·Clinical Research·

Practical method to calculate post-LASIK corneal power: the Actual K_{a+p} method

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Abstract

• AIM: To evaluate the accuracy of a practical method (the Actual K_{a+p} method) of corneal power measurement for post-LASIK eyes undergoing cataract surgery.

• METHODS: Ten eyes of 7 patients (4 male, 3 female, average age 50.10 ±4.01 years, with -11.01 ±3.55D mean refraction before LASIK), underwent post-LASIK phaco+IOL cataract surgery. We used the posterior corneal curvature as measured by the Pentacam in a method we named Actual K_{a+p} to calculate the post-LASIK corneal power for IOL calculation. The refractive outcomes after cataract surgery were evaluated. The Actual K_{a+p} was compared with the back-calculated corneal power (BCK), which was thought to be the benchmark of true corneal power. The corneal power estimated by other published methods, including Maloney, Shammas, Koch-Maloney, Savini, and McCulley, together with the true net power and equivalent K reading (EKR) as found by the Pentacam were also compared with the BCK.

• RESULTS: All eyes achieved satisfied refractive status after cataract surgery. The difference between the postoperative refraction and the target refraction was 0.04±0.40D, range from -0.63D and +0.85D. Among all the methods we studied, although the Bonferroni multiple comparison tests did not detect significant differences between any two of them, the Actual K_{a+p} yielded the highest agreement with the BCK, with 80% of the eyes falling within ±0.5D and 100% within ±1.0D from the BCK values.

• CONCLUSION: The Actual K_{a+p} method can provide encouraging results in post-LASIK eyes undergoing cataract surgery.

• KEYWORDS: corneal power measurement; LASIK; anterior and posterior corneal curvature; Pentacam

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INTRODUCTION

An increasing number of patients who have undergone LASIK are now developing symptomatic cataracts requiring surgery. Erroneous determination of post-LASIK corneal power makes it difficult to ensure an accurate refractive outcome following cataract surgery. The determination of intraocular lens (IOL) power in these patients continues to be a therapeutic dilemma for cataract surgeons.

Over the past decade, more than 20 formulas and methods have been devised to more accurately determine IOL power after keratorefractive surgery. As these methods have not been clinically studied with a large sample size and some are based upon theory alone, no method has emerged as superior [2,6,14,18,19,21]. The historical method, which requires pre-refractive surgery data, is often thought of as the best approach. But since the duration between the LASIK and cataract procedures often extends to more than 10 years and because the second surgery will often be performed by a different surgeon, LASIK history data, including both corneal power and refraction pre- and post-LASIK surgery, are difficult and sometimes impossible to obtain in many cases. An ideal method would be one that could accurately determine corneal power without pre-LASIK data. True corneal power can be determined if anterior and posterior corneal curvatures can be directly measured [5]. Direct measurement of posterior corneal curvature is now possible by developed machines like Orbscan, Pentacam *et al.* We recently developed a method of post-LASIK corneal power

Table 1 Corneal power estimating equations only dependent on post-LASIK K reading

Methods	Equation	K_{post}	Derive from
Maloney[2]	$P=1.114\ K_{post}-4.9$	$ACCP_{3mm}$	A+PCC
Shammas[3]	$P=1.14\ K_{post}-6.8$	SimK	Regression analysis
Koch-Maloney[2]	$P=1.114\ K_{post}-6.1$	EffRP	A+PCC
Savini[4]	$P=1.114\ K_{post}-4.98$	SimK	A+PCC
McCulley 1[5]	$P=1.114\ K_{post}-6.062$	SimK	Regression analysis
McCulley 2[5]	$P=1.151\ K_{post}-6.799$	$ACCP_{3mm}$	Regression analysis

