Intraocular lens power calculation in patients with corneal ablative treatments or corneal pathologies: perspective

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Abstract

Intraocular lens power calculation in patients with abnormal corneas secondary to ablative treatments or pathologies is challenging. The historical data methods, which collect data before corneal ablative treatment, are preferred for the intraocular lens power calculation. It is recommended to perform the calculation with several formulas and to compare the calculated lens powers. The Barrett True-K (total keratometry) provides good prediction after myopic and hyperopic laser treatment. In general, mild myopia should be aimed for, and aspheric lenses are preferred in these cases. The corneal irregularity in patients with keratoconus necessitates measurements of the back surface of the cornea. Postoperative myopia should be aimed for owing to the risk of hyperopic refractive outcomes. Implantation of toric lenses is only recommended in selected cases. In patients with Fuchs' endothelial dystrophy, preoperative measurements should be performed after administration of hyperosmolar eye drops and as late as possible during the course of the day. Measurements should include the posterior corneal surface. Owing to the hyperopic shift after Descemet membrane endothelial keratoplasty or Descemet stripping automated endothelial keratoplasty, a slight myopia should be aimed for, followed by cataract surgery in future. In exceptional cases, the implantation of toric lenses may be considered.

Key words: Corneal surgery, laser; Fuchs' endothelial dystrophy; Keratectomy; Keratoconus

Calculation after photorefractive keratectomy or laser in situ keratomileusis

The calculation of intraocular lens (IOL) power in patients after laser vision correction (LVC) treatment is challenging, particularly increasingly more pretreated patients reach the age when cataract surgery is necessary. During the course of LVC, changes in the cornea occur, which must be taken into account in the IOL calculation.

Three factors may result in refractive errors.[1] First, the corneal refractive power (K-value) is not measured directly. Instead, the radius of corneal curvature is determined, and the refractive power is derived from it using the corneal refractive index. Owing to the changed ratio of anterior to posterior corneal surface caused by LVC, the assumed corneal refractive index is not valid and the calculated K-values are incorrect. After a myopic LVC, too high values are determined. Consequently, an IOL with too little power is implanted, and patients become more hyperopic than intended. The opposite is true for a hyperopic LVC. To solve this issue, the anterior and posterior surfaces should be measured using the Scheimpflug camera or optical coherence tomography (OCT).

Second, the radius of the corneal curvature is measured by devices outside the optical center, and the central curvature is estimated. Therefore, after a myopic LVC, the cornea is considered steeper than it actually is in the center when measured peripherally (**Figure**).

Third, the K-value is used in third-generation formulas (ie, Hoffer Q, Holladay 1, and SRK/T) to calculate the effective lens position and the lens power. Based on incorrect K-values, myopic LVC underestimates the effective lens position and the lens power to be implanted. Thus, the Aramberri double K method uses the preoperative K-value to calculate the effective lens position and the postoperative K-value to calculate the lens power.

There is no consensus on the superiority of any formula for IOL calculation after LVC. Some are difficult to implement in practice, as they require manual calculations of lens power or special measuring devices. The most common options in clinical practice with good results are presented below.

The historical data methods, which collect data before LVC, are preferred to the non-historical data methods. If post-LVC refraction is used for calculations, values should be determined approximately 6 months after surgery to prevent bias from subsequent myopic cataract. Non-historical data methods can be divided into regression formulas and formulas based on measurement of the anterior and posterior corneal surfaces using the Scheimpflug camera or OCT. In the absence of data regarding LVC, corneal topography is recommended prior to IOL implantation to assess the nature of LVC and any corneal irregularities.

