DETERMINATION OF CORNEAL POWER AFTER REFRACTIVE SURGERY WITH EXCIMER LASER: A CONCISE REVIEW

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SUMMARY

Refractive surgery with excimer laser has been a very common surgical procedure worldwide during the last decades. Currently, patients who underwent refractive surgery years ago are older, with a growing number of them now needing cataract surgery. To establish the power of the intraocular lens to be implanted in these patients, it is essential to define the true corneal power. However, since the refractive surgery modified the anterior, but not the posterior surface of the cornea, the determination of the corneal power in this group of patients is challenging. This article reviews the different sources of error in finding the true corneal power in these cases, and comments on several approaches, including the clinical history method as described originally by Holladay, and a modified version of it, as well as new alternatives based on corneal tomography, using devices that are able to measure the actual anterior and posterior corneal curvatures, which have emerged in recent years to address this issue.
Keywords: corneal power, refractive surgery, corneal tomography, clinical history method

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INTRODUCTION

The modification of the corneal curvature by means of refractive surgery is currently a widely used procedure to correct ametropia [1]. Its refractive results are very good and visual satisfaction is high. However, there is the inconvenience when a patient gets older and develops a cataract, since, having modified the anterior curvature of the cornea, the determination of corneal power by manual or automated keratometry is usually imprecise, making it difficult to calculate the power of the intraocular lens to be implanted. Since there will be an increasing number of patients with a past history of corneal refractive surgery who will require cataract surgery, an effective method is necessary and pertinent to solve this inconvenience [2].

REFRACTIVE SURGERY WITH EXCIMER LASER

Refractive surgery with excimer laser consists of modifying the anterior surface of the cornea by applying excimer laser energy that breaks the bonds of the stromal tissue molecules – a process known as photoablation. In a myopic eye in which the parallel rays are focused in front of the retina, photoablation is performed centrally, making the cornea flatter in order to reduce its optical converging power, moving the focus backwards, reaching the macula. On the contrary, in a hyperopic eye, the parallel rays are focused behind the retina, so photoablation is performed in the periphery of the cornea, making it steeper in the central region in order to increase the converging power, moving the focus forward (Figure 1) [2].

CALCULATION OF THE POWER OF INTRAOCULAR LENSES

The calculation of the power of the intraocular lens to be implanted after cataract extraction is performed using biometric formulas that take into account at least two data from measurements taken in the eye under study: the corneal power and the axial length. With these two data, the third-generation formulas (SRK/T, Hoffer Q, Holladay 1) try to predict the position in which the intraocular lens will be located (effective lens position) and, subsequently, with this third data, they calculate the dioptric power that the lens should have so that the eye is as close to target refraction as possible. The newer formulas (Haigis, Holladay 2, Olsen, Barett Universal II, Kane) introduce additional data (including preoperative anterior chamber depth), in order to predict the position in which the intraocular lens will be located [2,3]. It has been shown that, for any biometric formula, if the measured value of the corneal power of a patient with a history of photorefractive surgery is used, an error will be introduced in this calculation, roughly proportional to the amount of stromal ablation performed. In addition, the use of third-generation formulas in those eyes which have undergone refractive surgery, will introduce a second error, represented by an incorrect prediction of the effective position of the intraocular lens, as will be discussed later [4-7].

