articles

Intraocular lens power calculation after corneal refractive surgery: Double-K method

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Purpose: To determine the accuracy of a method of calculating intraocular lens (IOL) power after corneal refractive surgery.

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Methods: The SRK/T formula was modified to use the pre refractive surgery K-value (Kpre) for the effective lens position (ELP) calculation and the post refractive surgery K-value (Kpost) for IOL power calculation by the vergence formula. The Kpre value was obtained by keratometry or topography and the Kpost, by the clinical history method. The formula was assessed in 9 cases of cataract surgery after laser in situ keratomileusis (LASIK) or photorefractive keratectomy (PRK) in which all relevant data were available. Refractive results of the standard SRK/T and the double-K SRK/T were compared statistically.

Results: The mean IOL power for emmetropia and the achieved refraction (mean spherical equivalent [SE]), respectively, were +17.85 diopters (D) ± 3.43 (SD) and +1.82 ± 0.73 with the standard SRK/T and +20.25 ± 3.55 D and +0.13 ± 0.62 D with the double-K SRK/T. No case in the standard SRK/T group and 6 cases (66.66%) in the double-K group achieved a ±0.5 D SE.

Conclusion: Double-K modification of the SRK/T formula improved the accuracy of IOL power calculation after LASIK and PRK.

J Cataract Refract Surg 2003; 29:2063–2068 © 2003 ASCRS and ESCRS

Postoperative hyperopia is a frequent result of cataract surgery in eyes having previous keratorefractive surgery.[1–7] One reason for the underestimation of intraocular lens (IOL) power is the wrong corneal power measurement given by keratometers and corneal topography systems, as described by several authors over the past few years. Theoretically, this problem could be overcome using a refraction-derived keratometric value (clinical history method), which does not use post refractive surgery corneal measurements.[1–4] However, this method alone does not eliminate hyperopic results, although their magnitude is less.[5,6]

The reason for the residual hyperopia is incorrect effective lens position (ELP) estimation calculated by third-generation theoretical formulas in which the post refractive surgery K-value is used. This, usually short, value underestimates the ELP and IOL power, resulting in hyperopia between 1.0 diopter (D) and 3.0 D.

This problem can be solved with a simple change in the calculation formula, which I call the double-K

Accepted for publication February 10, 2003.

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

Javier Mendicute, MD, San Sebastián, Jose Alfonso, MD, Oviedo, Larrauri, MD, Vitoria, Daniel Elies, MD, Barcelona, and Jose Fernandez Vigo, MD, Madrid, Spain, provided cases for the study. Kenneth J. Hoffer, MD, Santa Monica, California, USA, helped in the correction of this study.

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Published by Elsevier Inc.

0886-3350/03/$–see front matter
doi:10.1016/S0886-3350(03)00232-3

method. This method uses 2 K-values: pre refractive surgery (Kpre) for the calculation of the ELP and post refractive surgery (Kpost) for the vergence formula that finally gives the IOL power. The Kpost is calculated with the clinical history method.

In this paper, I describe the method and its results in 9 cases of cataract surgery after excimer laser refractive surgery and compare the results with those of the standard calculation procedure.

Patients and Methods

Twenty-eight cases of cataract surgery after laser in situ keratomileusis (LASIK) or photorefractive keratectomy (PRK) for myopia (with or without astigmatism) were reviewed. Some were provided by other surgeons, and some were from my practice. Cases were accepted for analysis when all the following data were available: preoperative keratometry and/or topography; preoperative refraction; postoperative stabilized refraction; postoperative topographic and refractive evolution until cataract surgery; axial length (AL) before cataract surgery; IOL model and power; stabilized refraction after cataract surgery.

If a myopic shift greater than 2.0 D occurred between the 2 surgeries, the case was excluded to avoid inaccurate Kpost calculations. Nine of the 28 cases met the inclusion criteria and were included in the study. Six cases were provided by other surgeons, and 3 were from my hospital.

Cases 1 to 5 had implantation of IOLs whose power was determined by a standard IOL calculation. Cases 2 and 3 had IOL exchange for a hyperopic refractive surprise. Cases 6 to 9 had IOL implantation following the double-K method. The data in these 9 cases were used to compare the results of standard SRK/T calculation with those of SRK/T double-K calculation.