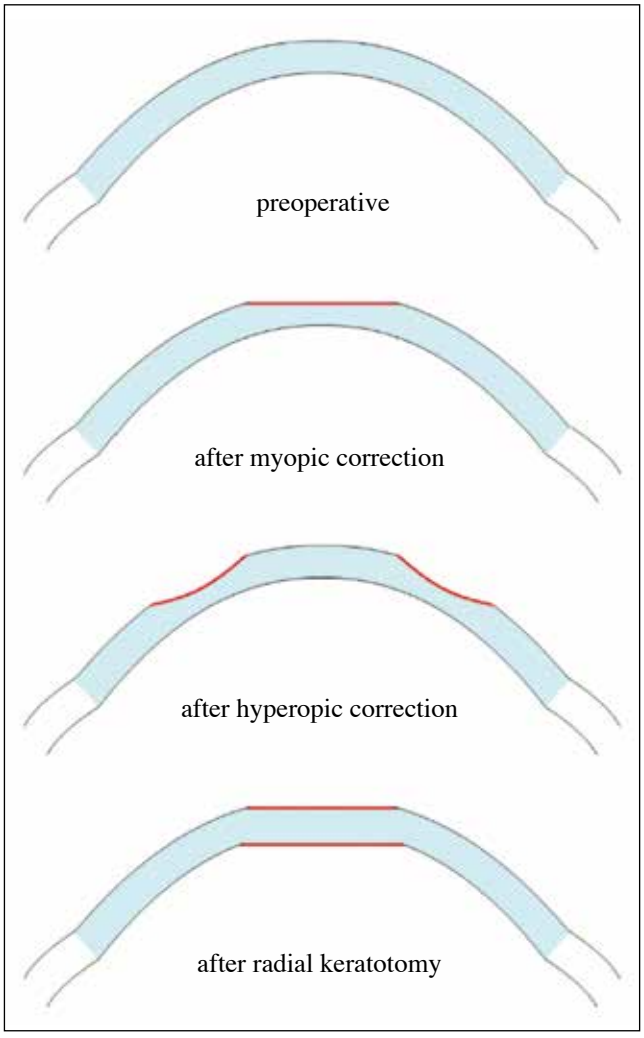

Figure. Corneal changes after ablative treatments

The American Society of Cataract and Refractive Surgery (ASCRS) website (iolcalc.ascrs.org) and the Asia-Pacific Association of Cataract and Refractive Surgeons (APACRS) website (apacrs.org) provide formulas and calculations and include an option for toric lenses.

Non-historical data methods for IOL calculation after myopic and hyperopic refractive surgery include (1) Holladay 2: IOLMaster 500 & 700, Lenstar LS 900, Holladay IOL Consultant Software & Surgical Outcomes Assessment (HICSOAP); (2) Shammas-PL (after myopic LVC) or Shammas-PHL (after hyperopic LVC): ASCRS, Lenstar LS 900; (3) Haigis-L: ASCRS, IOLMaster 500 & 700; (4) OCT-based formula: ASCRS; and (5) Barrett True-K no-history: ASCRS, APACRS, IOLMaster 700, Lenstar LS 900.

Historical data methods for IOL calculation after myopic and hyperopic refractive surgery include (1) variations of double-K Holladay 1: ASCRS, HICSOAP, Pentacam; (2) Masket and modified-Masket: ASCRS, Lenstar LS 900; and (3) Barrett True-K: ASCRS, APACRS, IOLMaster 700, Lenstar LS 900, Pentacam.

Masket is a modification of SRK/T in formerly myopic eyes or Hoffer Q in formerly hyperopic eyes. The change in refraction secondary to LVC must be known. It provides more accurate results than the Haigis-L in post-myopic eyes.[1] The pre-LVC refraction is also required for the Barrett True-K. Compared with other formulas in the ASCRS calculator, Masket achieves comparable or better predictions after myopic correction, as does the Barrett True-K no-history.[2]

In case there are no historical data, obtaining keratometry measurements from the Pentacam, the total corneal refractive power or the true refractive power in the 4-mm zone are good options for IOL power calculations using the Haigis formula.[3] An alternative is the Shammas no-history formula in combination with the true net power in the 4-mm zone.[4]

Precise measurements of the cornea can be made using ray-tracing. Calculations are offered directly on the GALILEI and SIRIUS or in the OKULIX and PhacoOptics programs. Calculations based on intraoperative aberrometry with the Optiwave Refractive Analysis show good results, compared with the Haigis-L or Masket, as does the OCT formula from the ASCRS website.[5]

Calculating multifocal lenses is even more challenging. For post-myopic eyes, the Barrett True-K no-history is the best non-historical data method of the ASCRS calculator. If pre-LVC data are available, the Masket, modified-Masket, Barrett True-K, and Haigis-L are comparable and superior to the Shammas-PL.[6] After hyperopic LVC, all available ASCRS formulas are suitable for calculation, except for the modified-Masket.[7]

