current measurements. The focus of this review will be on methods most relevant to current practice.

Methods that rely entirely on historical data depend on the accuracy of prior data often acquired elsewhere. This group, including the clinical history method [12], has generally been found to be less accurate than techniques in which current measurements are utilized. Multiple modified methods use a combination of prior data and current corneal measurements.

Given that historical data on keratometry and refraction from the time of LVC are often not readily available and even if available, corneal changes since the LVC procedure are not accounted for, the most practical approach is one that is independent of historical data.

Contact lens overrefraction is less accurate and less reliable than other approaches [13,14]. It suffers from a relatively inaccurate visual endpoint in patients with cataract, as vision is significantly decreased from the media opacity [15].

Some newer methods for post-LVC IOL calculation do not rely on historical data or refraction.

The Koch method uses standard keratometry to measure the anterior corneal power and then adds a constant posterior corneal power [16]. The Haigis-L method uses empirical linear regression analysis of post-LVC cataract surgery results to optimize the estimate of corneal power from standard keratometry [17]. Theoretically, these methods should work well for eyes with average posterior curvature but may be less accurate in eyes that deviate largely from the average [15].

In order to accurately ascertain the appropriate IOL power for cataract surgery post-LVC, one must utilize a method that best estimates the true corneal power. The best estimate of the true corneal power may be accomplished through techniques that allow one to measure the curvature of anterior and posterior corneal surfaces in each eye. Optical coherence tomography (OCT) and other corneal tomography systems such as slit-scanning tomography (Orbscan II, Bausch & Lomb, Orbtek Inc., Salt Lake City, Utah, USA), rotating slit Scheimpflug-camera (Pentacam, Oculus GmbH, Wetzlar, Germany) and dual-Scheimpflug (Galilei, Ziemer Ophthalmic Systems AG, Port, Switzerland) have this capacity.

Tang *et al.* [15] demonstrate that the clinical history method and contact lens overrefraction method are inferior to OCT-based IOL calculation. Also, Tang *et al.* [15] found that OCT-based IOL calculation had better predictive accuracy than the Haigis-L formula and the Orbscan II device, but the differences were not statistically significant. Compared with OCT, slit-scanning tomography is subject to motion error and has a relatively poor axial resolution, which can lead to large errors in measurement in the presence of corneal haze or opacity [15]. There are limited data comparing the Pentacam and Galilei instruments to more commonly used methods due to expense and lack of widespread use. These instruments have superior depth of focus and use rotational scanning, which may theoretically outperform the Orbscan II device.

PRACTICAL APPLICATION

In everyday clinical practice, no-history methods are the most important. These include the R-factor method of Rosa *et al.* [18], the no-history method of Shammas and Shammas [19], the BESSt formula of Borasio *et al.* [20] based on Pentacam results [21], the Geggel ratio method [20] and the Haigis-L formula for the IOLMaster (Zeiss Meditec, Jena, Germany) [17].

The IOLMaster is widely used at academic institutions in the USA. Haigis studied 278 eyes post-LVC after IOL implantation. Two hundred and twenty-two eyes were previously myopic and 56 were hyperopic. IOLMaster was used to perform keratometry/biometry and IOL calculation was performed from current measurements using the Haigis-L formula (included in the IOLMaster software version 4.x onwards) [7]. Of the myopic eyes, 98.6% were correctly predicted within ±2.00 D, 82.9% within ±1.00 D and 59.9% within ±0.50 D. The respective percentages for eyes after surgery for hyperopia were 96.4, 82.1 and 58.9%. These results compare favourably with normal eyes, although the error margins for the predicted refraction are slightly higher in eyes after refractive surgery [7]. Two benchmark standards proposed in 2009 by the British National Health Service are that 55% of routine, virgin cornea cataract surgeries should be within 0.50 D and 85% within 1.00 D of the targeted spherical equivalent [22]. The Haigis-L outcomes for eyes post-LVC meet the standards for 0.50-D error margin and closely approximate those for 1.00-D error margin.

There have been few studies comparing different algorithms. Savini *et al.* [23] found that the Masket method [24] was the most reliable method when corneal power before refractive surgery was unavailable and refractive change was known even if uncertain. This was because the Masket method omitted the double K step [25] required by other pre-LASIK/PRK K-dependent methods. Using K values from the IOLMaster, the Masket method calculates IOL power in the standard fashion and then modifies by about 33% of the refractive correction.

