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# IOL CALCULATION AFTER REFRACTIVE SURGERIES: CHALLENGES, TIPS AND PEARLS

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Achieving a good and consistent refractive outcome after cataract surgery has become more achievable following marked advances in modern intraocular lens (IOL) manufacturing technology, better instruments to perform preoperative biometry, and improved surgical techniques. It has been reported that postoperative refraction can fall within ±0.50 D of target refraction in 70% to 80% of operated eyes that have not undergone previous refractive surgery. However, this target percentage can be considerably lower in the group of patients who had undergone previous refractive surgery, and efforts are still ongoing by some of the brightest minds in the world of ophthalmology to identify the best method or methods to achieve a more consistent and more predictable results in this group of patients.

Over the years, many methods have been proposed to achieve this, and the sheer number of methods that can be found in the literature clearly show that the optimal methodology has yet to be found.

To understand the challenges, we must first understand that after laser-assisted in situ Keratomileusis (LASIK), photorefractive keratectomy (PRK) or radial keratotomy (RK) surgery, IOL power miscalculation occurs due to three types of error:

1. ***Keratometric Index Error***
2. ***Radius Error***
3. ***Formula Error***

Calculations are more accurate, and a larger range of methods can be used, when the refractive change induced by LASIK or PRK and the preoperative corneal power are known. The ideal method for IOL power calculation may vary according to the available data for that particular patient. The various results from these calculations can then be compared and a decision can be made with regards to the best IOL power to be selected for the best chance of achieving the optimal postoperative outcome.

## Number 1: Keratometric Index Error

Keratometers, corneal topographers, and any devices developed to measure corneal power use a standardized, fictitious keratometric index of refraction—usually 1.3375—to convert the measured radius of the anterior corneal surface into keratometric diopters.

Keratometers and topographers measure the radius of anterior corneal curvature, but the keratometric index of refraction posits a keratometric index of refraction posits a theoretical single refractive lens representing both corneal surfaces. It assumes a *constant ratio of anterior to posterior corneal curvature.*

Since LASIK, PRK and other laser refractive procedures modify only the anterior corneal curvature but leave the posterior curvature unchanged, the normal anterior/posterior curvature ratio is significantly altered, and the keratometric refractive index therefore becomes invalid.

RK flattens both the anterior and posterior corneal surfaces, but only in a small central optical zone. The effective optical zone diameter can be significantly smaller than the measurement zone of standard keratometry. Therefore, standard keratometry tends to *overestimate* the true corneal power due to the large variation in the central cornea power and the paracentral zones outside the small optical zone where the standard keratometry readings are taken.

As a consequence, after myopic laser correction, keratometry (K) readings usually **overestimate** corneal power, and the IOL power is *underestimated*, so that patients are likely to experience postoperative hyperopia. Conversely, in hyperopic laser correction, corneal power is underestimated, IOL power is overestimated, and patients risk postoperative myopia. Usually, the higher the attempted correction, the higher the resulting under- or overcorrection.

It has shown that, after myopic excimer laser surgery, the keratometric index of refraction should be decreased proportional to the amount of correction in order to get a correct of correction in order to get a correct measurement of corneal power. Alternatively, the keratometric index error can be overcome by measuring the actual curvature of both corneal surfaces using technologies such as Scheimpflug imaging or optical coherence tomography (OCT).

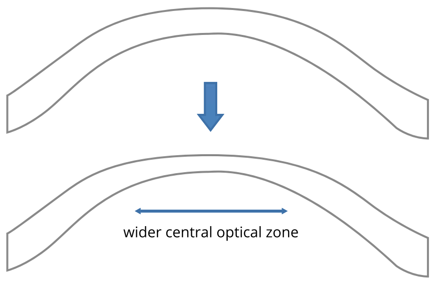


Figure 1. Laser vision correction alters the anterior corneal curvature but not the posterior curvature. This alters the normal anterior/posterior corneal curvature ratio.

