# Intraocular lens power calculation after previous laser refractive surgery

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Methods to attempt more accurate prediction of intraocular lens power in refractive surgery eyes are many, and none has proved to be the most accurate. Until one is identified, a spreadsheet tool is available and can be used. It automatically calculates all the methods for which data are available on a single sheet for the patient's chart. The various methods and how they work are described.

*J Cataract Refract Surg 2009; 35:759–765* © 2009 ASCRS and ESCRS

The subject of accuracy in intraocular lens (IOL) power prediction in eyes that have had corneal refractive surgery is becoming increasingly important. Often, these patients are considering a refractive or multifocal IOL, which adds to the problem. Intraocular lens power calculation is considered a routine in most practices, and the results are usually acceptable in the standard cataract patient. That is not true in patients who are expecting (perhaps demanding) perfection and possibly paying extra for the IOL. It behooves every surgeon entering this area of surgical treatment to become completely familiar with the complexity of attempting to improve the accuracy of IOL power calculation in his or her practice.

## REASONS FOR POWER CALCULATION ERRORS

Intraocular lens power calculation errors in eyes with previous refractive surgery occur for 3 main reasons: instrument error, index of refraction error, and formula error.

### Instrument Error

The problem of IOL power calculation errors in eyes after corneal refractive surgery was first described in 1989 by Koch et al.[1] The first problem that arises is that the instruments we use cannot accurately measure the corneal power needed in the IOL power formula in eyes that have had radial keratotomy (RK), photorefractive keratectomy (PRK), laser in situ keratomileusis (LASIK), or laser-assisted subepithelial keratectomy (LASEK). This major cause of error is that most manual keratometers measure at the 3.2 mm zone of the central cornea, which often misses the central flatter zone of effective corneal power. The flatter the cornea, the larger the zone of measurement and the greater the error. The instruments usually overestimate the corneal power, leading to a hyperopic refractive error postoperatively.

### Index of Refraction Error

The second problem is that the assumed effective index of refraction of the normal cornea is based on the relationship between the anterior and posterior corneal curvatures. This relationship is changed in PRK, LASIK, and LASEK, but not in RK. Radial keratometry causes a relatively proportional equal flattening of both the front and back surfaces of the cornea, leaving the index of refraction relationship relatively the same. The other refractive procedures flatten the anterior surface but not the posterior surface, thus changing the refractive index calculation. This creates an overestimation of the corneal power by approximately 1.0 diopter (D) for every 7.0 D of refractive surgery correction obtained. A manual keratometer measures the curvature of the front surface of the cornea only and converts the radius (r) of curvature obtained to diopters using an index of refraction that is usually 1.3375. The formula to change from diopters to radius (in mm) is $r = 337.5/D$ and from radius (in mm) to diopters, $D = 337.5/r$.

### Formula Error

The third problem is that most modern IOL power formulas (Hoffer Q,[2,3] Holladay 1[4] and 2 (unpublished),

Submitted: April 28, 2008.
Final revision submitted: November 18, 2008.
Accepted: January 12, 2009.

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The author has no financial or proprietary interest in any material or method mentioned.

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Published by Elsevier Inc.
0886-3350/09/$—see front matter
doi:10.1016/j.jcrs.2009.01.005

and SRK/T,[5] but not the Haigis[6]) use the axial length (AL) and corneal power (K) reading to predict the position of the IOL postoperatively. The flatter than normal K in RK, PRK, LASIK, and LASEK eyes causes an error in this prediction because the anterior chamber dimensions do not really change in these eyes.

## HISTORY OF SOLUTIONS

In 1989, Holladay[7] was the first to publish and popularize 2 methods to attempt to predict the true corneal power in eyes after refractive surgery. I referred to them as the clinical history method[8] and the contact lens method.[9] The latter was first described by Frederick Ridley[10] in the United Kingdom in 1948 and introduced in the United States by Soper and Goffman[11] in 1974. Over the years, many researchers and authors have proposed multiple methods to solve this problem. No one procedure has yet to be proven to be the most accurate in all cases.