A+PCC= separate evaluation of anterior and posterior corneal curvatures; EffRP= effective refractive power of the cornea

calculation using the information of the posterior corneal power as measured by the Pentacam to calculate the IOL power for cataract surgery. We named this the Actual K_{a+p} method. The Pentacam (Oculus, Lynnwood, WA) is an instrument that uses a rotating Scheimpfulg video camera to obtain over 25 000 true elevation points for both the corneal front and back surfaces, from limbus to limbus. These images of the posterior cornea are a more accurate representation of the posterior corneal topography [13,20]. Because standard topographers and keratometers do not measure the cornea's back radius of curvature, most of the corneal power calculating equations currently in use require using a constant for the mean posterior curvature. Using direct posterior corneal curvature measurements from the Pentacam eliminates the use of an extrapolated constant value. In this retrospective study, we evaluated the refractive outcomes following cataract surgery in 10 post-LASIK eyes to evaluate the effectiveness of the Actual K_{a+p} method in patients whose LASIK history data were not completely available. We also compared this method with the back-calculated corneal power, which we thought to be the benchmark for true corneal power, and with other popular corneal power estimation methods.

MATERIALS AND METHODS

Materials Ten eyes of 7 patients who had previous myopic LASIK had uneventful phacoemulsification cataract surgery between Jun. 2006 and Aug. 2009. The same cataract surgery procedure was used in all cases, and the same experienced surgeon did all the surgeries. A corneal incision was made and a capsulorrhexis was created. Phacoemulsification was then performed after hydrodissection, followed by placement of the IOL (Acrysof SN60AT, ALCON Laboratories. Inc., or AMO AR40e, Advanced Medical Optics. Inc.) into the bag.

IOL Calculation In each case, the pre-LASIK K-value and the amount of myopic correction were not completely available at the time of the cataract surgery. The axial length (AL) was determined by applanation ultrasound (CineScan A/B Ultrasound, Quantel Medical, Inc., France). The simulated keratometric values (SimK) and the average central corneal power over the central 3.0mm Placido ring ($ACCP_{3mm}$) were evaluated using the Humphrey Atlas corneal topographer (Carl Zeiss Meditec, Jena, Germany). The mean power of the posterior corneal surface (Cornea back Km), the central corneal power (true net power), and the 2mm, 3mm, 4.5mm equivalent K readings (EKR) were measured by the Pentacam. The Pentacam calculates the central corneal power using the BESSt Corneal Power Calculator, an improved version of the Gaussian Optics Formula for Paraxial Imagery. The calculator uses the cornea's anterior and posterior radius of curvature and central thickness values to determine the true central corneal power.

For each eye, we used the Actual K_{a+p} method to calculate corneal power. It is based on the assumption that the total refractive power of the cornea can be calculated by adding the powers of the anterior and posterior corneal surfaces. The power of the anterior corneal surface can be derived from the measured corneal power by the following formula:

P_a= measured K* [(1.376-1.000)/ (n-1.000)]=measured K* 1.114(for n=1.3375 by Humprey Atlas corneal topographer).

The actual corneal power can be calculated as follows:

Actual $K_{a+p}=P_a+P_p=1.114K_{post}+K_p$

Where

P_a= power of the anterior corneal surface after refractive surgery

P_p= power of the posterior corneal surface after refractive surgery

K_{post}= $ACCP_{3mm}$ measured by Humphrey Atlas after refractive surgery

K_p= cornea back Km measured by Pentacam after refractive surgery

The IOL power was calculated using the SRK/T formula. The target post-phacoemulsification refractions were set to achieve a plano result in most cases. The refractive outcomes after cataract surgery were evaluated. The Actual K_{a+p} was compared with the back-calculated corneal power (BCK). The suggested corneal power estimated by the following published methods, together with the true net power and EKR from Pentacam were also compared with the BCK (Table 1).