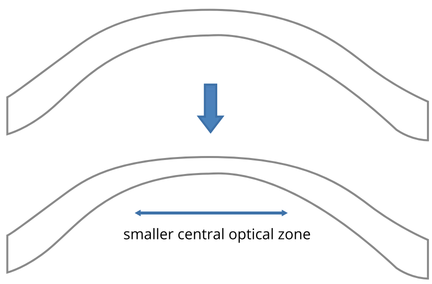


Figure 2. Radial keratotomy flattens both the anterior and posterior curvature, within a small central optical zone. This leads to an extreme variation in corneal power between the center and periphery.

## Number 2: Radius Error

Radius error is related to another assumption made by most devices that extrapolate central corneal curvature from paracentral measurements. After myopic ablations, these instruments can measure a paracentral corneal curvature that is steeper than the central corneal curvature. Accordingly, several authors have shown that central corneal curvature

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measurements better reflect the refractive change induced by surgery and have suggested using central values provided by corneal topography, rather than simulated keratometry, to calculate corneal power after excimer laser surgery. This issue is clinically relevant in eyes with small or decentered treatments, in which the corneal radius may be measured on the periphery of the treated zone and may be different with respect to the radius passing through the visual axis. When the optical zone diameter is 6 mm or larger, the radius error is negligible.

### Number 3: Formula Error

Third-generation IOL power formulas, such as Hoffer Q, Holladay 1, and SRK/T, use corneal power to predict the effective lens position (ELP). After myopic LASIK or PRK, the reduced corneal power leads to an underestimation of ELP, and this can further contribute to IOL power underestimation. The opposite effect occurs after hyperopic surgery.

To address this issue, Dr. Jaime Aramberri, developed the **double-K method**, which uses two K values: the *pre-refractive surgery* K value for the calculation of the ELP and the post-refractive surgery K value for the vergence formula that finally calculates IOL power.

All of the errors described above also occur after RK. In these eyes, however, the keratometric index error is the opposite of that after myopic LASIK or PRK, as the posterior corneal curvature flattens more than the anterior corneal curvature after RK. Due to the small optical zone, the most relevant error in post-RK eyes is radius error.

### Best Approach to IOL Calculation post-refractive surgery

Most published IOL calculation methods for use after refractive surgery rely on pre- and postoperative refractive measurements being available. Calculations are more accurate, and a larger range of methods can be used, when both the refractive change induced by corneal surgery and the preoperative corneal power are known. The refractive change is required by methods such as those developed by Masket and Savini. The preoperative corneal power is mandatory to calculate double-K formulas as well as some other derivative formulae.

If these data are not available, the surgeon can still try to determine the refractive change by asking the patient the power of his or her old contact lenses or eyeglasses. The preoperative corneal power can also be estimated by measuring the postoperative posterior corneal radius; assuming that this did not change after surgery, one can calculate the preoperative anterior radius, which is on average 1.21 times greater than the posterior radius.

If these options are unavailable, the surgeon can rely on no-history methods such as those described by Shammas and Haigis.

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| Corneal power method | Post-laser visual correction | Post-radial keratotomy |
|---|---|---|
| Clinical history | Yes | No |
| Contact lens over-refraction | Yes | Yes |
| Topography based post-LASIK adjustment | Yes | No |
| Central-ring topography | No | Yes |
| Net corneal power measurement | Yes | Not tested |

Table 1. Methods of Adjusting or Measuring True Corneal Power after Refractive

## Methods to Obtain True Corneal Power After Refractive Surgery

These estimations of the true corneal power are then used as input for IOL formulae that are specialized for post-refractive cataract surgery. Some methods are suitable for post-laser vision correction (LVC) eyes, some for post-RK eyes, and some are applicable to both situations.