Double-K SRK/T Formula

The SRK/T formula was programmed into a spreadsheet program (Microsoft® Excel 2000) using the corrected version of the formula.[8] The programming was done so that ELP calculation algorithms used Kpre and vergence formula algorithms used Kpost. The modified formula is shown in the Appendix. Independent variables were AL, Kpre, Kpost, and the A-constant of the IOL.

Equations 1 to 6 calculate the ELP (named ACDest in the original publication). Therefore, Kpre was programmed to be used in equations 1 and 3. The Kpost value is used in equation 9, which converts the dioptric power value in millimeters or corneal radius of curvature, which goes into the vergence formula (equation 10). This calculates the emmetropic IOL power. With this formula, the emmetropic double-K method IOL power ($IOL_{d\text{-}k}$) in each case was calculated.

The standard-method IOL power (IOL_{stand}) was calculated with the corrected version of the SRK/T formula.[8] The only K-value used was Kpost.

Determining Corneal Power

The Kpre value was obtained from the examination performed before refractive corneal surgery. When both keratometry and topography values were available, the first one was used.

The Kpost value was calculated from refractive history: The refractive change was determined once the refraction stabilized after corneal surgery. This value was converted to the corneal plane and then subtracted from Kpre.

Determining AL

All AL measurements were done by ultrasound (US) contact biometry. The automatic phakic mode (4-gate method) was used in all cases, with 1532 m/sec US speed for the anterior chamber and vitreous and 1640 m/sec US speed for the lens.

Analysis of Results

The emmetropic IOL power in each case was calculated using the known implanted lens power and A-constant and the postoperative refraction. This was done by calculating the magnitude of IOL power that should produce 1.0 D of refractive change at the spectacle plane (IOL_{1DRx}) with the expected refraction formula of the SRK/T formula.[8] To achieve this, the expected refraction with a certain IOL power was subtracted from the expected refraction with an IOL power 1.0 D higher or lower than the first one. This is the refraction difference for a change of 1.0 D in IOL power in an eye with those biometric numbers (Rx_{1DIOL}). Then, 1 was divided by Rx_{1DIOL}, resulting in the magnitude in IOL power that should produce 1.0 D of refractive change (IOL_{1DRx}).

This value was multiplied by the refractive error (Rx) and added to the implanted lens power (IOL_{imp}). The result is the emmetropic power (IOL_{emme}) in the case.

$$IOL_{emme} = IOL_{1DRx} \times Rx + IOL_{imp}$$

The refractive result of both $IOL_{d\text{-}k}$ and IOL_{stand} were calculated from the emmetropic power using

$$Rx_{d\text{-}k} = (IOL_{emme} - IOL_{d\text{-}k})/(IOL_{1DRx})$$

$$Rx_{stand} = (IOL_{emme} - IOL_{stand})/(IOL_{1DRx})$$

To avoid the influence of plus and minus signs, absolute refractions of both methods $[Rx_{stand}]$ and $[Rx_{d\text{-}k}]$ were determined and compared. For example, case 1 is analyzed as follows: Kpre = 43.50 D; Kpost = 33.98 D; AL = 26.83 mm; IOL_{imp} = +26.00 D; Rx = −0.25 D (postoperative refraction). Using these data, $IOL_{d\text{-}k}$ = +25.03 D and IOL_{stand} = +21.80 D.

When calculating the emmetropic IOL power with the expected-refraction SRK/T formula, the predicted refraction for a +25.00 D IOL is +0.02 D and for a +26.00 D

Table 1. Refractive and cataract surgery data.

Case	Ref Surg Date	Surgery Type	Corrected (D) Spectacle Plane	Corrected (D) Corneal Plane	Kpre (D)	Kpost (D)	AL (mm)	A-Constant	IOLimp	Rx
1	1999	LASIK	10.75	9.52	43.50	33.98	26.83	118.90	26.00	−0.25
2	1999	LASIK	12.50	10.86	43.00	32.14	26.46	118.00	27.00	−0.50
3	1997	LASIK	9.12	8.22	44.09	35.87	28.45	118.00	19.00	0.63
4	1998	LASIK	13.00	11.25	42.93	31.68	30.33	118.00	17.00	1.50
5	1994	PRK	8.75	7.91	42.42	34.51	27.95	118.00	19.00	0.88
6	1996	PRK	7.75	7.09	44.30	37.21	28.20	118.90	18.00	−1.00
7	1997	LASIK	7.00	6.46	41.50	35.04	28.00	118.90	19.50	0.50
8	1997	PRK	6.00	5.60	43.85	38.25	26.46	118.90	20.50	−0.25
9	1997	PRK	7.00	6.46	45.67	39.21	27.60	118.50	17.50	−1.00