The IOLMaster 700 allows measurement of the posterior corneal surface using swept source OCT and thus the total keratometry. The difference between standard keratometry and total keratometry values after LVC is 0.21-0.36 diopters.[8] Calculations using the standard Haigis + total keratometry are comparable to those using the Haigis-L + standard keratometry and Barrett True-K no-history + standard keratometry.[9] The use of total keratometry (rather than standard keratometry) improves the performance of the Barrett True-K.[8] In the IOLMaster, total keratometry is then selected in the calculation, and the patient is not indicated as preoperative. In the APACRS version of the Barrett True-K, the refractive power of the corneal posterior surface and thickness can be entered separately. These calculations give better results after myopic LVC than those with the standard Haigis + total keratometry, Haigis-L + standard keratometry, and Shammas-PL + standard keratometry. If no pre-LVC data are available, the APACRS version of the Barrett True-K currently provides the best prediction for post-myopic and hyperopic patients.[8]

The ASCRS website allows calculations using different formulas with one-time data entry. The suggested lens powers can be compared and outliers can be detected. The mean of the remaining values can be used for IOL selection.

No single method is superior to others. Calculations should be made with several formulas, and the calculated lens powers compared. Nonetheless, the Barrett True-K formula provides good predictions after myopic and hyperopic LVC. It can be used with or without pre-LVC data. To avoid undesirable hyperopic results, a mild myopia (a spherical equivalent of -0.25 to -0.50 diopters) should be aimed for. As positive spherical aberrations occur after myopic LVC, aspheric lenses with negative aberrations should be implanted in these cases.

Calculation after to small incision lenticule extraction (SMILE)

SMILE is a relatively new method for correction of ametropia, and its data are limited. Nonetheless, both LASIK and SMILE are excision procedures with removal of corneal tissue and thus similar limitations and errors in IOL power calculation are assumed. Principles that apply to LASIK may also be valid for SMILE. The use of the Barrett True-K no-history, Barrett True-K, or Masket can lead to good results.[10]

Calculation after radial keratotomy

With radial keratotomy, in contrast to the ablative methods, the anterior and posterior corneal surfaces are flattened (**Figure**). Postoperatively, the corneal refractive power is overestimated when normal measurement methods are used. In addition, the cornea is unstable after radial keratotomy, and the instability is exacerbated by the incisions made during cataract surgery, further decreasing the predictability of the IOL calculation. The preinstalled formulas of the Lenstar LS 900 and the Haigis-L of the IOLMaster 700 can be used for the calculation, according to the manufacturer. The ASCRS and APACRS websites also offer options. The Barrett True-K yields the best results. If no pre-LVC refraction is available, the Haigis-L, OCT-based formula, and Barrett True-K no-history are suitable.[11,12]

IOL calculation in patients with keratectasia

Keratectasia usually occurs primarily in patients with keratoconus. During the course of keratoconus, myopia and astigmatism occur. Refractive errors after cataract surgery are common, because the cornea is usually irregular, and keratometry does not provide reliable values. In addition, measurement of K-values and axial lengths (AL) often do not correspond to those of the optical axis, because the apex (the steepest part of the cornea) is usually located in the inferior region. The reliability of the corneal measurement decreases with increasing keratoconus. A stable keratoconus is necessary for reliable IOL calculation. The Pentacam tends to measure lower K-values than optical biometry devices such as IOLMaster or Lenstar LS 900.[13] Devices that measure anterior and posterior corneal surfaces to determine total refractive power (such as the Pentacam) should be used. IOL power calculation using total corneal refractive power of the central 3 mm zone instead of simulated K-values leads to a myopic shift. Simulated K-values based on anterior surface measurements overestimate corneal refractive power and may result in hyperopic results. For severe keratoconus, a standard K-value of 43.25 diopters (rather than actual K-values) can be used for calculation. In general, a myopic outcome should be aimed for.

Wearing contact lenses flattens the anterior cornea and alters the astigmatism magnitude and axis. Recovery rates of corneal warpage range from about 2 weeks for soft contact lenses to 9 weeks for rigid gas-permeable lenses. Many patients with keratoconus are impaired during daily routine without rigid contact lenses. Hence, maintaining a contact lens-free period prior to measurements for keratorefractive surgery is difficult. To obtain reliable K-values, serial measurements are recommended until the values are stable.[14]

The HICSOAP software offers a Holladay II version specifically for keratoconus, but it is inferior to the standard Holladay II. The Kane version modified for keratoconus (Kane-keratoconus) includes toric IOL calculations (iolformula.com). The Kane-keratoconus performs better than Hoffer Q, SRK/T, Holladay I and II, Haigis, Barrett