In this regard, Giacomo Savini of Bologna, Italy, and I collaborated over a 2-year period to create an Excel spreadsheet (Microsoft Corp.) tool that would automatically calculate most proposed methods and also provide a place to store all the data collected and entered. The information could be stored in 1 place, printed out on 1 sheet, and stored in the patient's chart. The Hoffer/Savini LASIK IOL Power Tool (Figure 1) was finished on July 4, 2007, and can be downloaded at no cost from www.EyeLab.com (accessed January 27, 2009) by clicking on the "IOL Power" button and then the "Hoffer/Savini" button.

In the creation of the tool, we divided all published methods into those that attempt to predict the true power of the cornea and those that fudge the target IOL power calculated with the standard data. We then divided each group into methods that require historical data regarding the status of the patient's eye before refractive surgery and those that do not require historical data.

Before finishing the tool, we asked each formula author to beta test it to make sure they agreed with our calculations and assumptions. We converted their formula abbreviations to ours to maintain consistency. The legend for these abbreviations is listed on sheet 3 in the tool and in the Appendix to this paper.

## METHODS TO ESTIMATE TRUE POSTOPERATIVE CORNEAL POWER

### Those Requiring Clinical History

*Clinical History Method*[1–8]

$$K = K_{PRE} + R_{PRE} - R_{PO} \text{ or } (K = K_{PRE} + RC_C)$$

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

Originally, it was recommended to vertex-correct the refractive errors to the corneal plane. Odenthal et al.[12] showed that clinical results were better if they were not corrected. We decided to use vertex correction in the Hoffer/Savini tool because it is more scientifically accurate. Several IOL power calculation computer programs calculate the clinical history method automatically when needed (Hoffer programs and Holladay IOL Consultant).

*Hamed et al.*[13] *Method*

$$K = TK_{PO} - (0.15 \times RC) - 0.05$$

This method requires knowledge of the refractive change from the surgery and the postoperative simulated keratometry from the topography unit.

*Speicher*[14] *(Seitz et al.*[15,16]*) Method*

$$K = 1.114 \times TK_{PO} - 0.114 \times TK_{PRE}$$

This method requires obtaining the preoperative and postoperative topographic simulated K values.

*Jarade et al.*[17] *Formula*

$$K = TK_{PRE} - [0.376 \times (TK_{POr} - TK_{PREr})]/(TK_{POr} \times TK_{PREr})$$

This method requires obtaining the preoperative and postoperative topographic simulated K values in radius of curvature, not diopters.

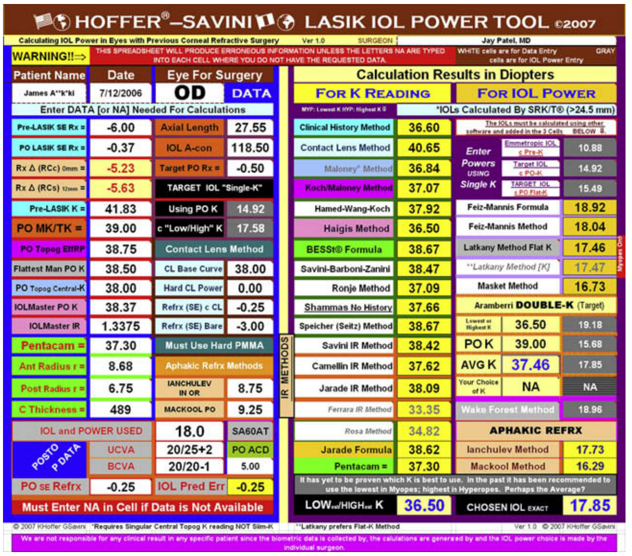


Figure 1. Hoffer/Savini LASIK tool for IOL power calculation in eyes having previous refractive surgery.

*Holladay Method*

$$K = K_{POFLAT} + 0.25 \times RC$$

This method requires knowledge of the refractive change from the surgery and the postoperative flattest K reading measured now (J.T. Holladay, MD, "Measuring Corneal Power After Corneal Refractive Surgery; How the Pentacam Improves the Accuracy of These Calculations," In: Why Cataract and Refractive Surgeons Need the Pentacam. Insert to Cataract Refract Surg Today, January 2006, pages 4–6. Available at: http://www.oculus.de/en/downloads/dyn/sonstige/sonstige/press_cataract_pentacam_0206pdf. Accessed January 27, 2009).