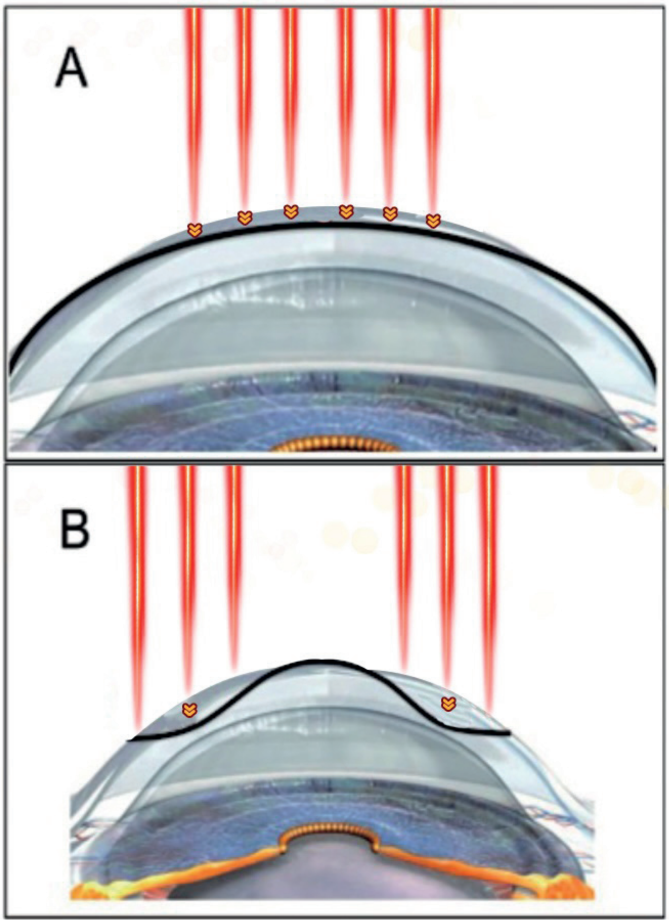

Figure 1. The excimer laser (represented by the red lines) ablates tissue (yellow arrowheads) in the central and paracentral areas (**A**) to correct myopic errors, and in the periphery of the cornea (**B**) to correct hyperopic errors

DETERMINATION OF CORNEAL POWER

In a normal eye, corneal power can easily be determined by measurement with a keratometer, using a Placido disk-based topographer, or using a corneal tomographer (which utilises either an optical slit with a source of visible light, as in the Orbscan®, Pentacam®, Galilei® or Sirius® devices, or infrared light, as in the optical coherence tomography devices: MS-39® or Casia2®, or many multi-coloured LED, e.g. Cassini®). With the reflection approaches used by manual keratometers or Placido disk-based topographers, the radius of curvature of the anterior surface of the cornea is measured and converted from millimeters to diopters, applying a fictitious refractive index ("Keratometric Index"), which compensates for the optical (diverging) effect of the posterior corneal surface, to provide an estimate of total corneal power. Devices that are based on the projection of a slit light on the cornea (with or without Scheimpflug system), and those based on multi-coloured LED, on the other hand, are able to determine the radius of curvature of the anterior surface and can apply this same principle already mentioned with the Keratometric Index, but additionally can also measure the radius of curvature of the posterior surface of the cornea. Thus, by using various optical calculation approaches, the actual total corneal power can be established. For a detailed analysis of the principles of Gaussian Optics applied to the determination of corneal power, consult a previously published review [2].

BIOMETRIC ERRORS POST REFRACTIVE SURGERY

Errors in the determination of corneal power

Paracentral measurement

The first inaccuracy in determining corneal power in patients with a history of refractive surgery consists of the paracentral measurement made with the keratometer, in an area of approximately 3.0 mm in diameter. In non-operated corneas, this works well, as the measurement at 3.0 mm closely reflects the central radius of curvature, where the cornea is nearly spherical or only slightly prolate. However, after myopic ablation, particularly in eyes operated with the ablation algorithms of the first-generation excimer laser devices and when optical zones smaller than 6 mm in diameter were used, due to central flattening, the paracentral measurement will overestimate the power of the cornea, underestimating the power of the intraocular lens. In contrast, after hyperopic ablation, because the central curvature is increased, the paracentral measurement will underestimate the power of the cornea, overestimating the power of the intraocular lens (Figure 2).

