Intraocular lens power calculation after myopic excimer laser surgery with no previous data

Juan Carlos Mesa-Gutiérrez, MD, PhD, FEBO; Antonio Rouras-López, MD; Isabel Cabiró-Badimón, MD; Vicente Amías-Lamana, MD; José Porta-Monnet, MD; Laura Solanas-García, Opt.

ABSTRACT: How many ways are there to calculate intraocular lens (IOL) power in eyes that have myopic laser in situ keratomileusis (LASIK)? The list is long, and growing. As is always the case when there are several solutions to a problem, none is perfect. In this review, we describe the most reliable methods in the worst scenario: no data prior to LASIK available. When no preoperative corneal power and refractive change are available the lowest mean absolute error is achieved with the methods of Masket, Seitz/Seicher/Savini, Shammas, and Camellin/Calessi. When preoperative corneal power is unknown but the surgically induced refractive change is known the lowest mean absolute error is achieved with the Masket method followed by the the Savini method, Seicher/Seitz method modified by Savini, and Shammas no-history method.

Ideally, it would be optimal to have a spreadsheet that allows the clinician to insert all values available. The various formulas would then be calculated automatically. When faced with a range of values for the IOL power, you’d better look for values that are consistent with at least one other reading. Values that select higher IOL powers are preferable, leaving the patient slightly myopic rather than hyperopic.

Resolution of this problem will require a method for accurately measuring posterior corneal power or a technique for adjusting IOL power after implantation. Until then, surgeons are faced with performing multiple calculations to “guesstimate” the correct IOL for patients who, by their original decision to have LASIK, have demonstrated that they have above-average refractive demands.

KEY WORDS: Intraocular lens; refractive surgery; corneal refractive power; cataract surgery.

J Emmetropia 2011; 2: 97-102

INTRODUCTION

Intraocular power calculation after keratorefractive surgery has been a major challenge for the ophthalmic community and has generated numerous scholarly works and efforts trying to optimize current formulas and tailor new methods to better predict the correct intraocular lens (IOL) power. Aramberri’s work on the double-K adjustment of third-generation IOL formulas significantly improved the hyperopic results stemming from inaccurate estimation of the effective lens position by those formulas. IOL power calculation can lead to unexpected refractive outcomes for 2 primary reasons. The first is that the surgically induced corneal power change is underestimated because the standard keratometric refractive index (usually 1.3375) is not valid once the laser modifies the anterior to posterior corneal curvature ratio. The second reason is that the IOL position is erroneously predicted by third-generation theoretical formulas (eg, Hoffer Q, Holladay 1, SRK/T) that derive the prediction from the corneal curvature. A third reason may be partially responsible for the inaccuracy of IOL power calculation for eyes with a small optical zone and large correction; in this case, the difference between the paracentral corneal area (where keratometry [K] and simulated K readings are taken) and the central cornea area (where the visual axis passes) can be clinically relevant.

When no previous data are available the calculations are more misleading as no double-K adjustment can be done. Various formulas have been described, and surgeons can now choose from many methods. This can
easily generate confusion rather than accuracy. The aim of the present study was to provide with various methods of calculating IOL power in patients with no pre-LASIK data available. We address two possible scenarios with no preoperative corneal power known.

When neither preoperative corneal power nor refractive change are available the lowest mean absolute error is achieved with the methods of Masket, Seitz/Speicher/Savini, Shammas, and Camellin/Calossi. When preoperative corneal power is unknown but the surgically induced refractive change is known the lowest mean absolute error is achieved with the Masket method followed by the Savini method, Speicher/Seitz method modified by Savini, and Shammas no-history method. Good results can also be obtained with the Awwad and Camellin/Calossi methods when the calculated corneal power is entered into the double-K Holladay 1 formula instead of the double-K SRK/T21.