AL = axial length; IOLimp = implanted IOL power; Kpre = pre-refractive-surgery K-value; Kpost = post-refractive-surgery calculated K-value; LASIK = laser in situ keratomileusis; PRK = photorefractive keratectomy; Ref Surg = refractive surgery; Rx = postoperative spherical equivalent

IOL, −0.69 D. Thus, 0.02 − (−0.69) = 0.71. This is the refraction difference for a 1.0 D change in IOL power (Rx_{1DIOL}). Then 1/0.71 = 1.41. This is the IOL power that should produce 1.0 D of refractive change (IOL_{1DRx}).

This formula is then used: $IOL_{emme} = IOL_{1DRx} \times Rx + IOL_{imp}$ $(1.41 \times -0.25) + 26 = 25.64$. This is the power that should have produced emmetropia in that case (IOL_{emme}).

Knowing IOL_{emme}, we can calculate the refraction that should result implanting $IOL_{d\text{-}k}$ and IOL_{stand}:

$$Rx_{d\text{-}k} = IOL_{emme} - IOL_{d\text{-}k})/(IOL_{1DRx})$$

$$Rx\ d\text{-}k = (25.64 - 25.03)/1.41 = 0.43$$

$$Rx_{stand} = (IOL_{emme} - IOL_{stand})/(IOL_{1DRx})$$

$$Rx\ stand = (25.64 - 21.80)/1.41 = 2.72$$

Bivariate comparisons were performed with the Wilcoxon test. A *P* value of 0.05 or less was considered statistically significant.

Results

Table 1 summarizes the refractive and cataract surgery data. Cases 2 and 3 show the refractive result after an IOL exchange for a first hyperopic refractive surprise. In cases 6, 7, 8, and 9 the choice of the IOL power was done using the double-K method.

Table 2 shows the calculated emmetropic IOL power (IOL_{emme}), standard SRK/T emmetropic IOL power (IOL_{stand}), and double-K emmetropic IOL power ($IOL_{d\text{-}k}$) as well as their calculated refractive results (Rx_{stand} and $Rx_{d\text{-}k}$).

Standard calculation with the SRK/T formula using a refraction-derived keratometric value gave a mean IOL power of 17.85 D ± 3.43 (SD) with a postoperative spherical equivalent (SE) of 1.82 ± 0.73 D (range 0.96 to 3.19 D). No case achieved a ±0.5 SE; 1 case (11.11%) was between ±1.0 D of SE (Figure 1). As all cases were hyperopic, the absolute SE mean and standard deviation were equal. Double-K SRK/T calculation achieved a more powerful mean IOL of 20.25 ± 3.55 D, decreasing the mean postoperative refractive error to 0.13 ± 0.62 D (range −0.56 to 1.47 D). Six cases (66.66%) were in the ±0.5 D SE range and 8 (88.88%) in the ±1.0 D SE range. The mean absolute SE was 0.43 ± 0.44 D (range 0.02 to 1.47 D).

The difference between IOL_{emme} and $IOL_{d\text{-}k}$ was not significant ($P = .68$). The difference between IOL_{emme} and IOL_{stand} and between IOL_{stand} and $IOL_{d\text{-}k}$ was significant (both $P = .008$). The difference between Rx_{stand} and $Rx_{d\text{-}k}$ and between $[Rx_{stand}]$ and $[Rx_{d\text{-}k}]$ was also significant (both $P = .008$).

Discussion

Intraocular lens power calculation for an eye having previous keratorefractive surgery by any technique has 2 main challenges: determination of the total corneal power and inaccuracy of the calculation formula. Much has been said and written about the first and little about the second.

Measuring the net corneal power is inaccurate as the assumptions made by the algorithms used by keratometers and topographers are not true in these eyes. The

Table 2. Summary of calculation results.