*Adjusted Refractive Index Methods*

These methods attempt to "correct" the index of refraction to better predict the corneal power. The first 2 methods require knowing the surgically induced refractive change at the spectacle plane and the average radius of curvature of the cornea now. The third method requires knowing the surgically induced refractive change at the corneal plane and the average radius of curvature of the cornea now.

1. *Savini et al.*[18] *Method*

$$K = [(1.338 + 0.0009856 \times RC) - 1]/(K_{POr}/1000)$$

2. *Camellin and Calossi*[19] *Method*

$$K = [(1.3319 + 0.00113 \times RC_S) - 1]/(K_{POr}/1000)$$

3. *Jarade and Tabbara*[20] *Method*

$$K = [(1.3375 + 0.0014 \times RC_C) - 1]/(K_{POr}/1000)$$

## Those Not Requiring Clinical History

*Contact Lens Method*[10,11]

$$K = B_{CL} + P_{CL} + R_{CL} - R_{NoCL}$$

The contact lens method was first described by Frederick Ridley[10] of England in 1948 and taught by Soper and Goffman[11] in 1974. This method is based on the principle that if a hard poly(methyl methacrylate) (not rigid gas-permeable) contact lens of plano power ($P_{CL}$) and a base curve ($B_{CL}$) equal to the effective power of the cornea is placed on the eye, it will not change the refractive error of the eye. Therefore, the difference between the manifest refraction with the contact lens ($R_{CL}$) and without it ($R_{NoCL}$) is zero. The formula above computes the effective corneal power if there is a difference in any parameter.

Originally, it was recommended to vertex-correct the refractive errors to the corneal plane. Odenthal et al.[12] showed that clinical results were better if they were not corrected. We decided to use vertex correction in the Hoffer/Savini tool because it is more scientifically accurate. Several IOL power calculation computer programs calculate this method and the clinical history method automatically, when needed (Hoffer programs and Holladay IOL Consultant). Plano contact lens sets for performing this procedure are commercially available (Figure 2).

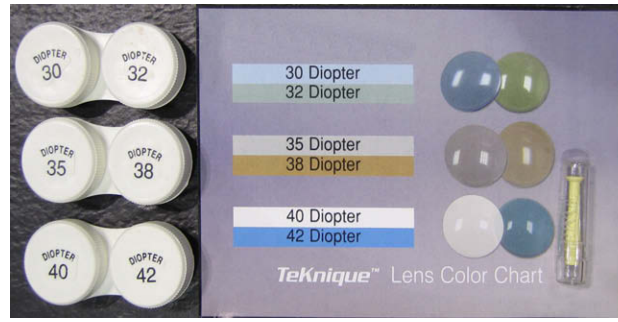


**Figure 2.** Plano contact lens kits commercially available for performing the contact lens method.

Obviously, this method is impossible if the cataract precludes performing an accurate refraction whereby the visual acuity is worse than 20/80.

*Smith et al.*[21] *Central Topography Method*

$$K = 1.1141 \times TK_{PO\text{-}CTR} - 5.5$$

Based on their analysis of post-LASIK corneal topography central Ks (TK) in LASIK eyes, Smith et al. developed a formulation to predict true corneal power using only the single central postoperative reading TK.

*Koch and Wang*[22] *Method*

$$K = 1.1141 \times TK_{PO} - 6.1$$

Koch and Wang analyzed several of these methods and obtained the best results using the Smith et al.[21] method, but only after increasing the constant from 5.5 to 6.1. They also offer a second method to calculate true corneal power if the change in the patient's refractive error (RC) is known. The formula is

$$K = Kt_{PO} - (0.19 \times RC)$$

*Savini et al.*[23] *Method*

$$K = 1.114 \times Kt_{PO} - 4.98$$

This method only requires the postoperative simulated K value from topography.