In a separate study, McCarthy *et al.* [26] compared different methods for IOL power calculations in 173 eyes and ranked the top five corneal power adjustment techniques and formula combinations as follows: the Masket method in combination with the Hoffer Q formula, the Shammas method in combination with the Shammas-PL formula, the Haigis-L method, the clinical history method in combination with the Hoffer Q formula and the Latkany Flat-K [27] method in combination with the SRK/T formula.

Without expensive, modern equipment such as the Scheimpflug camera and the IOLMaster, other accurate methods can be used for IOL power calculation after laser refractive surgery. Online IOL calculators provide a straightforward, user-friendly, efficient option for IOL power calculation post-LVC. ASCRS offers the use of a postrefractive IOL calculator online free of charge.

The ASCRS calculator has three modules: prior myopic LASIK/PRK, prior hyperopic LASIK/PRK and prior radial keratotomy [5]. Using this calculator, Wang *et al.* [28] evaluated 72 post-LASIK/PRK eyes that had cataract surgery and found that methods using the achieved refractive change and methods using no previous data gave better results (smaller IOL prediction errors, smaller variances and greater percentage of eyes within 0.50 and 1.00 D of refractive prediction errors) than methods using historic K values and achieved refractive change.

The Ocular MD calculator is another relevant online option for IOL power calculation post-LVC. The ASCRS calculator uses 11 formulae and produces one average IOL power, whereas the Ocular MD calculator uses 20 methods and produces two average IOL powers, one for SRK/T and one for Haigis formulae [6].

DeMill *et al.* [11▪] compared the IOL calculator options and determined that the ASCRS average outperforms the Ocular MD SRK/T and Ocular MD Haigis averages. The ASCRS calculator uses an Aramberri Double-K method modification of the Holladay 1 formula for the majority of IOL power calculations, whereas the Ocular MD calculator utilizes either the corrected SRK/T or Haigis formula for most IOL power calculations. The ASCRS and Ocular MD calculators shared the following methods in this study: clinical history, Feiz/Mannis, Corneal Bypass (Walter), Masket and Shammas. The ASCRS calculator was unique in using the adjusted Atlas 0–3, Modified Masket, Wang-Koch-Maloney and Haigis-L formulae, whereas only the Ocular MD calculator included the Aramberri double-K, Latkany Flat-K, Latkany Average-K, Koch and Mannis Normogram formulae [11▪].

The ASCRS, Ocular MD and all-calculator averages met the British National Health Service criteria. Although not statistically significant, the data from DeMill *et al.* [11▪] demonstrate a trend towards improved percentage of outcomes within the ± 0.50 and ± 1.00 D with the Ocular MD average or the all-calculator average when compared with the ASCRS average alone. Both the Ocular MD average and all-calculator average, when compared with the individual formulae, decrease the mean arithmetic IOL prediction error, mean absolute upper limit of IOL prediction error and variance while increasing the percentage of outcomes within ± 0.50 D [11▪].

Su *et al.* [29▪] evaluated the predictability of ASCRS online IOL calculator using a variety of adjustment methods in a small study of 11 eyes previously treated with myopic LASIK or PRK. Use of the Masket method with the double K Holladay I formula yielded reliable predictions with the highest degree of accuracy [29▪].

From the outset, the creators have made it clear that these tools will be continually refined on the basis of feedback from ophthalmologists. To their credit, these online calculators are constantly evolving and are frequently updated to make them more user-friendly, accurate and relevant to clinical practice.

GUIDANCE TO THE PHYSICIAN

If historical data will be used, to maximize accuracy, one should validate the historical data and use the most recent refraction obtained before cataract development. Generally, no-history methods may be more reliable. We recommend that multiple approaches are considered and evaluated in the challenging scenario of planning for cataract surgery in an eye that has undergone kerato-refractive surgery. Look for consistency in the different values obtained for IOL power. It is often preferred to select higher IOL powers, leaving the patient slightly myopic rather than hyperopic [30].