Keratometric Index

The second error is related to the use of the previously mentioned Keratometric Index. In non-operated corneas, this approach, based on the assumption of a standard relationship between the anterior and posterior corneal curvatures, works acceptably well. However, after performing laser photoablation, as the anterior surface is modified without modifying the posterior surface, the relationship between them is changed, which invalidates its use (Figure 3) [2].

Error in predicting the effective position of the intraocular lens (for third-generation biometric formulas)

Finally, the last source of inaccuracy consists of the imprecision in estimation of the effective position of the intraocular lens with the use of third-generation biometric formulas (SRK/T, Hoffer Q, and Holladay 1). This is because these formulas do not take into account the preoperative measurement of the anterior chamber depth, and assume that, if the keratometry is steep, the anterior chamber is deep, and therefore the position of the intraocular lens will be further from the cornea. On the contrary, if the keratometry is flatter, the formulas assume that the anterior chamber is shallow, so the position of the intraocular lens will be closer to the cornea. These assumptions, which are true in the majority of eyes not surgically treated, are erroneous in patients with a past history of refractive surgery, since, although post-myopic ablation corneas are flatter, this does not mean that the anterior chamber is shallower. In the same way, although post-ablation hyperopic corneas are steeper, this also does not imply that the anterior chamber is deeper. (Figure 4). On the other hand, as newer biometric formulas do not rely significantly on keratometric measurement to predict intraocular lens position, they do not make this mistake.

DETERMINATION OF CORNEAL POWER POST REFRACTIVE SURGERY

The "clinical history method" described by Holladay in 1989 has for many years been considered the gold

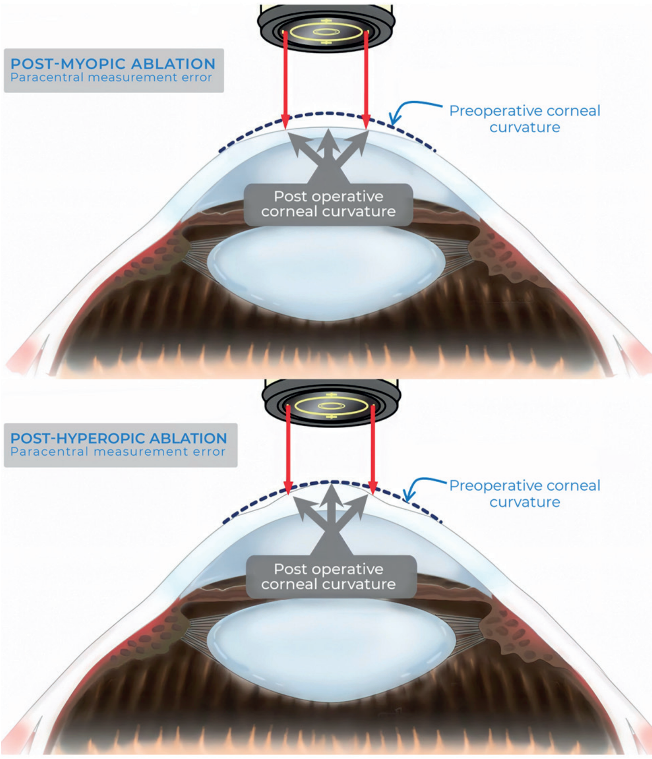

Figure 2. After myopic ablation, the paracentral measurement will overestimate central corneal power (top), and, after hyperopic ablation, it will underestimate central corneal power (bottom)