*Shammas et al.*[24] *No History Method*

$$K = 1.14 \times K_{PO} - 6.8$$

Shammas et al. studied a series of eyes that had LASIK. Their analysis led them to propose a formula to predict the effective power of the cornea in which none of the patient's clinical history is available. Only the

**Table 1.** Rosa correction factor conversion table based on AL.

| AL (mm) | Correction Factor |
|---|---|
| 22.0 to <23.0 | 1.01 |
| 23.0 to <24.0 | 1.05 |
| 24.0 to <25.0 | 1.04 |
| 25.0 to <26.0 | 1.06 |
| 26.0 to <27.0 | 1.09 |
| 27.0 to <28.0 | 1.12 |
| 28.0 to <29.0 | 1.15 |
| >29.0 | 1.22 |

AL = axial length

postoperative K reading obtained with manual keratometry is needed.

*Adjusted Refractive Index Methods*

*Ferrara et al.*[25] *Method*

$$K = \left[\left(-0.0006 \times AL^2 + 0.0213 \times AL + 1.1572\right) - 1\right] / (K_{POr}/1000)$$

This method requires the AL measurement and the postoperative K reading in radius of curvature.

*Rosa et al.*[26] *Method*

$$K = (1.3375-1)/[(K_{POr} \times RCF)/1000]$$

This method requires the postoperative K reading in radius of curvature and the use of a table (Table 1) to obtain a factor (RCF) based on AL. Unfortunately, they used the SRK II regression formula in their computation, with which I disagree.

*Haigis Method*[27,28]

$$K = -5.1625 \times K_{POr} + 82.2603 - 0.35$$

This method requires only the postoperative K reading from the Zeiss IOLMaster in radius of curvature (or converted to diopters using the index of refraction setting in the IOLMaster.)

*Pentacam*

A relatively new comprehensive eye scanner, the Pentacam (Oculus, Inc.), images the anterior segment of the eye by a rotating Scheimpflug camera measurement. This rotating process supplies pictures in 3 dimensions, provides a topographic analysis of the corneal front and back surfaces as well as central corneal thickness, and generates a TrueNetPower map of the cornea as well as calculates an equivalent K called the Holladay Report.

The equivalent K (at the recommended 4.5 mm zone) of the postoperative cornea has been proposed as an accurate measure of the true corneal power. Initial results were disappointing, and the software was reconfigured in early 2007. Several recent studies of the new software indicate the new configuration also does not live up to expectations, and some have found better results with the 3.0 mm zone than with the clinical history method.

*The BESSt Formula*[29]

Published by Borasio et al.,[29] the BESSt formula uses the anterior and posterior corneal curvatures as well as the central pachymetry from the Pentacam unit to produce a predicted central corneal power. Although the formula is complicated, it is incorporated in the Hoffer/Savini tool.

## METHODS TO ADJUST/CALCULATE THE TARGET INTRAOCULAR LENS POWER

### Those Requiring Clinical History

*Aramberri*[30] *Double-K Method*

$K_{PRE}$ used to calculate effective lens position (ELP)

$K_{PO}$ used calculate IOL power

One of the most important developments to improve the prediction of corneal power in eyes that have had refractive surgery, termed the double-K method, was proposed in 2001 by Aramberri of San Sebastian, Spain. His proposal makes eminent sense. The modern theoretic formulas (except the Haigis) use the input of corneal power for 2 purposes. The first is to predict the ultimate position of the IOL (anterior chamber depth [ACD] or ELP), and the second (along with AL, target refraction, and ELP) is to calculate the power of the IOL. The formulations and algorithms used to predict the ELP are based on the anatomy of the anterior segment, which is not changed by corneal refractive surgery (only the center is flattened and thinned). Therefore, if the postoperative refractive surgery K reading (which is flatter) is used to calculate the ELP, it will produce an erroneous ELP value. Because the anatomy has not changed, Aramberri recommends the use of the preoperative K reading to calculate the ELP. The IOL power is then calculated using the postoperative K reading, thus the use of 2 K readings (double K). Aramberri's analysis of a small series of eyes proved the benefit of this idea.

*Feiz et al.*[31] *Formula*

$$P = P_E - RC_S/0.7$$

In this method, the emmetropic IOL power is calculated using the post-refractive surgery K reading. That value ($P_E$) is adjusted using the surgically induced refractive change.

