Intraocular lens power calculation after corneal refractive surgery

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Purpose of review
Corneal refractive procedures have become increasingly popular over the past decade, allowing patients to have excellent uncorrected visual acuity and spectacle independence. As these individuals mature, many will eventually undergo cataract surgery. With the advances in modern cataract surgery and lens implant technology, particularly presbyopic intraocular lens implants, patients and physicians have greater expectations regarding visual outcomes and independence from glasses after cataract surgery. Therefore, it is important to understand methods to accurately determine intraocular lens power calculation after keratorefractive procedures to avoid refractive surprises and patient dissatisfaction.

Recent findings
In this review article, we provide an overview of intraocular lens power determination after corneal refractive surgery, highlighting sources of errors and potential methods to improve the accuracy of the lens power estimation.

Summary
Newer methods to address errors in intraocular lens power calculations after keratorefractive surgery represent a paradigm shift from the previous gold standard of the clinical history method. Understanding the advantages and limitations of the various methods may be beneficial in obtaining more accurate estimations of the intraocular lens power after corneal refractive surgery, resulting in improved visual outcomes.

Keywords
intraocular lens calculation, laser-assisted in-situ keratomileusis, photorefractive keratectomy

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Introduction

Calculating intraocular lens (IOL) power in patients who have undergone prior refractive surgery has been the subject of a significant amount of research over the past decade, including many reviews and editorials [1–5,6•,7]. It is becoming an increasingly important issue for two particular reasons. First, millions of patients over the past decade have undergone laser refractive surgery [i.e. laser-assisted in situ keratomileusis (LASIK), laser-assisted epithelial keratomileusis (LASEK), photorefractive keratectomy (PRK)] and as they age, they will eventually undergo cataract surgery. According to surveys of members of the American Society of Cataract and Refractive Surgery, approximately 1 million refractive surgery procedures were performed in the United States per year in 2004 and 2005 [8]. Second, with the increasing popularity of multifocal and accommodating lenses, there is a greater necessity to obtain accurate results in this group of patients, as small errors in lens power choice can result in patient dissatisfaction or the need for further surgery. Since myopic laser refractive surgery has been the most prevalent corrective procedure over the last decade, the majority of research and interest has dealt with this topic. There are, however, significant differences in the calculation methodology after other refractive procedures such as hyperopic LASIK or radial keratotomy. It is important for the cataract surgeon to be able to perform IOL calculations in patients with previous myopic laser refractive surgery as well as to understand the differences in calculation methodology for other procedures.

Our understanding and ability to address this issue has also evolved over time. First, the options for estimation of the corneal power after laser refractive surgery have progressed from historical methods, to topographic methods using 'correction' factors for the cornea, and now to more direct objective measurements of the corneal power. Furthermore, examination of existing third-generation formulas has brought forward additional factors that play a role in the accuracy of these calculations. Finally, specific formulas and methodologies have been introduced that may be used in these patients

Intraocular lens power determination: sources of error

IOL power calculations are based upon several measured parameters, including at least corneal power and axial length. Modern two-variable third-generation formulas such as the SRK/T, Holladay 1 and Hoffer Q use these two variables to calculate IOL power [5]. In addition to these variables, other formulas such as the Holladay 2 and the Haigis utilize additional parameters to calculate appropriate lens power.

Corneal power

The most obvious reason for inaccuracy of lens calculations after refractive surgery is that the power of the cornea has changed. This includes a direct 'reshaping' of the cornea but also may involve changes in the refractive index of the cornea [9]. In an unoperated eye, the corneal shape is typically measured by either manual or automated keratometry to calculate a corneal power to insert in an IOL calculation formula [10]. Since these devices measure the anterior surface of the cornea and not the posterior surface, a 'net' index of refraction is used to determine the corneal power. Most keratometers and topographers assume that the radius of curvature of the posterior surface of the cornea is 1.2 mm less than the anterior curvature [11]. By using a net index of refraction of 1.337 5 (instead of the actual corneal refractive index, 1.376), the keratometer can compensate for the negative power of the posterior surface [12]. This value is based on Gullstrand's model eye with the cornea as one refractive surface [13]. Whether these assumptions are completely accurate has been questioned, but they work very well in eyes without previous refractive surgery [14,15].

