臺北醫學大學50週年慶
眼科學最近之發展 國際學術研討會
International Symposium on Current Ophthalmology
May 1st 2010 Shuang Ho Hospital

IOL Power Calculation in Eyes with Previous Refractive Surgery

Jau-Der Ho, M.D. PhD. 何昭德

IOL Power Calculation in Eyes with Previous Refractive Surgery

臺北醫學大學附設醫院 眼科
何昭德

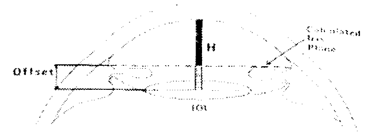
IOL power calculations in post-refractive surgery eyes

Inaccurate K estimation if standardized keratometric index of 1.3375 is used

Keratometers measure only 4 points on the cornea at a paracentral region, ignoring flatter (or steeper), more central regions resulting from myopic (or hyperopic) photoablation

IOL position (effective lens position, ELP) estimation using Kpost is inaccurate

Effective lens position and corneal height



Double-K clinical history method
(2003, Aramberri)

Kpost (obtained by clinical history) for vergence formula

Kpre for ELP (effective lens position) estimetion

While being an effective method, however, needing Kpre, refractive data both before and after refractive surgery; and the post-refractive surgery refraction must be the one before cataract development

Bypass method

the IOL power as determined by a standard calculation technique with the Kpre

the amount of prerefractive surgery myopia be set as the target for refraction

needing Kpre, refractive data both before and after refractive surgery; and the post-refractive surgery refraction must be the one before cataract development)

1

IOL power vergence formula

$$\text{IOL power} = \frac{n_a}{AxL - ELP} - \frac{n_a}{\frac{n_a}{K} - ELP}$$

Kpre for ELP calculation

Kpost for K

Two main problems faced in post-refractive surgery eyes when history is unavailable

Determine post-refractive surgery corneal power (Kpost) by direct measurement

Effective lens position (ELP: IOL position) estimation without using Kpost

Determine post-refractive surgery corneal power (Kpost) by direct measurement

Determine post-refractive surgery corneal power by direct measurement

Most of the time, only the anterior corneal curvature (power) can be measured (exception: Orbscan, Pentacam)

Which keratometric index should be used?

Study	Keratometric index
Dubbelman et al.	1.329 ± 0.0001
Dunne et al.	1.3283
Fam and Lin	1.3273 ± 0.0013
Ho et al.	1.3281 ± 0.0018
conventional	1.3375
Gullstrand schematic eye	1.3315
Shammas	1.3375
Holladay I	4/3
SRK/T	1.333
Haigis	1.3315

Determine post-refractive surgery corneal power by direct measurement

The keratometric indices (and thus the corneal refractive powers) used by most of the IOL power calculation formulae currently in use are not the actual ones.

In the currently used theoretical IOL power calculation formulas, the keratometric index used ranged from 1.3315 to 1.3375.

This range of keratometric index values does not calculate the true corneal power.

However, these IOL power calculation formulas have been optimized to account for the priori error in keratometric index (and the total corneal power) by calculating against actual post–cataract surgery refractive outcome

e.g., optimizing the A constant (SRK/T) and surgeon factor (Holladay 1)

Determine post-refractive surgery corneal power by direct measurement

Savini method: Kpost = (the simulated K value obtained by corneal topography × 376/337.5) [≅1.114] - 4.98

modified Maloney method: Kpost = 1.114 × (central power on axial topography map) −6.1

[inaccurate on Placido-based topography]

Determine post-refractive surgery corneal power by direct measurement

Shammas clinically-derived method Kpost = 1.14 × (Sim-K on topogeraphy or K on autorefractor) – 6.8

(used in Shammas-PL formula)

BESSt formula : based on the Pentacam measurement and Gaussian optics formula

Gaussian optics formula in determining corneal power

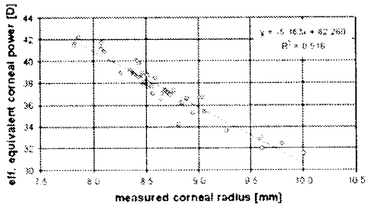
$$P_{actual} = \frac{n_c - 1}{r_{ant}} + \frac{n_a - n_c}{r_{post}} - \frac{d}{n_c} \times \left(\frac{n_c - 1}{r_{ant}}\right) \times \left(\frac{n_a - n_c}{r_{post}}\right)$$

BESSt formula
(2006, Borasio)

Determine post-refractive surgery corneal power by direct measurement

Haigis-L formula (in IOLMaster)

$$r_{corr} = \frac{331.5}{-5.1625 \times r_{meas} + 82.2603 - 0.35}$$



Why –6.1 D in modified Maloney method and –4.98 D in Savini method

Table 2. Summary of corneal parameters.