*Feiz et al.*[32] *Method*

This method uses the change in refractive error to offset the calculated target IOL power. There is 1 formula for myopic eyes and another for hyperopic:

$$\text{Myopic eye}: P = P_{TARG} - 0.595 \times RC_C + 0.231$$

$$\text{Hyperopic eye}: P = P_{TARG} - 0.862 \times RC_C + 0.751$$

*Latkany et al.*[33] *Methods* (myopic eyes only)

$$P = P_{TARG\ FlatK} - 0.47 \times R_{PRE} + 0.85$$

This method requires knowledge of the pre-LASIK refractive error and the calculation of the target IOL power using the flattest postoperative K rather than the usual average K.

*Masket and Masket*[34] *Method*

$$P = P_{TARG} - 0.326 \times RC_C + 0.101$$

(SRK/T: myopes; Hoffer Q: hyperopes)

This method is a play on the Latkany method, which adjusts the power of the IOL, calculated using the postoperative measured data using the knowledge of the surgically induced refractive change. They recommend using the SRK/T formula for myopic ALs and the Hoffer Q for hyperopic ALs. Example calculations are shown in Table 2. In a series of 28 post-LASIK eyes, they reported 43% of the eyes obtaining a postoperative refractive error of plano, 95% within ±0.50 D of prediction and a total error range from –0.75 D to +0.50 D.

*Wake Forest Method*[35]

Use $R_{PRE}$ as the $RX_{TARG}$ using measured AL and $K_{PRE}$

In 2005, Walter et al.[35] from Wake Forest University published an alternative calculation method that has been discussed by others over the past 20 years. This method simply uses the patient's preoperative refraction before LASIK as the target or "desired" postoperative refraction in the calculation and the measured AL and K readings without modification.

### Those Not Requiring Clinical History

*Aramberri*[30] *Double-K Method*

Use 43.50 or 44.00 to calc ELP

Use $K_{PO}$ to calculate IOL power

The use of a standard normal K reading in the double-K method is a great improvement over using the calculated very flat K reading.

*Ianchulev et al.*[36] *Intraoperative Aphakic Refraction Method*

$$P = 2.02 \times AR + (A - 118.4)$$

In 2005, Ianchulev et al.[36] proposed calculating IOL power by performing an aphakic refraction on the operating room table using a handheld automated refractor immediately after the cataract is removed and the anterior chamber is inflated to normal status. The resultant refraction is entered into a formula and then the calculated IOL is immediately implanted.

The early results are quite promising. This method would completely eliminate the need for AL and corneal power measurements as well as the problems with LASIK and silicone oil-filled eyes. However, it would require a large IOL inventory in the operating room.

*Mackool et al.*[37] *Secondary Implant Method*

$$P = 1.75 \times AR + (A - 118.84)$$

This method is similar to the above except the patient is removed from the operating room without an IOL implanted, then refracted in a refraction lane, and then taken back to the operating room for secondary IOL implantation. It is my impression that this method would not be popular with most surgeons.

**Table 2.** Examples of calculations of the Masket and Masket method in a myopic and hyperopic LASIK eye.

| Myopic Eye | Hyperopic Eye |
|---|---|
| SRK/T calculates 16.0 D IOL | Hoffer Q calculates 22.0 D |
| Change in Rx = −6.0 D | Change in Rx = +3.0 D |
| −0.323 × (-6) + 0.138 = +2.076 | −0.323 × (+3) + 0.138 = −0.82 |
| P = 16.0 + 2.0 = 18.0 D | P = 22.0 − 1.0 = 21.0 D |

## IMPORTANT THINGS TO KEEP IN MIND

Be sure the index of refraction is set to 1.3375 in the setup screen of the IOLMaster computer for the Hoffer Q formula to operate properly for hyperopic refractive eyes.

If the AL is very difficult to obtain and the eye appears to have an AL greater than 25.0 mm, suspect a staphyloma.

Hard contact lenses (including gas permeable) should be removed permanently for at least 2 weeks before measuring corneal power for IOL power calculation in at least one eye. This is less crucial with soft contact lenses, which can be removed for 1 day.