Universal II, and standard Kane at all stages of keratoconus. Alternatively, good results can be achieved using the Barrett Universal formula. The SRK/T is a good option for long eyes, as it leads to a myopic shift at high K-values and axial lengths, which can compensate to some extent for the rather hyperopic outcome of patients with keratoconus.[15] For SRK/T, adjustments to the target refraction are recommended to correct for errors in effective lens position prediction as follows: 0.75 to 1.5 diopters in stage II and 2.0 to 3.0 diopters in stage III.[16]

Regarding lens design, toric lenses are a good option for correcting regular astigmatism. Nonetheless, in patients with keratoconus, the astigmatism is often irregular, which creates difficulties in both IOL calculation and IOL positioning. Higher-order aberrations can be exacerbated. In cases that keratoplasty is required in future or that form-stable contact lenses are worn postoperatively, toric IOL are not recommended. The pinhole lens IC-8 is suitable to reduce higher-order aberrations and improve central vision.

Patients with keratoconus have much higher K-values than healthy individuals. If the need for penetrating keratoplasty or deep anterior lamellar keratoplasty is foreseeable, it may be appropriate to anticipate the postoperative keratometric value and to calculate the IOL power accordingly. Otherwise, using the high preoperative K-values for IOL calculation results in a lower power to be implanted and considerably high hyperopic shifts after penetrating keratoplasty or deep anterior lamellar keratoplasty.

IOL calculation in patients with Fuchs endothelial dystrophy

Phacoemulsification with lens implantation can be performed separately before or after Descemet membrane endothelial keratoplasty (DMEK) or Descemet stripping automated endothelial keratoplasty (DSAEK) in Fuchs endothelial dystrophy or even combined as triple-DMEK or triple-DSAEK. For IOL calculation, the corneal posterior surface should be included in the preoperative measurements, as the ratio of anterior to posterior surface is altered, compared to healthy eyes. It should be noted that a myopic shift occurs in calculations with the total corneal refractive power instead of the simulated K-values.

In Fuchs endothelial dystrophy, the corneal edema leads to a myopic change secondary to the flattening of its posterior surface. In addition, the refractive indices change secondary to the disturbed arrangement of the fibrils. Therefore, measurement of non-preoperated eyes is more difficult. To reduce distortions, measurements should be made as late as possible after applying hyperosmolar eye drops. In case of a pronounced cornea guttata, a triple-procedure is not recommended, because central guttae lead to unreliable values.

Although the refractive power of the anterior corneal surface decreases only slightly, the absolute value of the refractive power of the posterior surface increases and thus total corneal refractive power decreases. A hyperopic shift occurs after DMEK or DSAEK. This is more pronounced in thicker (more edematous and decompensated) cornea. The greater the ratio of the radius of the posterior surface to that of the anterior surface, and the greater the posterior asphericity quotient (Q-value) [ie, the flatter the posterior surface], the higher the hyperopic shift. Considering only corneal thickness or posterior corneal radius is not sufficient to estimate the risk of hyperopic shift.[17] Owing to the hyperopic shift after DMEK, a myopic outcome of -0.5 to -1.0 diopters should be aimed for. The shift after DSAEK is slightly higher than that after DMEK. A target refraction of -1.5 diopters should be aimed for in order to prevent postoperative hyperopia after triple-DSAEK.[18] The higher the preoperative posterior Q-value, the higher the risk of a hyperopic shift and the stronger the myopic target refraction should be aimed for. The myopic target refraction should be set somewhat lower if decongestant eye drops are applied before measurement.

Compared with Hoffer Q, Holladay I, and Haigis, the SRK/T and the use of K-values of the IOLMaster without including the posterior corneal surface show the lowest deviations from ray-tracing-based calculations of the OKULIX software, which considers anterior and posterior corneal surface.[19] There are no recommendations regarding the superiority of specific calculation formulas.

Toric lenses can be implanted in selected patients with severe astigmatism. However, the unpredictable change in astigmatism caused by DMEK or DSAEK, especially its alignment, should be considered. If bilateral surgery is indicated, the calculation of the second eye can be based on the refractive results of the partner eye.

Contributors

All authors designed the study, acquired the data, analyzed the data, drafted the manuscript, and critically revised the manuscript for important intellectual content. All authors had full access to the data, contributed to the study, approved the final version for publication, and take responsibility for its accuracy and integrity.

Conflicts of interest

CK has disclosed no conflicts of interest. MS is a consultant for Alcon, Oculus, and Zeiss.

Funding/support

This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability

All data generated or analyzed during the present study are available from the corresponding author on reasonable request.

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