Parameter	Mean ± SD	Range	P Value*
r_{ant} (mm)	7.75 ± 0.28	7.06–8.49	.782
r_{post} (mm)	6.34 ± 0.28	5.62–7.00	.970
r_{simK} (mm)	7.75 ± 0.27	7.05–8.46	.905
AP ratio	1.223 ± 0.034	1.086–1.391	.299
Pachymetry (μm)	567.8 ± 36.0	450–684	.251
n_{cal}	1.3281 ± 0.0018	1.3209–1.3363	.047

AP ratio = ratio of the radius of the best-fit sphere for the anterior corneal elevation to the radius of the best-fit sphere for the posterior corneal elevation in the central 4.0 mm; n_{cal} = calculated keratometric index based on the Gaussian paraxial power; r_{ant} = radius of the best-fit sphere for the anterior corneal elevation in the central 4.0 mm; r_{post} = radius of the best-fit sphere for the posterior corneal elevation in the central 4.0 mm; r_{simK} = mean radius of the simulated keratometry
*Kolmogorov-Smirnov test

Why –6.1 D in modified Maloney method and –4.98 D in Savini method

Table 1A. Corneal power after myopic refractive surgery [illegible]

Parameter	History (tp)	BESSt	GOF	BESSt (Abs)	GOF (Abs)
Corneal power (D)					
Mean ± SD	39.15 ± 2.00	39.17 ± 2.06	37.73 ± 1.92	...	...
Range	34.53 to 45.08	34.61 to 45.78	31.52 to 44.09	...	...
Corneal power Δ (D)					
Mean ± SD	...	−0.01 ± 0.55	−1.45 ± 0.56	0.41 ± 0.37	1.45 ± 0.5[illegible]
Range	...	−2.21 to 1.52	−3.58 to 0.33	0.05 to 2.21	0.13 to 3.5[illegible]

Δ = difference between corneal power values estimated with each technique and the reference values obtained with the clinical history method; Abs = absolute values; GOF = Gaussian optics formula; History (tp) = history technique with corneal power referenced at the corneal plane

Why –6.1 D in Maloney method and –4.98 D in Savini method

Table 3. Mean values for the total corneal power calculated with different keratometric indices; the mean and absolute estimation errors from the actual total corneal power (P_{actual}) and the percentage of eyes within ±0.50 D of estimation error.

Parameter	P_{actual}	P_{cal}	$P_{Gullstrand}$	P_{conv}
Total corneal power (D)				
Mean ± SD	42.39 ± 1.54	42.38 ± 1.58	42.81 ± 1.52	43.59 ± 1.55
Range	38.43 to 46.30	38.79 to 46.55	39.18 to 47.02	39.89 to 47.87
Estimation error for total corneal power (D)				
Mean ME ± SD	...	0.00 ± 0.24	0.43 ± 0.23	1.21 ± 0.24
Error range	...	−1.18 to 0.87	−0.64 to 1.27	0.17 to 1.99
Within ±0.50 D (%)	...	85.0	60.2	0.9
Mean MAE ± SD	...	0.17 ± 0.17	0.45 ± 0.23	1.21 ± 0.24
Error range	...	0.00 to 1.18	0.00 to 1.27	0.17 to 1.99

MAE = mean absolute estimation error; ME = mean arithmetic estimation error; P_{actual} = actual total corneal power with Gaussian paraxial optics formula; P_{cal} = total corneal power calculated with the mean keratometric index derived in this study (1.3281); P_{conv} = total corneal power calculated with the conventional keratometric index of 1.3375; $P_{Gullstrand}$ = total corneal power calculated with the keratometric index derived from the Gullstrand schematic eye (1.3315)

Effective lens position (ELP: IOL position) estimation without using Kpost

Shammas –PL formula (fudged formula)

Kc = 1.14 × K − 6.8,

C = pACD = 0.5835 × A − 64.40.