Corneal power is overestimated with manual keratometry, automated keratometry, and topography instruments in patients after myopic laser refractive surgery. This is because the anterior surface of the cornea has been altered without a change to the posterior surface [12,16,17]. Traditional keratometry instruments measure the corneal power of a central 3.2 mm ring. With myopic laser refractive surgery, these measurements will not reflect the central flattening that has occurred. Further, because myopic laser refractive surgery decreases the anterior curvature of the cornea, the relationship to the posterior cornea is no longer valid and the assumed index of refraction (1.3375) used by these instruments is now erroneous. If standard keratometry instruments are used, this leads to an overestimation of the true corneal power [18]. There is also an overestimation of corneal power after radial keratectomy because of the greater flattening of the central cornea compared with the paracentral cornea [7,19]. These errors will lead to a more hyperopic result than intended after cataract surgery.

In patients who have undergone hyperopic laser refractive surgery, the central cornea is now steeper and there will be an underestimation of corneal power using standard devices [20•]. This will lead to a myopic result after cataract surgery [21–23].

Effective lens position

Another source of error in calculating IOL power after laser refractive surgery is an incorrect estimation of the effective lens position (ELP) [5,24,25]. The ELP is the effective position of the IOL (the principal plane of the thin lens) in relation to the anterior corneal vertex. Using a postmyopic (flatter) corneal power will have the effect of calculating a more forward ELP, thus resulting in an underestimation of required IOL power [5,26•]. In eyes that have undergone myopic laser refractive surgery, the formulas underestimate the ELP and IOL power, resulting in hyperopia [27]. The opposite is true in eyes that have undergone previous hyperopic refractive surgery, resulting in a myopic surprise [20•].

Methods to address the errors of intraocular lens power determination

There are many methods available to help a clinician address the sources of error and calculate IOL power in a patient who has undergone previous laser refractive surgery.

Methods to overcome the error in corneal power

The methods that have been described attempt to calculate corneal power utilizing historical data, or in its absence, using objective measurements.

Clinical history method

The clinical history method was one of the first methods to estimate corneal power after refractive surgery and for years was considered the 'gold standard'. Introduced by Holladay in 1989 [28], this method involves subtracting the change in spherical equivalent refraction induced by the refractive procedure from the known preoperative keratometric power. It is based on the assumption that the final change in refractive error the eye obtains from laser vision correction (LVC) is due only to a change (flattening) in the effective corneal power. If this change in refractive error is added to the presurgical corneal power, one obtains the present effective corneal power [4].

If the pre-LVC and post-LVC data are reliable, this method can be effective; however, this methodology can be suspect for several reasons. First, preoperative measurements are not always available. Second, it is difficult to determine if the postoperative refraction was accurate and stable. Finally, there is often a myopic shift in patients due to the development of a cataract [29]. Any of these factors can affect the feasibility and accuracy of this method.

The clinical history method has been well established in the literature [2,11,30–32] but is only as good as the availability and accuracy of the data.

Contact lens overrefraction method

Another method that has been traditionally used is the contact lens overrefraction method [11]. This has been demonstrated to be reliable in eyes without previous refractive surgery [33]. It can be used when prerefractive surgery data are unavailable in eyes that have undergone previous refractive surgery. With this method, the post-refractive surgery keratometric diopters is the difference between the overrefraction (ORx) and the manifest spherical equivalent (MRx), which is then added to the base curve of the rigid contact lens (BC) and contact lens power (P): $K_{\mathrm{post}} = \mathrm{BC} + P + (\mathrm{ORx} - \mathrm{MRx})$ [1,34]. The major limitation of the contact lens method is the reliability of the patient's refraction in the presence of a cataract and often with a decrease in best-corrected visual acuity. A patient should have at least 20/80 vision to be a candidate for this method. Further, while a traditional method, it has been pointed out by others that this methodology is unreliable [15].