**TWO POSSIBLE SCENARIOS**

1. **Preoperative corneal power and refractive change unknown**

According to a recent paper these are the most reliable methods21:

1.A) **Shammas no-history method + Shammas-PL**

\[ K_{\text{Shammas}} = 1.14 \times K - 6.8. \]

The main advantage of this method is that the corrected corneal power is used in the Shammas post-LASIK (Shammas-PL) formula and in this formula the effective lens position (ELP) does not vary with the corneal curvature, which has been altered by the LASIK procedure22.

1.B) **Seitz/Speicher/Savini + Double-K SRK/T**

The method of separately considering the anterior corneal curvature and posterior corneal curvature, first described by Seitz and Langenbucher and later reviewed by Speicher, could be considered the most accurate, at least when coupled with the double-K SRK/T formula22-23. If the preoperative corneal power is unknown, the Seitz/Seiper method can be modified according to Savini et al., who suggest using a mean value of -4.98 D for posterior corneal curvature21,24. The Seitz/Seiper/Savini method:

\[ K = \text{simulated } K \times 1.144 - 4.98, \]

is similar to other methods like the one proposed by Maloney25:

\[ K = \text{central corneal power} x 1.114 - 4.9 , \]

and the modified version developed by Wang4:

\[ K = \text{central corneal power} x 1.114 - 6.1, \]

equation 6 of Awwad11,26.

SimKadj no history = 1.114 x SimK - 6.062

and, to a lesser extent, the Shammas et al.no-history method22:

\[ K_{\text{Shammas}} = \text{simulated } K \times 1.14 - 6.8. \]

Ho et al. found that the Seitz/Speicher method modified according to Savini et al. is highly accurate27,28. Obviously, this method (developed for eyes for which the preoperative corneal power is not known) must be used in conjunction with double-K formulas, which require entry of the preoperative corneal power. There are 3 possibilities to solve this contradiction: (1) calculate the preoperative corneal power by adding the refractive change to the postoperative corneal power (2), use a mean value such as 43.13 or (3) estimate the effective lens position (ELP), as suggested by Ho27,29. The good results obtained with the Seitz/Seiper method (with or without the Savini modification) could be related to its total independence of the surgically induced refractive change (a likely source of errors)27.

1.C) **Rosa method + Single-K SRK/T**

Refraction with Rosa method (Rrosa) = R x (0.0276 AL + 0.3635)

\[ K(R_{\text{rosa}}) = 337.5/R_{\text{rosa}} \]

\[ AL = \text{Axial length}; R=K/337.5 \]

Another method proposed by Rosa is as follows30:

\[ K_{\text{Rosa}} = (1.3375-1)/[(K x RCF)/1000]. \]

RCF: Rosa Correction Factor based on axial length (mm):

<table>
<thead>
<tr>
<th>AL</th>
<th>Rrosa</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 - &lt;23: 1.01</td>
<td></td>
</tr>
<tr>
<td>23 - &lt;24: 1.05</td>
<td></td>
</tr>
<tr>
<td>24 - &lt;25: 1.04</td>
<td></td>
</tr>
<tr>
<td>25 - &lt;26: 1.06</td>
<td></td>
</tr>
<tr>
<td>26 - &lt;27: 1.09</td>
<td></td>
</tr>
<tr>
<td>27 - &lt;28: 1.12</td>
<td></td>
</tr>
<tr>
<td>28 - &lt;29: 1.15</td>
<td></td>
</tr>
<tr>
<td>29: 1.22</td>
<td></td>
</tr>
</tbody>
</table>

1.D) **Ferrara method**

\[ K = \left[ (-0.0006 \times AL^2 + 0.0213 \times AL + 1.1572) -1 \right] / (Kr/1000). \]

\[ AL = \text{Axial length}. \]

\[ Kr: \text{Keratometry (radius of curvature in mm)}. \]

Rosa and Ferrara method may easily lead to postoperative myopia32.

1.E) **BESSt method + doble-K formula**

The formula takes into account anterior and posterior corneal radii and pachymetry (Pentacam, Oculus) and does not require pre-keratorefractive surgery information33.