### 1. Clinical History Methods (refraction and keratometry)

The effective keratometry value is calculated by subtracting the change in refraction induced by the treatment from the preoperative mean corneal power. This method effectively bypasses the index of refraction error. The main disadvantage of the clinical history method and similar formulae is the reliance on preoperative keratometry and refractive data. The effectiveness of these methods may be reduced by the possibility of further errors including but not limited to the use of inaccurate central corneal measurements, variation in measurement units before and after surgery and measurement units before and after surgery and the potential impact of index myopia, as well as the common difficulty in obtaining these historical data. High variability in the predicted outcome means these methods are generally no longer recommended. Also, clinical history method is not suitable for RK because of unstable corneal power (post-RK cornea typically flattens progressively over many years)

### 2. Methods based on change in Manifest Refraction

The aim is to bypass the need for preoperative refraction and keratometry data.

A number of methods propose applying a correction based on the change in refraction to the postoperative keratometry value. This value is then appropriately inserted into the Double-K formula to provide the final IOL power. The “Adjusted Effective Refractive Power (EffRP)” and “Adjusted Atlas 9000 (4 mm Zone)” methods are commonly used examples available through the American Society of Cataract and Refractive Surgeons (ASCRS) IOL Calculator.

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These methodsrely on the availability of the particular topographical unit and require the examiner to directly assess the measurement to confirm the quality of the reading.

Masket and Masket recognized the difficulty in obtaining accurate postoperative corneal measurements and effectively bypassed these potential errors by creating a formula based on the change in laser correction. The authors determined that the chief corrective factor in post-refractive patients was the amount of pre-ablative myopia. Subsequently, a value based on a simple regression formula deriving the change in manifest refraction was added to the standard IOL calculation. Other authors have undertaken similar approaches with basic variations of the regression formulae. However, reliability is limited due to the small sample size used in deriving the formulae.

The risk of index myopia related errors remains considerable for methods based on the change in manifest refraction.

### 3. Methods based on No Historical Data

A. Contact Lens Over-Refraction

This effectively re-measures the corneal curvature rather than providing a recalculated value. This approach has been limited by technical and time constraints. Difficulty in achieving an adequate refraction in patients with poor visual acuity further reduces the effectiveness of this method.

B. Topography and Equation Based

Shammas et al. previously described a simple equation modifying post-laser keratometry values to determine the corrected corneal power to be used in IOL calculation formulae. Other researchers have taken similar approaches. The Maloney and Koch-Maloney methods convert the post-laser keratometry values from corneal topography to the exact power present at the anterior corneal surface and then add an average negative power value for the posterior corneal surface. These latter formulae have been based on values obtained by the Atlas topography (Zeiss, Germany) and thereby remain of limited value to practices without this unit.

**Haigis-L formula** bypasses the various errors through the use of a correction formula then applied to the standard Haigis formula. The relative availability of the Haigis-L formula across several platforms which includes both instrument (eg. IOL Master) and web-based programs, and the ease of use, has led to the formula rapidly becoming a favourite and frequently used tool for these calculations. The recently introduced hyperopic version of the Haigis-L formula is also very useful for patients who have undergone prior hyperopic LASIK. It is a purely objective methodology that uses small zone keratometry and requires no prior historical information.

C. Intraoperative Measurements

Mackool et al. and other authors have proposed an alternative approach. The cataract is first removed and the patient is required to wait for an hour before an aphakic refraction is undertaken. An algorithm is then applied to the refraction to determine the true IOL power to be inserted but with mixed results. Intraoperative reforming of the anterior chamber either with balanced salt solution or viscoelastics and variable refractive indexes remain significant obstacles for these methods in achieving consistent postoperative outcomes. More recently, the use of intraoperative wavefront aberrometry has been described to further refine outcomes. However, the results have yet to be fully verified.

D. Ray Tracing

The principles of ray tracing suggest that using this method for IOL calculations may provide more accurate, reproducible results compared to existing alternative keratometric methods. Ray tracing technology is currently available in many topographical systems although results may be enhanced with the addition of external computational programs. This remains an uncommonly used methodology.