The Shammas-PL formula is as follows:

$$\text{IOL power} = \frac{1336}{AL - 0.1(AL - 23) - (C + 0.05)} - \frac{1}{\frac{1.0125}{Kc + R} - \frac{C + 0.05}{1336}},$$

where R is the target refraction at the corneal plane.[12]

Haigis and Haigis-L formulae (not using corneal curvature in estimating ELP)

The optical ACD d is given by

$d = a0 + a1\ AC + a2\ L$ for $AC \neq 0$

Haigis formula (not using corneal curvature in estimating ELP)

$D_L = \frac{n}{L-d} - \frac{n}{\frac{n}{z}-d}$ with $z = D_C + \frac{R_Y}{1-R_Y \, d_x}$ and

$D_C = \frac{n_C - 1}{R}$

The optical ACD d is given by

$d = a0 + a1\ AC + a2\ L$ for $AC \neq 0$

ELP estimation by SRK/T

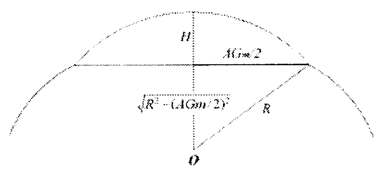
$ELP = H + ACDconst - 3.336$

$H = R - \sqrt{R^2 - (Cw/2)^2}$ (Fyodorov equation)

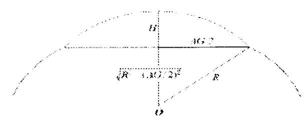
Corneal height (Fyodorov equation)

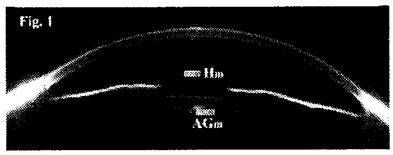
$H = R - \sqrt{R^2 - (AG/2)^2}$

AG : anterior chamber diameter



Get Hm and AGm by Pentacam (rotating Scheimpflug camera)





Ht (theoretical) vs. Hm (measured)

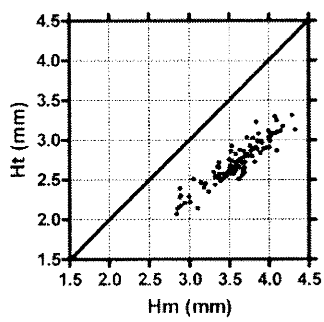
$Ht = Rm - \sqrt{Rm^2 - (AGm/2)^2}$

Hm (corneal height measured by Pentacam)

If Ht $\simeq$ Hm, then ELP can be obtained easily by

ELP = Ht + ACDconst - 3.336

ELP $\simeq$ Hm + ACDconst - 3.336



$r = 0.904\ (p < 0.0001)$

Ht (theoretical) vs. Hm (measured)

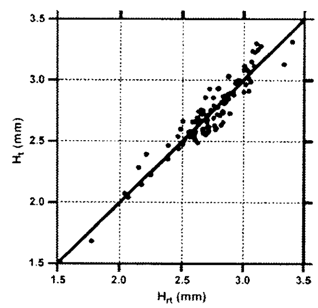
To correlate Ht with Hm, a linear regression function *f* was developed, the value of which is Hrt (to approximate Ht); Hm, AGm, and AL can be obtained by measurement

$$H_t \cong H_{rt} = f(H_m, AG_m, AL)$$

Regression function (Hrt) which is aimed to approximate Ht

The regression function obtained from 106 unoperated eyes by stepwise linear regression was

$$Hrt = 0.4979H_m + 0.2425AG_m - 0.0141AL - 1.5672(r = 0.941)$$



Rrt (R derived by regression) to approximate Rm (Rpre)