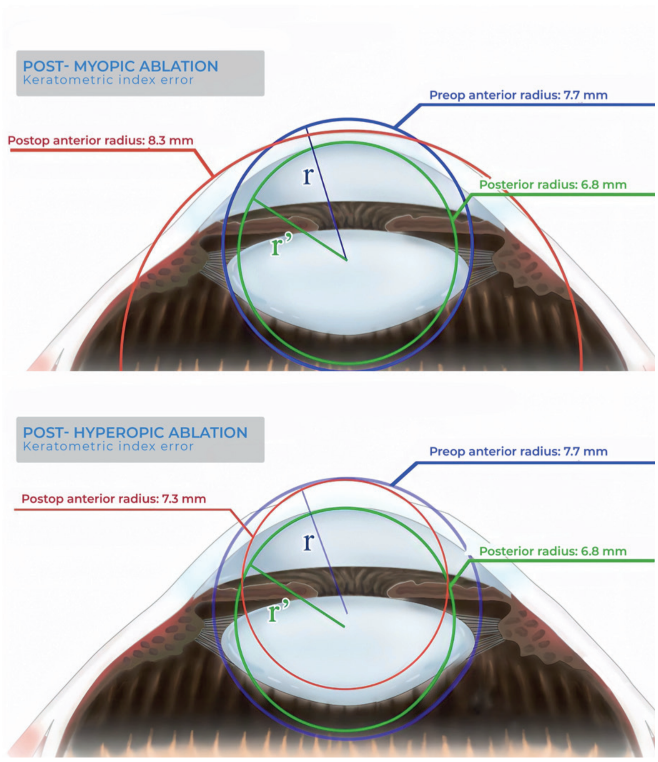

Figure 3. After myopic ablation, the anterior curvature is flattened (top), and, after hyperopic ablation (bottom), the anterior curvature is steepened, while the posterior one is unchanged in both instances. This causes the assumptions of the Keratometric Index to be invalidated

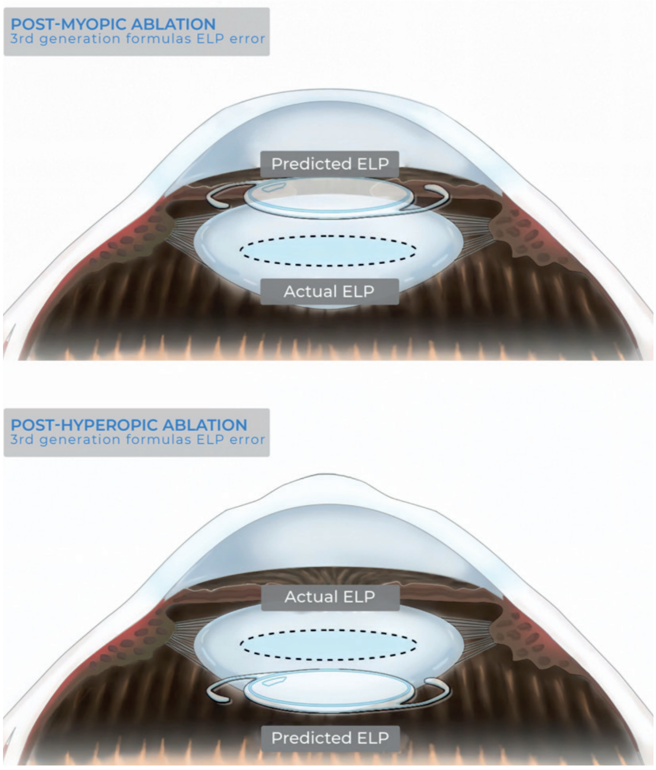

Figure 4. After myopic ablation, since the anterior curvature is flattened, third-generation biometric formulas (SRK/T, Hoffer Q and Holladay I) will erroneously predict a too-shallow postoperative anterior chamber depth, and therefore an excessively anterior effective intraocular lens position (top), and, conversely, after hyperopic ablation, they will wrongly predict an excessively posterior effective intraocular lens position (bottom)

standard for calculating corneal power after refractive surgery. This method consists of subtracting from (in the case of myopia), or adding to (in the case of hyperopia) the preoperative keratometric power, the induced change in the spherical equivalent, adjusted to the distance to the corneal vertex, using the following formula:
Kc = Kpre - RC

where Kc = pop corrected keratometry, Kpre = preoperative keratometry, RC = spherical equivalent refractive change adjusted to the corneal vertex [8].