Case	IOL_{emme} (D)	IOL_{stand} (D)	Rx_{stand} (D)	$[Rx_{stand}]$ (D)	IOL_{d-k} (D)	Rx_{d-k} (D)	$[Rx_{d-k}]$ (D)
1	25.68	21.80	2.73	2.73	25.03	0.44	0.44
2	26.34	24.60	1.35	1.35	27.05	−0.54	0.54
3	19.90	15.34	3.19	3.19	17.80	1.47	1.47
4	19.05	16.15	2.12	2.12	18.95	0.07	0.07
5	20.17	17.87	1.72	1.72	20.03	0.10	0.10
6	16.48	15.02	0.96	0.96	17.33	−0.56	0.56
7	20.18	17.91	1.66	1.66	19.65	0.39	0.39
8	20.13	18.15	1.35	1.35	20.12	0.02	0.02
9	15.94	13.87	1.32	1.32	16.34	−0.26	0.26
Mean	20.43	17.85	1.82	1.82	20.25	0.13	0.43
SD	3.54	3.43	0.73	0.73	3.55	0.62	0.44

IOL_{d-k} = double-K emmetropic IOL power; IOL_{emme} = calculated emmetropic IOL power; IOL_{stand} = standard SRK-T emmetropic IOL power; Rx_{d-k} = calculated refraction for IOL_{d-k}; $[Rx_{d-k}]$ = absolute calculated refraction for IOL_{d-k}; Rx_{stand} = calculated refraction for IOL_{stand}; $[Rx_{stand}]$ = absolute calculated refraction for IOL_{stand}

main reason seems to be the change in the relationship between the anterior and posterior corneal radii of curvature, which is no longer 7.5/6.3.[4] This invalidates the value of the different corneal indices of refraction (standardized index of refraction = 1.3375; SRK/T = 1.3333) that allows total corneal power calculation from the anterior surface radius of curvature in nonoperated eyes. Other explanations for the difference between refractive change and corneal power change after corneal refractive surgery include stromal refractive index change[9,10]; higher central asphericity of the cornea so that after surgery, the central power is much flatter than paracentral power[11]; more peripheral measurement as mires locate farther from the center in a surgically flattened cornea.[12] The result is that corneal power overestimation occurs after keratorefractive surgery with both keratometers and topographers.

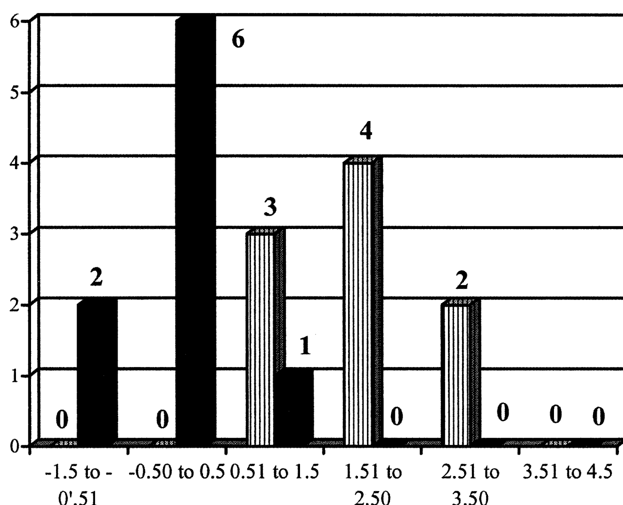

Figure 1. (Aramberri) Postoperative SE with both methods (black bars = Rx_{stand}; striped bars = Rx_{d-k}).

Another problem is that we cannot accurately quantify the discrepancy between measured corneal power change and refractive change to determine a correction factor that could derive true from the measured corneal power. Although several average values have been provided (14% to 25% of the refractive change[4,13]), dispersion is usually too high, probably as a result of factors such as the variability of posterior corneal curvature changes after excimer laser surgery, treatment centration, and treatment profiles.