Use of topographic data to estimate corneal power

Other methods to determine the corneal power is through direct measurement using topography and then adjusting corneal power using correction factors. The Maloney method uses the central corneal power on the topographic map and is modified according to the following formula: central power = (central topographic power × [376/337.5]) − 4.9 [25]. This formula was subsequently modified by Wang *et al.* [25] by subtracting a value greater than the 4.9 D originally proposed by Maloney. Shammas and Shammas [26•,35] have also developed a method to calculate corneal power using videokeratography with and without refractive information. Another method of estimating the corneal power after refractive surgery is measuring the central corneal power using the effective refractive power (EffRP) from the Holladay Diagnostic Summary on the EyeSys device [36]. This value is the calculated mean refractive power of the cornea over the central 3 mm. This value is then used to calculate the EffRPadj by subtracting 0.15 D of power per diopter of LASIK-induced refractive change [37].

Direct corneal power measurement

There are other methods of determining corneal power in postrefractive surgery patients that may be more direct and objective. Scanning slit topographic analysis has been investigated as a possible method to measure both the anterior and posterior curvature. Tomographers, like the Orbscan II (Bausch & Lomb, New York, USA), measure both the central zone of the cornea and the back surface which may aid us in measuring the true corneal refractive power. Several studies have also looked at the various optical diameter zones from which data can be collected using the Orbscan II and have determined the optimal diameter zone to be 4.5 mm in eyes that have undergone LASIK and 5.0 mm in eyes that have undergone radial keratectomy [38].

More recently, the Oculus Pentacam (Oculus Inc, Lynnwood, Washington, USA), which is a rotating Scheimpflug camera anterior segment imaging system that can measure or estimate both the anterior and posterior corneal curvatures has been used [39]. Borasio and colleagues [39] used this principle and looked at both virgin corneas and post-refractive corneas, adjusting the Gaussian optics formula to create the BESSt formula. Some authors suggest that a Scheimpflug camera also offers improved mapping of the corneal center by maintaining a fixed point on the vertex of the cornea. There are sensitivity issues, however, when calculating curvature from elevation data rather than directly measuring it with a placido [38].

Methods to overcome the error in effective lens position

There are multiple ways to account for the ELP calculation after refractive surgery. In two-variable third-generation formulas it can be accomplished by separating the vergence calculation and the ELP calculation in a specific formula. Aramberri [27] did this with the SRK/T formula and demonstrated more accurate lens calculations compared with clinical history methods alone. Another potentially easier manipulation of this calculation in all third-generation formulas was described by Ladas and Stark [40]. Others used this methodology to show more accurate results than the clinical history method alone [41]. Koch and Wang [5] have published tables to account for this error. Finally, this issue is addressed by Holladay in the Holladay 2 software which can separate vergence and ELP calculations.

Methods to predict intraocular lens power

Current methods to accurately determine IOL power take into account the above sources of error by either directly accounting for those sources or incorporating regression analysis to make up for these. These methods can be divided into three main categories: those that require preoperative data without topography, those that require preoperative data and topography, and those that require no preoperative data.

Methods that require historical data without topography

The Double-K method by Aramberri, the Bypass, the Feiz-Mannis, and Masket methods all require preoperative data without the use of topographic data. The preoperative corneal power can be used to calculate the ELP utilizing the SRK/T formula and a spreadsheet developed by Aramberri [27]. Alternatively, a similar calculation can be performed by bypassing the change in corneal power

[40,41]. The surgeon inserts the initial prerefractive corneal power into the chosen formula. The only calculation then needed is to determine the refractive correction in diopters that occurred during the refractive procedure. This value is then inserted as the goal refraction for emmetropia in the specific formula.

The Feiz–Mannis method [7,21] first calculates the IOL power as if the patient has not undergone corneal refractive surgery, using the pre-LASIK corneal power values and the axial length measured just before cataract surgery. This IOL power value is then adjusted by adding a correction factor to the IOL to be implanted that is based on the LASIK-induced change in refraction. These authors have also developed a nomogram that can be used if the preoperative keratometry is unknown as long as the refractive change from LVC is available [22].