The drawback of this method is that preoperative data (both keratometry and refraction) are often not available. Postoperative refraction, if obtainable from medical records, may have been measured many years earlier and thus does not consider a possible regression or progression of the myopic error, or, if it is recent, it may have been measured after the onset of the cataract, and then shows a myopic shift unrelated to changes in axial length or corneal curvature. A modification of the method of calculating corneal power based on clinical history, originally published by Holladay, has been developed on the basis that the change in curvature with keratorefractive surgery occurs almost exclusively in the anterior surface, and therefore the refractive change should be calculated only affecting this surface, while the power of the posterior surface remains stable [9-11]. This approach is used by some programs linked to excimer laser devices, such as Schwind CAM® (Schwind eye-tech-solutions GmbH, Kleinostheim, Germany).

In a study published in 2009, Holladay and co-authors compared the corneal power obtained using the Equivalent Keratometric Readings (EKR) map of the Pentacam® (Oculus Optikgeräte GmbH, Wetzlar, Germany) tomographer at a diameter of 4.5 mm, with the corneal power obtained by the clinical history method in post-LASIK patients, reaching a mean prediction error of -0.06 ±0.56 dioptres (D) with a range of -1.63 to +1.34 D. As shown, both standard deviation and range of error seemed to be clinically significant. However, the authors concluded that, when historical refractive data were not available, corneal tomography using Scheimpflug images with the Pentacam® may provide an alternative method for determining corneal power in eyes with a history of refractive surgery [12].

In a recent study, Baradaran-Rafii et al. determined that the corneal power obtained by applying an adjusted formula to the values of the Effective Refractive Power (EffRP) map with the EyeSys 2000® topographer (Eyesys Vision, Houston, TX 77060, United States) was closer than manual keratometry, and information from another 3 devices, to the power determined by the clinical history method [13]. However, within this adjustment, the refractive change caused by the procedure was included as a factor. Therefore, the practical usefulness of this "Adjusted Effective Refractive Power" is very limited, since the vast majority of patients will lack preoperative information, as previously mentioned [13].

Another study conducted by Jaramillo et al. concluded that the corneal power obtained postoperatively from the Sirius® tomographer (Costruzione Strumenti Oftalmici CSO, Firenze, Italy), using the Mean Pupil Power (MPP) map, averaged either with the values of the postoperative manual keratometry or with the values of the postoperative Sirius® SimK, resulted in a corneal power which did not show a statistically significant difference when compared to the one obtained from the clinical history method [14]. This was due to the fact that the MPP generally underestimated postoperative corneal power by a value similar in magnitude to its overestimation generated by both postoperative manual keratometry and Sirius® postoperative SimK [14].

On the other hand, Lekhanont et al. found a strong positive correlation of the clinical history method with the Total Optical Power of the Orbscan II® (Bausch & Lomb Surgical Inc., Bridgewater, NJ, USA) when measured in the 3.0 and 4.0 mm zones; as with the Pentacam® EKR in the 3.0, 4.0 and 4.5mm diameter zones [15]. However, the differences of the means of all these methods to the medical history method were significant, with the exception of the Pentacam® EKR at 3.0 mm. In addition, the 95% limits of agreement for all values with respect to the clinical history method were considered too wide by the investigators, even for the EKR option at 3.0 mm (which was between -2.48 and +2.12 D). With these results, they concluded that these direct postoperative measurements were not really reliable to determine the real corneal power after keratorefractive surgery, if the clinical history method was taken as the gold standard [15].

In another study published by Ng et al., using the Pentacam®, they reported a high correlation of the EKR at 4.0 mm and at 4.5 mm; of the True Net Power (TNP), and of the Total Corneal Refractive Power (TCRP), with respect to the clinical history method, in a group of post-LASIK patients. Of these measurements, the only one that did not show statistically significant differences with respect to the clinical history method was the EKR at 4.0 mm, with a mean error of 0.09 D (p = 0.23). However, the 95% limits of agreement in the Bland and Altman test were very wide: TCRP from -0.88 to +1.95 D; TNP from -0.62 to +2.20 D; EKR at 4.0 mm from -1.10 to +1.28 D and EKR at 4.5 mm from -1.05 to +1.36 D [16].