Input Variables

- rF: Front corneal radius (mm)
- rB: Back corneal radius (mm)
- CCT: central corneal thickness (microns)

Formula

\[ n_{\text{air}} = 1 \]

\[ n_{\text{vc}} = 1.3265 \]

\[ n_{\text{CCT}} = n_{\text{vc}} + (\text{CCT} \times 0.000022) \]
\[ K_{\text{conv}} = \frac{337.5}{rF} \]

\[ n_{\text{adj}}: \]
- if \( K_{\text{conv}} < 37.5 \) then \( n_{\text{adj}} = n_{\text{CCT}} + 0.017 \)
- if \( K_{\text{conv}} < 41.44 \) then \( n_{\text{adj}} = n_{\text{CCT}} \)
- if \( K_{\text{conv}} < 45 \) then \( n_{\text{adj}} = n_{\text{CCT}} - 0.015 \)
- ELSE \( n_{\text{adj}} = n_{\text{CCT}} \)

\[ n_{\text{acq}} = 1.336 \]

\[ d = \frac{d_{\text{cct}}}{n_{\text{vc}}} \]

\[ d_{\text{cct}} = \frac{n_{\text{cct}}}{1000000} \]

\[ \text{Fant} = \frac{1}{rF} \times (n_{\text{vc}} - n_{\text{air}}) \]

\[ \text{Fpost} = \frac{1}{rB} \times (n_{\text{acq}} - n_{\text{vc}}) \]

Using the BESSt formula, 46% of eyes were within +/-0.50 D of the intended refraction and 100% were within +/-1.00 D.

Output

KBESSt (corneal power after keratorefractive surgery, D) =

\[ \left[ \left( \frac{1}{rF} \times (n_{\text{adj}} - n_{\text{air}}) \right) + \left( \frac{1}{rB} \times (n_{\text{acq}} - n_{\text{adj}}) \right) \right] - \left[ \frac{d \times \left( \frac{1}{rF} \times (n_{\text{adj}} - n_{\text{air}}) \times \frac{1}{rB} \times (n_{\text{acq}} - n_{\text{adj}}) \right)}{1000} \right] \]

BESSt formula has been replaced by the BESSt2 algorithm. Corneal power is still estimated with gaussian optic formula as with BESSt1 but some improvements can be found:

- prediction of preoperative anterior radius from postoperative posterior radius measurements.
- automatic application of double-K adjustment to the the predicted preoperative anterior radius.
- It uses a modified 3rd generation formula for IOL power calculation, preventing the cusp phenomenon which may happen using SRK/T formula.
- Automatic adjustments for extreme axial lengths.
- Contribution of corneal wavefront (spherical aberration) from Pentacam.
- It has two separate algorithms: one for myopia and other one for hyperopia.

According to his author BESSt2 is more accurate than BESSt1 in hyperopia and more accurate than Haigis-L in myopia\(^{34,35}\).

1.F) Awwad method + double-K Holladay II

In the absence of information about the change (D) in spherical equivalent (ASE), a regression based solely on average corneal power in the central 3.0 mm area (ACCP3mm) should be used\(^{26}\):

\[ \text{ACCPadj no history} = 1.151 \times \text{ACCP3mm} - 6.799 \]

In the absence of topographic data a regression based on SimK is to be used:

\[ \text{SimKadj no history} = 1.114 \times \text{SimK} - 6.062 \]

1.E) Quantitative area topography (Orbscan II) and Total corneal power (Galilei)

In 2004, Sónego-Krone et al reported that the refractive change at the corneal plane after myopic LASIK had a difference of -0.08 +/- 0.53 D with the corneal power change determined by quantitative area topography in a 4-mm–diameter central zone of Orbscan II total-mean postoperative maps\(^{36}\).