$$H_{rt} = R_{rt} - \sqrt{R_{rt}^2 - (AG_m/2)^2}$$

then $\sqrt{R_{rt}^2 - (AG_m/2)^2} = R_{rt} - H_{rt}w$

By squaring both sides,

$$R_{rt}^2 - AG_m^2/4 = R_{rt}^2 - 2R_{rt}H_{rt} + H_{rt}^2$$

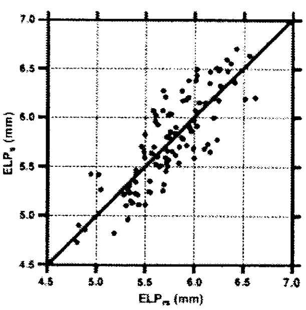
$$2R_{rt}H_{rt} = H_{rt}^2 + AG_m^2/4$$

$$\therefore R_{rt} = \frac{4H_{rt}^2 + AG_m^2}{8H_{rt}}$$

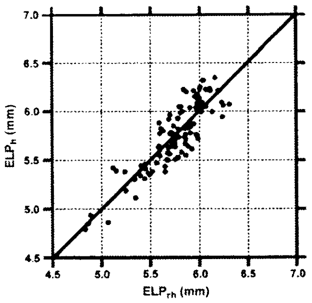
Using Rrt (which is aimed to approximate Rm or Rpre) to develop ELP in SRK/T

$$H_{rs} = R_{rt} - \sqrt{R_{rt}^2 - (Cw/2)^2}$$

$$ELP_{rs} = H_{rs} + ACD_{const} - 3.336$$



Mean estimation error = −0.011±0.263 mm



Mean estimation error = -0.004 ± 0.167 *mm*

- Obtain Kpost from other well-established methods (the Savini method and the BESSt formula) for 11 post-refractive surgery eyes which require cataract surgery
- Calculate the IOL power in a double-K manner in these 11 post-refractive surgery eyes even when historical data are unavailable

The Savini's method

Kpost = measured K × 376/337.5 - 4.98

The BESSt formula

Kpost is calculated based on the Pentacam measurement and Gaussian optics formula.

Results

Application on post-refractive eyes undergoing cataract surgery

11 eyes of 8 patients

our ELP estimation method, combined with the BESSt formula or the Savini's method for estimating Kpost in the Double-K SRK/T formula [(ELP + BESSt + Double-K SRK/T), or (ELP + Savini's + Double-K SRK/T)] provided the best IOL prediction results

Arithmetic and absolute IOL prediction error in 11 post-refractive surgery eyes

Table 3. Mean arithmetic and absolute IOL prediction errors using different methods not requiring data from before refractive surgery (implanted IOL power − predicted IOL power).

Method	DK ELP + Savini	DK ELP + BESSt	SK Rosa	SK Ferrara	SK Savini	SK BESSt	DK CHM	Shammas'
Holladay 1								
ME								
Mean ± SD	1.19 ± 0.71	1.10 ± 0.75	−1.56 ± 3.40	−6.16 ± 6.10	2.46 ± 0.96	2.39 ± 1.02	1.15 ± 1.37	1.06 ± 1.95
Range	0.16 to 2.60	0.12 to 2.50	−8.04 to 1.97	−18.47 to −0.49	1.50 to 4.42	1.10 to 4.35	−0.77 to 4.05	−1.67 to 4.38
MAE								
Mean ± SD	1.19 ± 0.71	1.10 ± 0.75	2.36 ± 2.84	6.16 ± 6.10	2.46 ± 0.96	2.39 ± 1.02	1.32 ± 1.19	1.59 ± 1.50
Range	0.16 to 2.60	0.12 to 2.50	0.09 to 8.04	0.49 to 18.47	1.50 to 4.42	1.10 to 4.35	0.06 to 4.05	0.09 to 4.38
SRK/T								
ME								
Mean ± SD	0.03 ± 0.73	−0.05 ± 0.62	−1.56 ± 3.58	−5.98 ± 6.22	2.34 ± 1.04	2.25 ± 1.10	−0.10 ± 1.49	…
Range	−1.18 to 1.19	−0.87 to 1.09	−8.35 to 2.05	−18.51 to −0.30	1.17 to 4.37	0.75 to 4.30	−2.24 to 2.69	
MAE								
Mean ± SD	0.60 ± 0.36	0.49 ± 0.34	2.46 ± 2.98	5.98 ± 6.22	2.34 ± 1.04	2.25 ± 1.10	1.11 ± 0.91	…
Range	0.05 to 1.19	0.07 to 1.09	0.35 to 8.35	0.30 to 18.51	1.17 to 4.37	0.75 to 4.30	0.20 to 2.69	

Eyes within certain refractive prediction error in 11 post-refractive surgery eyes