If corneal power determination were the only problem, calculating a refraction-derived keratometric value should allow accurate IOL calculation.[1–4] However experience shows that hyperopic results still occur.[5,6]

This remaining hyperopia can be explained by the inaccuracy of the IOL power calculation formula when we input the post refractive surgery K-value (even if it is correct). Any third-generation theoretic formula (eg, Holladay, SRK/T, Hoffer Q) works in 2 successive steps: First it uses both AL and K-values to calculate the ELP. Then, this last variable, and AL and K again,

is used in the vergence formula to calculate the IOL power.[8,14,15] If we consider that the first step is an estimation of the anterior chamber depth and that this anatomic distance should not change after this kind of surgery, it seems obvious that using a lower than original K-value (as results from refractive corneal surgery) will lead to an underestimation of the ELP and thus IOL power, with a subsequent hyperopic postoperative refraction.

The solution is to allow the formula to work logically using the Kpre for calculation of the ELP and the Kpost for calculation of the vergence formula.

Any third-generation formula can be easily programmed to use Kpre for the ELP calculation and Kpost for the final IOL power calculation. I chose the SRK/T as it works well in long eyes.[15]

To validate this method, it was important to be selective about the inclusion criteria. The key point has been the determination of the Kpost value. In some cases, there was a myopic shift after refractive surgery; it was difficult to ascertain how much was the result of corneal regression (as the topographical evolution does not correlate perfectly with the refractive evolution) and how much was caused by cataract-induced index myopia. To avoid this error, cases with a myopic shift greater than 2.0 D were excluded.

The results of the study show that the double-K method improves the accuracy of IOL power calculation after keratorefractive surgery. Predictability can be considered similar to what we achieve in nonoperated eyes: 90% within $\pm$1.0 D of SE. Only case 3 exceeded this limit, with an SE of 1.58 D. This patient could not be evaluated again to ascertain the reason for the refractive error.

The high precision of this method validates the thesis of a wrong ELP estimation as the cause of postoperative hyperopia in these eyes. This modification should be programmed in any third- or fourth-generation theoretic formula to improve ELP calculation after keratorefractive surgery to avoid postoperative hyperopia.

This study provides some important conclusions. First, recording the Kpre is critical for the correct calculation of ELP. Second, refraction and topographic follow-up throughout the years will be important to determine the correct Kpost (with the clinical history method), at least until other methods of K-value determination from anterior and posterior radii of curvature measurement are improved (eg, corneal tomography, high-frequency US).

In conclusion, the double-K method, which uses the Kpre for the ELP calculation and the Kpost for the IOL power determination by the vergence formula, improves the accuracy of IOL power calculation after excimer laser keratorefractive surgery.

Appendix

Double-K SRK/T Formula

Equation 1: Preoperative corneal radius of curvature:

$$r_{pre} = 337.5/\text{Kpre}$$

Equation 2: Corrected axial length (LCOR):

$$\text{If } L \leq 24.2,\ \text{LCOR} = L$$

$$\text{If } L > 24.2,\ \text{LCOR} = -3.446 + 1.716 \times L - 0.0237 \times L^2$$

Equation 3: Computed corneal width (Cw):

$$Cw = -5.41 + 0.58412 \times \text{LCOR} + 0.098 \times \text{Kpre}$$

Equation 4: Corneal height (H):

$$H = r_{pre} - \text{Sqrt}\,[r_{pre}2 - (Cw2/4)]$$

Equation 5: Offset value:

$$\text{Offset} = \text{ACD}_{const} - 3.336$$

Equation 6: Estimated postoperative ELP (ACD):

$$\text{ACD}_{est} = H + \text{Offset}$$

Equation 7: Constants:

$$V = 12;\ n_a = 1.336;\ n_c = 1.333;\ n_c m1 = 0.333$$

Equation 8: Retinal thickness (RETHICK) and optical axial length (LOPT):

$$\text{RETHICK} = 0.65696 - 0.02029 \times L$$

$$\text{LOPT} = L + \text{RETHICK}$$

Equation 9: Postoperative corneal radius of curvature:

$$r_{post} = 337.5/\text{Kpost}$$

Equation 10: Emmetropia IOL power (IOL_{emme}):

$$\text{IOL}_{emme} = [1000 \times n_a \times (n \times r_{post} - n_c m1 \times \text{LOPT})]/[(\text{LOPT} - \text{ACD}_{est}) \times (n_a \times r_{post} - n_c m1 \times \text{ACD}_{est})]$$

Variables

L = axial length; Kpre = pre refractive surgery K-value; Kpost = post refractive surgery K-value; ACDconst = IOL constant (can be computed from A-constant).

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