Quantitative area topography is distinct from quantitative point topography, which assesses the average of only two single steeper and flatter values. The total-mean power maps represent the spherical equivalent refraction of both corneal curvatures with regard to the corneal thickness and are comparable to the equivalent power of the cornea assessed by the thick lens formula. The total-optical power maps represent the ray tracing of light through the whole cornea. The advantage of this method is that the final total corneal powers to be used in IOL calculation may be obtained directly from the topographic maps, as measured after the previous corneal refractive surgery without depending on regression formulas, artificial refraction indices, contact lens over-refraction, apheric intraoperative refraction, previous refractive or topographic data, algorithms, or correction factors\(^{36,37}\).

It has been applied in a multicenter study using the total mean power (equivalent power) and the total optical power\(^{38,39}\). Total optical power maps by the Orbscan Topography System appear to be relatively accurate in detecting the changes in corneal power measured by refraction after LASIK. The correlation is highest when averaging within the central 4.0 mm zone. The corneal power change derived from axial power maps correlates less well than that derived from the TOP maps, as expected. Total optical power maps appear to provide an accurate measure of corneal power change in LASIK\(^{37-39}\).

This same method has been applied with success using the Galilei’s total corneal power (TCP) by ray tracing from a central zone of 0 to 4 mm diameter. Similar to the Orbscan II total-optical power, the Galilei uses a 4-mm diameter central zone for the TCP derived from ray tracing. Galilei TCP represents the average total corneal power for the central 4 mm diameter of the cornea. This TCP is calculated using the ray tracing method, which takes the actual refractive indices of the cornea into account. The post-LASIK corneal power is estimated using the following formula\(^{40,41}\):

\[ \text{Post-LASIK adjusted corneal power} = 1.057 \times \text{TCP} - 1.8348 \]

2. Preoperative corneal power unknown and refractive change known

2.A) Masket method

The equation was determined to be as follows:

IOL Power Adjustment = LSE \times (-0.0.326) + 0.101

where LSE is the total prior laser treatment, adjusted for vertex distance, in spherical equivalent (SE).

Clinical example is as follows:
Previously myopic eye:
- SRK/T formula suggests 16.0 D for emmetropia after cataract surgery
- Prior laser correction (SE) = - 6.0 D
- Adjustment calculation: -6.0 D x (-0.326) + 0.101 = + 2.057 D
- IOL power adjusted by adding +2 D to the original + 16 D = +18 D for emmetropia

The Masket method had a great advantage in that it omits the double-K step required by the Savini and Seitz/Speicher/Savini methods. The latter methods can be significantly influenced by the choice of the preoperative corneal power to be entered into the double-K formulas. In contrast, the Masket method (like the Shammas no-history method) does not have this drawback.

2.B) Savini + Double-K SRK/T

Ksavini = [(1.338+ 0.0009856 x ΔSEsp) -1] / (Kr/1000)
ΔSEsp: Change in spherical equivalent at spectacle plane
Kr: Keratometry (radius of curvature in mm)

2.C) Seitz/Speicher/Savini + Double-K SRK/T

See above.

2.D) Camellin + Double-K Holladay 1

KCamellin = [(1.3319 + 0.00113 x ΔSEsp) – 1] / (Kr/1000).
ΔSEsp: Change in SE at spectacle plane.
Kr: Keratometry (radius of curvature in mm).
When entered into the double-K SRK/T formula, the corneal power calculated with the Camellin/Calossi method results in a positive arithmetic error in IOL power prediction, with a subsequent myopic outcome. The suboptimal results are probably due to the fact that this method was developed to be used with the Camellin/Calossi formula for IOL power calculation, which is a modified Binkhorst II formula, and not with the double-K SRK/T formula. The Camellin/Calossi formula calculates the ELP from the preoperative anterior chamber depth. Considerably better results can be obtained by entering the calculated corneal power into the double-K Holladay 1 formula.

2.E) Shammas no history + Shammas PL
See above.

2.F) Awwad method + Double-K Holladay 1

Two variables, ACCP3mm and ΔSE, were shown to be vital and sufficient for accurate refractive power prediction. The multiple regression based on these 2 independent variables successfully predicted corneal refractive power:

ACCPadj = ACCP3mm – 0.16 x (SEpostLASIK – SEpreLASIK)

adjusting for the fact that the measured ACCP3mm overestimates the true value by about 0.16 D for every diopter of myopic laser correction.