The Masket method [42] uses a simple IOL power corrective adjustment regression formula where the IOL power adjustment equals 0.101 plus the spherical equivalent of the total laser treatment multiplied by −0.326. The equation for the adjustment is as follows: IOL power adjustment $= \mathrm{LSE} \times (-0.326) + 0.101$, where LSE is the spherical equivalent of the total prior laser treatment, adjusted for vertex distance.

Latkany *et al.* [43,44] have also described a formula that uses a correction factor based on the pre-LVC spherical equivalent. While this methodology can be used in patients with unreliable or questionable pre refractive information, the authors concluded that a method with known historical information was optimal.

The above methodology and rationale may be used with previous hyperopic surgery and has been described. As mentioned previously, errors, if made, after previous hyperopic surgery tend to be in the myopic direction.

Methods that require historical data and topography

Methods have been described that use topographic adjustment of corneal power and a correction for effective lens position. Wang *et al.* [5,24] proposed methods using topographic measurement of corneal power, either the EffRPadj or a modified Maloney method, with insertion of this power into a double k formula by using tables. Further iterations of this methodology have been presented using various topographers and correction factors.

Topographic methods appear to be the most reliable for patients that have undergone previous radial keratotomy. Packer utilized topographic analysis of post radial keratectomy eyes and Holladay 2 software to calculate power in these eyes with reasonable accuracy [45]. Eyes with previous radial keratectomy may be the most difficult because of instability of the cornea and inaccuracy of the intended refractive procedure.

Methods that require no historical data or topography

There are also methods of calculating IOL power that do not require preoperative data. Shammas and Shammas [26•] have described a method to perform these calculations which uses a corrected corneal power as previously described but does not have the ELP calculation vary with the corneal curvature. By using an arbitrary ‘average’ corneal power is used to calculate the ELP; this formula compared favorably with other formulas in their series of patients. At the time of this review, there is also a formula available, the Haigis-L, that is available as software on the IOLMaster. It has been presented in abstract form but has not been compared with other no-history formulas.

There is also a formula that can be used with data obtained from the Pentacam alone. This method was derived from corneal measurements on eyes that had and had not undergone previous refractive surgery. A series of 13 eyes demonstrated comparable results to other methods that required preoperative data. Further, this formula was used in eyes that had undergone myopic or hyperopic LASIK. Interestingly, there was no correction for ELP. Whether this direct measurement of the cornea, combined with a formula that does not use corneal power (Haigis) for ELP determination, improves accuracy is not known.

Methods to bypass the intraocular lens power calculation

Additional methods that do not use standard calculation formulas at all have been investigated. The aphakic refraction technique determines the IOL power for emmetropia during cataract surgery. The measurements are obtained after the cataract has been removed, but prior to lens implantation. Currently, two proposed methods accomplish this. One performs an aphakic refraction using a portable autorefractor [46], while the patient is still on the operating table and the other waits 30 min after lens extraction and measures the aphakic refraction in an examination room [47]. The formulas to calculate IOL power multiply a constant by the autorefraction and then add a correction that takes into account a particular constant of the lens being used. For example, the formula used by Mackool was $P = 1.75 \times \mathrm{AR} + (\mathrm{A} - 118.84)$, where P is the target IOL power, AR is the aphakic refraction, and A is the A-constant for the intended IOL in both formulas [46,47].

Conclusion

Over the past decade, numerous methods have been devised to more accurately determine IOL power after keratorefractive surgery. As these methods have not been clinically studied with a large sample size and some methods are based upon theory, no one method has emerged as the ideal means to determine IOL implant power. Therefore, it is important for the cataract surgeon to understand the advantages and limitations of the various methods to achieve more precise refractive outcomes after cataract surgery.

Research in this arena continues to evolve and progress. Until we devise a more precise and consistent means to determine IOL power in this population of patients, we consider it standard of care in our practice to provide our patients with their preoperative keratometry measurements and refraction, often providing the patient with the actual operative report. Clinical studies using direct comparisons of the various methods with sufficiently powered sample sizes would be beneficial in furthering our understanding and in developing newer, more precise methods. Finally, a continued shift toward objective, automated data acquisition systems to obtain the information necessary for lens power determination would be beneficial and eliminate introducing sources of human error.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

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Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 366).

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