All patients having corneal refractive surgery should be given the following data to maintain in their personal health records: (1) preoperative corneal power, (2) preoperative refractive error, and (3) postoperative healed refractive error (before lens changes affected it). They should be told to give this information to anyone planning to perform cataract/IOL surgery on them.

## WHAT FORMULA TO USE

My study[2] of 450 eyes (by the same surgeon using 1 IOL style) showed that in the normal range (72%) of AL (22.0 to 24.5 mm), almost all formulas function adequately but that the SRK I formula is the leading cause of poor refractive results in eyes outside this range. As far back as 1989, Koch et al.[1] warned against the use of regression formulas in eyes that have had refractive surgery.

The study also showed that the Holladay 1 formula was the most accurate in medium long eyes (24.5 to 26.0 mm) (15%) and the SRK/T was more accurate in very long eyes (>26.0 mm) (5%). In short eyes (<22.0 mm) (8%), the Hoffer Q formula was most accurate; this was confirmed in an additional large study of 830 short eyes ($P > .0001$) as well as in a multiple-surgeon study by Holladay. A repeat study of 317 eyes also confirmed this.[38] Holladay postulates that the other formulas overestimate the shallowing of the ELP in these very short eyes.

## HOW TO HANDLE PROBLEMS AND ERRORS

The major problem is an unacceptable postoperative refractive error. The sooner it is discovered, the sooner it can be corrected and the sooner the patient will be satisfied. Therefore, it is wise to perform K readings and a manifest refraction on the first postoperative day in these demanding patients. Immediate surgical correction (24 to 48 hours) will allow easy access to the incision and the capsular bag, a single postoperative period, and excellent uncorrected vision.[39] The majority of medicolegal cases today are the result of a delay in diagnosis and treatment of this iatrogenic problem.

Until now, we could only correct this problem by lens exchange, which creates the dilemma of determining which factor created the IOL power error: AL, corneal power, mislabeled IOL, or a combination. Today, with the advent of low-powered IOLs, the best remedy may be a piggyback IOL. With a piggyback IOL, it is not necessary to determine what caused the error or to remeasure the AL of the freshly operated pseudophakic eye.

In conclusion, IOL power calculation is a real problem in eyes that have had refractive surgery. Because it has yet to be proven which proposed method works best in all eyes, it behooves the surgeon to use as many methods as data are available and carefully evaluate the results. The Hoffer/Savini tool is an attempt to make this process easier. If surgeons using the tool forward their results to us, we may be able give an accuracy weight to each method.

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## APPENDIX

### Formula Legend

A = intraocular lens (IOL) A constant for planned IOL style

AL = axial length

AR = aphakic refractive error (spherical equivalent).

B = base curve; PCL = power of contact lens; NoCL = bare refraction

CL = contact lens

K = predicted postoperative corneal power

$K_{postoperative}$ = average postoperative corneal power by manual keratometry (D)

$K_{postoperativeFLAT}$ = flattest measured postoperative manual keratometry

$K_{postoperativer}$ =average postoperative corneal power by “ “ (in radius r [mm])

$K_{PRE}$ = refractive surgery preoperative corneal power (K readings)

P = IOL power

$P_{EMM}$ = IOL power calculated for emmetropia

$P_{FlatK}$ = IOL power calculated for $Rx_{TARG}$ using the postoperative flattest K

$P_{TARG}$ = target IOL power to produce the postoperative desired refractive error

R = refractive error: $_{PRE}$ = preoperative, $_{postoperative}$ = postoperative

$RC_C$ = surgical change in refractive error (spherical equivalent) vertexed to corneal plane

RCF = Rosa correction factor based on axial length

$RC_S$ = surgical change in refractive error (spherical equivalent) at apectacle plane

$R_{postoperative}$ = refractive surgery postoperative refractive error (spherical equivalent)

$R_{PRE}$ = refractive surgery preoperative refractive error (spherical equivalent)

$Rx_{TARG}$ = planned postoperative target refractive error

TK = average postoperative topography central simulated K (SimK) or effective refractive power (EffRP)

$TK_{CTR}$ = exact singular postoperative topography central K