In the absence of topographic data, SimK and ΔSE are to be used:

SimKadj = SimK- 0.23 x (SEpostLASIK – SEpreLASIK).

as the measured SimK overestimates the true value by about 0.23 D for every diopter of laser correction.

2.G) Hamed-Wang-Koch method + double-k formula

K = SimK – (0.15 x ΔSE) – 0.05
This method requires knowledge of the refractive change from the surgery and the postoperative Sim-K from the topography unit.
They also offered a second method to calculate true corneal power by substituting 0.15 by 0.19.

2.H) Ronje method

K = Kflat + 0.25 x ΔSE
This method requires knowledge of the refractive change from the surgery and the postoperative flattest K reading measured now (Kflat).

2.I) Jarade method + double-k formula

Requires knowing the surgically induced refractive change at the corneal plane (ΔSEcp) and the average radius of curvature of the cornea now (Kr):

KJarade = [(1.3375 + 0.0014 x ΔSEcp) – 1]/(Kr/1000)

2.J) Haigis-L method

KHaigis = –5.1625 x Kr + 82.2603 – 0.35
This method requires only the postoperative K reading form the Zeiss IOLMaster in radius of curvature (or converted to diopeters using the index of refraction setting in the IOLMaster).

2.K) Maloney Central Topography method

Central power = (central topographic power x [376/337.5]) – 4.9
Koch and Wang obtained the best results using the Maloney method using -6.1 instead of -4.9.
They also offered a second method to calculate true corneal power if ΔSE is known. The formula is:

K = EffRp – (0.19 x ΔSE)
2.L) Koch/Wang method

K = 1.1141 x TK – 6.1

Koch and Wang obtained the best results using the Maloney method (discussed earlier) but only after increasing the constant from 5.5 to 6.1. They also offered a second method to calculate true corneal power if ΔSE is known (38). The formula is:

\[ K = \text{EffRp} - (0.19 \times \Delta SE) \]

Where EffRp is the effective refractive power obtained from topography.

2.M) Feiz-Mannis method

This method utilizes the change in refractive error to offset the calculated target IOL power47.

\[ P = \text{PTARG} - 0.595 \times \Delta SEcp + 0.231 \]

\[ P = \text{IOL Power} \]

PTARG = the target IOL power to produce the postoperative desired refractive error.

FINAL ADVICE.

The historical K method, although theoretically considered the gold standard, is misleading in practice because myopic or hyperopic errors in post-LASIK refractions can easily translate into errors of the same magnitude in the final post-cataract surgery refraction. In addition, early occult cataractous stage can produce myopic shift and potentially lead to a falsely over- or under-corrected result, introducing an error in corneal power estimation. We recommend against using the historical K method48.

This method is based on the fact that the final change in refractive error the eye obtains from surgery was due only to a change in the effective corneal power. If this refractive change the patient experienced is algebraically added to the presurgical corneal power, we will obtain the effective corneal power the eye has now. Obviously this requires knowledge of the K reading and refractive error prior to refractive surgery48.

\[ K = \text{KPRE} + \text{RPRE} - \text{RPO} \text{ or } [K = \text{KPRE} + \text{RCC}] \]

KPRE = refractive surgery preoperative corneal power

RPO = refractive surgery PO refractive error (spherical equivalent)

RPRE = refractive surgery PO refractive error (spherical equivalent)

RCC = surgical change in refractive error (SE) vertexed to Corneal Plane

Our concerns about the clinical history method are in good agreement with several previous studies in which the clinical history method obtained less accurate results than other methods, even when the calculated corneal power was entered into double-K formulas. Hence, we recommend extreme caution when using the corneal power generated by the clinical history method in any double-K formula and agree with Awwad that this method should no longer be considered the gold standard for IOL power calculation after refractive surgery48,51.

REFERENCES