### Net Cornea Power Measurements

The fundamental solution to obtaining accurate post-LVC corneal power is to directly measure both anterior and posterior corneal curvature and thereby calculate the net corneal power. Several instruments can directly measure both anterior and posterior corneal surfaces. These methods include slit-scanning tomography, Scheimpflug photography, and OCT. These methods are being tested in post-laser vison correction cataract surgery and may not be suitable for post-RK cases.

### Avoiding other sources of Error

Besides focusing on the calculation formulae, it is also vital to carefully analyse the latest **Corneal Topography.**

To confirm that a refractive laser procedure had indeed been done, and the type of ablation, look for the definitive cornea changes induced by the surgery, i.e. central flattening (myopic laser ablation) or steepening (Hyperopic laser ablation) or steepening (Hyperopic laser ablation).

A **small or decentered optical zone** is likely to generate a relevant radius error, as the corneal radii of curvature may easily be measured on the periphery of the optical zone, where the curvature is different from that at the visual axis. This situation can be detected only by careful reading of the corneal topography.

Topography may also reveal if any astigmatism present is regular or irregular, the latter of which will be correctable by the use of toric IOLs.

In considering IOL selection for post-refractive patients, it is also important to remember that refractive surgery alters the corneal asphericity, thereby changing corneal **Spherical Aberrations.** The virgin cornea has positive spherical aberrations; however, prior hyperopic LASIK may induce corneal negative spherical aberrations, while myopic LASIK (and RK) generally causes an increase in positive spherical aberration. Decentred ablations also cause an increase in spherical aberrations.

Studying the corneal spherical aberrations on most modern topographers is relatively easy, and will help to determine the optimal IOL to be used, be it those that induce positive or negative spherical aberrations, or are zero spherical aberration lenses, to obtain the best quality vision post operatively. High induced corneal spherical aberrations may also preclude the use of multifocal IOLs in these patients.

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Automated keratometers, including those integrated into most optical biometers, do not allow surgeon to visualize the diameter and centration of the optical zone and are therefore insufficient for these cases. Should the optical zone be small (< 4 mm) or decentered, the radius error makes most methods of calculating corneal power invalid. In this scenario, IOL power calculation based on ray tracing is likely the best option.

## Conclusion

Although a number of formulae may now provide improved refractive outcomes in post-laser refractive surgery patients, it remains a difficult and time-consuming action to derive the IOL powers using multiple formulae, and it is generally impractical for most private practices.

For most ophthalmologists, they should avail of all resources that they can access, depending on the data available. They can then evaluate the postoperative results and determine the formula that provides them the most consistent and predictable results.

These may include:

1. Instrument based calculations eg. Haigis L, Holladay's IOL Consultant Program, etc.
2. Web based Calculators including:
   a. The ASCRS Post-refractive Calculator (www.iolcalc.org)
   b. The Hoffer-Savini LASIK IOL Power Tool (www.iolpowerclub.org/post-surgical-tiol-calc)
   c. The Asia Pacific Association of Cataract and Refractive Surgeons (www.apacrs.org) provides the Barrett True-K formula for post-refractive IOL patients
3. Apps like the Eye Pro application, which utilizes the BESSt post-refractive IOL formula and the PAK post-refractive IOL formula.

Because there are many methods of calculating IOL power after previous refractive surgery, it is useful to obtain a consensus of several methods by comparing the average or median recommended IOL power. When there is a wide range of recommendations (typically in cases of refractive surgery for high or extreme dioptric correction), it is wise to hedge in the direction of myopic results (choose higher IOL power or select lower corneal power estimation to use in IOL calculation).

Even with the use of many specialized methods, the predictability of refractive outcome of cataract surgery after previous refractive surgery remains less than optimal overall. Therefore, all patients who had previous refractive surgery should be warned about the potential need for refractive correction after their cataract surgery, including the possibility of IOL exchange for significant postoperative refractive surprise.

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1. Cataract & Refractive Surgery Today (CRST) Europe. IOL Power Calculation After Refractive Surgery. Retrieved from http://crstodayeurope.com/articles/2015-may/iol-power-calculation-after-refractive-surgery/.

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