Method	Number of Eyes							
	DK ELP + Savini	DK ELP + BESSt	SK Rosa	SK Ferrara	SK Savini	SK BESSt	DK CHM	Shammas
Holladay 1								
Within ±0.5 D	2	4	4	1	0	0	3	3
Within ±1.0 D	8	7	5	2	0	2	5	7
Within ±2.0 D	10	11	9	3	6	8	8	9
SRK/T								
Within ±0.5 D	8	7	4	1	0	1	5	0
Within ±1.0 D	10	11	5	2	4	7	6	0
Within ±2.0 D	11	11	9	4	7	11	9	0

DK = double-K method; DK CHM = double-K clinical history method; ELP = effective lens position estimation with our method; SK = single-K method

Discussion

The improvement in IOL power prediction accuracy made by the double-K method indicates that Kpre is more valuable than Kpost for estimating the ELP

This is the reason why we managed to obtain an estimate of Kpre (Krt) from the independent variables Hm, AGm, AL, which were not changed by refractive surgery and can be obtained by measurement on a post-refractive surgery eye

Discussion

Any method which estimates ELP and IOL power from only Kpost and axial length is susceptible to unacceptable error.

e.g.

Kpost = 36 D , AL = 26 mm can be from

ablation of 4 D on an eye with Kpre = 40 D

ablation of 9 D on an eye with Kpre = 45 D

Discussion

In this example, when using SRK/T formula, the ELP and IOL differ greatly

(for A = 118.4)

ELPs = 5.06 vs. 6.31 mm (Δ = 1.25 mm)

IOLp = 22.37 vs. 24.73 D (Δ = 2.36 D)

Discussion

Single-K Rosa's method provided good IOL prediction results in 5 of 11 eyes

In 2 eyes (cases 3 and 4) with high under corrections after the previous refractive surgery (residual refractive error: -11.0 and –11.75 D), both Rosa's and Ferrara's methods gave unacceptably high IOL prediction errors (-7.83 to –8.35 D for Rosa's method, –17.56 to -18.51 D for Ferrara's method)

TABLE 1. IOL Prediction Errors (Implanted IOL Power – Predicted IOL Power)* Using Different Methods (Units: Diopter)

Method	DK CHM + SRK-T	SK Rosa + SRK-T	SK Ferrara + SRK-T	Shammas
od	−0.66	−8.07	−17.56	−1.67
os	−0.81	−8.35	−18.51	−0.74

*A positive value indicates that the method predicts an IOL of lower power than the power of the implanted IOL, which would leave the eye hyperopic. A negative value indicates that the method predicts an IOL of higher power than the power of the implanted IOL, which would leave the eye myopic.

DK CHM, double-K clinical history method; IOL, intraocular lens; SK, single-K method; SRK-T, SRK-T IOL calculation formula.

Our ELP estimation method augmented the IOL prediction accuracy of the Kpost estimation method like the Savini's or the BESSt formula that gave Kpost estimates very close to the actual Kpost.

Further investigations are required to evaluate whether our method can be applied to patients with various amounts of residual refractive errors after previous refractive surgery (especially residual hyperopia).

Radial keratotomy (RK)

Posterior corneal curvature changes with RK (in contrast to LASIK, LASEK, PRK)

Original double-K method may not be applicable in ELP estimation because the relationship between ELP_{post} and K_{pre} may be altered

IOL prediction errors in 4 post-RK eyes

Methods/Eye	1	2	3	4	ME	MAE
Shammas	-1.94	-3.4	-3.64	-8.2	-4.30±2.71	4.30±2.71
Haigis-L	-2.67	-2.16	1.09	-1.01	-1.19±1.67	1.73±0.82
Savini + ELP + SRK/T	-1.06	-2.42	1.08	-1.06	-0.87±1.45	1.41±0.68
BESSt + ELP + SRK/T	-0.74	-2.75	1.14	1.97	-0.10±2.10	1.65±0.89

Summary

Methods	Characteristics
Double-K clinical history	need Kpre, REFpre, REFpost
Bypass method	need Kpre, REFpre, REFpost
Shammas	Simple, need no other instrument, ELP estimate by AL only
Haigis-L	need IOLMaster, ELP estimate by ACD, AL
Savini Kpost + ELP estimation + SRK/T	need Pentacam; complex calculation; ELP estimate by corneal height, AC diameter, and AL
BESSt Kpost + ELP estimation + SRK/T	need Pentacam; complex calculation; ELP estimate by corneal height, AC diameter, and AL

Thank You