Finally, among the most recent studies, de Rojas Silva et al. demonstrated a high correlation of Sirius® Mean Pupil Power (MPP) measured at 5.5 mm, compared to the clinical history method in patients with a history of SMILE for myopia. The difference between the means was not statistically significant, but the 95% limit of agreement was relatively wide from –1.179 to +1.174 D [17].

The characteristics of each of these studies comparing the corneal power measured with corneal tomography and the clinical history method are shown in Table 1.

Table 1. Recent studies comparing postoperative measured corneal power, versus Clinical History Method in patients with a history of refractive surgery

Author	Year	n	Technique	Corneal power	Method most associated with Clinical History Method
Holladay et al. [12]	2009	100	LASIK	- Pentacam - Clinical History Method	- Equivalent Keratometric Readings (EKR) of the Pentacam at 4.5 mm
Baradaran-Rafii et al. [13]	2017	33	PRK	- Manual keratometry - Orbscan II - Galilei - Tomey TMS4 - EyeSys 2000 - Clinical History Method	- Adjusted Effective refractive power (EffRP) of the EyeSys 2000 Formula: EffRP – 0.015*Δ refraction – 0.05
Lekhanont et al. [15]	2015	55	PRK/ myopic LASIK	- Orbscan IIz - Pentacam - Clinical History Method	- Orbscan IIz Total Optical Power (TOP): 3.0 and 4.0 mm zones - Pentacam Equivalent Keratometric Readings (EKR): 3.0, 4.0 and 4.5mm zones
Jaramillo et al. [14]	2018	50	LASIK/ Trans PRK	- Sirius -Clinical History Method	- Average of Mean Pupil Power (MPP) + postoperative manual keratometry - Average of Sirius Mean Pupil Power (MPP) + Sirius Postoperative SimK
Ng et al. [16]	2018	36	myopic LASIK	- Pentacam: EKR 4.0 mm, 4.5 mm TCRP 4 mm, NPT 4 mm -Clinical History Method	- Equivalent Keratometric Readings (EKR) at 4.0 mm from the Pentacam
De Rojas Silva et al. [17]	2022	50	SMILE	- Sirius: SimK (K post) MPP: 3, 3.5, 4, 4.5, 5, 5.5, 6 mm - Calculated True Net Power (NPT) from Sirius data - Calculated Equivalent keratometry reading (EKR) from Sirius data - Calculated Haigis K Post Clinical History Method	- Mean Pupil Power (MPP) at 5.5 mm from the Sirius

CONCLUSIONS

Although, theoretically, the method of determining corneal power after refractive surgery based on clinical history data, as originally described by Holladay, is still the gold standard, in reality, as these patients generally undergo cataract surgery several decades after having had keratorefractive surgery, it is highly unlikely that the surgeon has access to complete information about pre-excimer laser keratometry, original spherical equivalent, and a recent post-operative spherical equivalent assessment, not affected by the myopic shift generated by the cataract [8,18]. Due to this, when the clinician faces the older adult patient with a cataract, and with a history of keratorefractive surgery, in general the clinical history method is not useful. It is therefore necessary to develop and evaluate new methods that do not depend on historical data. Some of these new methods based on corneal tomography seem to be a good alternative comparable to the clinical history method. However, conflicting results have been published. If a reliable method is determined, the use of it could contribute to the reduction of errors in the calculation of the power of the intraocular lens when these patients require cataract surgery. Nevertheless, in most studies, the limits of agreement are still quite wide, and therefore the risk that a refractive surprise may occur in the postoperative period of cataract surgery in these cases still exists, and patients should be warned about this [19].

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