The naturally occurring positive spherical aberration of the cornea typically increases after radial keratotomy and myopic LASIK and decreases after hyperopic LASIK. Ophthalmologists should select an IOL such that the lens does not accentuate the change in spherical aberration produced by refractive surgery, which would further reduce contrast sensitivity [31]. Eyes with prior radial keratotomy or myopic LASIK generally do better with an aspheric IOL that adds negative spherical aberration [AcrySof IQ lens (Alcon Laboratories, Inc., Fortworth, USA) or Tecnis 1-Piece lens (Abbott Medical Optics Inc., Santa Ana, USA)]. Eyes that previously underwent hyperopic LASIK do well with spherical aberration-neutral IOLs [Sofport AO lens, model LI61AO (Bausch & Lomb, Inc., Rochester, USA)] or spherical IOLs after large amounts of hyperopic correction [31]. After refractive surgery, Toric and multifocal IOLs are generally contraindicated in eyes with irregular astigmatism. Multifocal IOLs are also contraindicated in eyes with obviously increased higher order aberrations, especially spherical aberration and coma. In this setting, a multifocal lens is likely to degrade visual function due to a loss of contrast sensitivity [31].

MANAGING OUTCOMES

Patients who have undergone refractive surgery tend to have high expectations and may be demanding. It is very important that patients are well informed of the limitations of accurate IOL power calculation in eyes that have had LVC. As a part of the informed consent for cataract surgery, the possible need for a piggyback IOL, IOL exchange or repeat kerato-refractive surgery must be discussed.

The major problem is an unacceptable postoperative refractive error. The sooner it is discovered, the sooner it can be corrected, and the patient made happy. Therefore, it is wise to perform K readings and a manifest refraction on the first postoperative day in demanding patients. Immediate surgical correction (24–48 h) will allow easy access to the incision and the capsular bag, a single postoperative period and excellent uncorrected vision [30]. If the cause of the unacceptable refractive outcome is iatrogenic (incorrect axial length, corneal power, mislabeled IOL or a combination of these), transparency is important in discussions with the patient. A delay in diagnosis and appropriate management may incite litigation.

THE FUTURE

Advances in OCT and other corneal tomography techniques will likely refine current approaches. Intraoperative measurement of aphakic eye using the Optiwave Refractive Analysis system (WaveTec Vision, Aliso Viejo, California, USA) shows great promise. However, estimation of ELP remains a challenge. Wang notes that the 'Holy Grail' may be an adjustable IOL, which could facilitate correction of residual spherical and astigmatic refractive errors and residual higher order aberrations. Ideally, such an IOL could be modified multiple times to adapt to the patient's changing visual needs and to compensate for ageing changes of the cornea [8].

CONCLUSION

There are a multitude of methods to aid in accurate calculation of IOL power for cataract surgery in eyes previously treated with kerato-refractive surgery. Mounting evidence points to accurate, predictable refractive outcomes when methods that do not require prior refractive data are utilized. Well established examples include the Shammas and Haigis-L methods, which do not rely on historical information, which may be inaccurate or unavailable. There are three major sources of error in IOL power calculation. The instrument error stems from an inability of most keratometers to directly measure central corneal power. Most keratometers assume a constant index of refraction (1.3375) between the anterior and posterior corneal surfaces. This leads to error, as this relationship may be altered post-LVC. Finally, IOL formula errors stem from an inaccurate estimate of the ELP in eyes post-LVC. The Shammas and Haigis-L methods avoid this error, as they do not use the corneal radius to predict the ELP. Several instruments are available for keratometry and biometry, but many require formulas to adjust for prior LVC. The IOLMaster is one of the widely used instruments for IOL power calculation and is relatively reliable. More advanced techniques utilizing OCT, slit-scanning tomography or Scheimpflug-based principles are likely to be more accurate in predicting refractive outcomes, as the posterior corneal curvature can be directly measured. However, these instruments are expensive and not readily available. The advent of online IOL calculators such as ASCRS and Ocular MD calculators has greatly facilitated reliable IOL power calculation in eyes postrefractive surgery. Despite some level of inevitable uncertainty, especially in nonvirgin eyes, the use of well established methods combined with clinical judgement provides for improved consistency in refractive outcomes.

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Conflicts of interest

No author has received any grants nor has any conflicts of interest relating to the content of the study.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
■ of special interest
■■ of outstanding interest
Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 362).

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This is a very useful, relevant study comparing commonly used online IOL calculators. Ocular MD and all-calculator averages may yield the most reliable predictions as opposed to using individual calculator results only.

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Using the popular ASCRS calculator, this small study provides an in-depth review of the variety of commonly used formulas to calculate IOL power postmyopic refractive surgery. This study found that the Masket method in combination with the double K Holladay I formula is the best choice for IOL power prediction after LASIK or PRK.

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