Table 2 Preoperative and postoperative data for each patient

Cases	Eye	Sex	Age (yr)	Q(D)	AL (mm)	K_{back}	IOL (D)	Pre-ph UCVA (log_{MAR})	Post-ph UCVA (log_{MAR})	Post-ph SE (D)	△SE (D)	Time RS-Ph (yr)
Case 1	L	F	49	-17.	30.7	-8.60	23	1.1	0.5	-2.75	-0.1	7
Case 1	R	F	52	-10.25	29.88	-6.59	14	1.0	0.1	-0.5	-0.63	10
Case 2	R	F	55	-10.75	27.67	-5.50	18.5	0.7	0.1	-0.5	-0.12	7
Case 2	L	F	55	-13.25	28.51	-6.11	20	0.7	0.1	0.75	0.85	7
Case 3	R	M	51	-11.5	29.04	-5.51	18	1.0	0.3	-0.75	0.26	8
Case 4	R	M	55	-15.25	31.12	-5.40	15	1.0	0.1	-1	0.11	10
Case 5	R	F	46	-10	27.89	-5.31	18.5	0.5	0	-0.5	0.4	5
Case 6	R	M	46	-8.75	28.26	-6.51	18	0.7	0	0	-0.12	3
Case 6	L	M	46	-8.75	28.1	-6.61	18.5	1.0	0	0	-0.09	3
Case 7	R	M	46	-4.5	25.65	-6.81	19	1.0	0.2	-0.25	-0.15	6
Mean			50.10	-11.01	28.68	-6.29	18.25	0.87	0.14	-0.55	0.04	6.60
SD			4.01	3.55	1.60	0.99	2.47	0.20	0.16	0.91	0.40	2.46

Ph=phacoemulsifiation; RS=refractive surgery; SE=spherical equivalent; AL= axial length; Q=mean refractive error before LASIK; K_{back}=cornea back Km measured by Pentacam; △SE =difference between the postoperative SE and Target SE (Post-ph SE-Target SE)

Table 3 Comparison of the estimated K value using different methods to the BCK

Methods	Mean±SD(D)	95% LoA *vs* BCK(D)	Variance from BCK (Method-BCK)		
			≤±0.5D	≤±1.0D	≤±1.5D
BCK	33.79±3.02	—	—	—	—
Actual K_{a+p}	33.82±2.96	-0.56 to +1.11	80	100	100
Maloney	35.21±2.62	-0.48 to +3.31	20	50	50
Savini	35.14±2.63	-0.55 to +3.24	20	50	50
Koch-Maloney	34.02±2.63	-1.69 to +2.13	30	90	90
Shammas	34.25±2.69	-1.41 to +2.32	20	70	90
McCulley	34.65±2.71	-1.00 to +2.71	50	50	70
True net power	32.93±2.89	-3.88 to +2.15	10	30	60
1mm EKR	34.22±2.59	-2.64 to +3.51	40	60	60
2mm EKR	34.31±2.72	-2.68 to +3.71	50	60	60
3mm EKR	34.72±2.57	-2.06 to +3.92	40	50	70
4.5mm EKR	35.72±2.22	0.87 to +4.72	10	40	40

BCK = back-calculated K-value using the SRK/T formula

Benchmark We used the back calculated corneal power as our benchmark for the true corneal power [12]. Manifest refraction was measured at 1 month after cataract surgery. To determine the BCK values, post-phacoemulsification refractive data were entered into the SRK-T IOL formula, which corrects for residual postoperative refractive error without altering other preoperative biometry values.

Statistical Analysis Statistical analyses were performed using SPSS (version 13.0). A P value less than 0.05 was considered statistically significant. A one-way analysis of variance (ANOVA) for repeated measures with Bonferroni multiple comparisons was used to compare all corneal power measurements. The agreement between the BCK and the Actual K_{a+p} and the corneal power measured by other methods was analyzed according to the method described by Bland *et al* [3]. The 95% limits of agreement (LoA) were defined as the mean difference ±1.96SD of the difference between the 2 values. A P value less than 0.05 was considered statistically significant.

RESULTS

The mean age of the 4 men and 3 women was 50.10 ±4.01 years (SD) (range 46 to 55 years). The mean refraction before LASIK was -11.01 ±3.55D. The mean time span between refractive surgery and cataract surgery was 6.6±2.46 years. All eyes achieved satisfied refractive status after cataract surgery. The difference between the postoperative refraction and the target refraction was 0.04±0.40D, range from -0.63D and +0.85D. Preoperative and postoperative data for each patient are shown in Table 2. A comparison of the estimated corneal power found using different methods to the BCK, as well as the variance in values from the BCK using different methods are shown in Table 3 and Figure 1.

The mean BCK was 33.79±3.02D, which was lower than the corneal power determined using the other methods, with the exception of the true net power. However, the Bonferroni multiple comparison tests did not detect significant differences between any two of them. Analysis of the 95% LoA showed that the Actual K_{a+p} yielded the highest

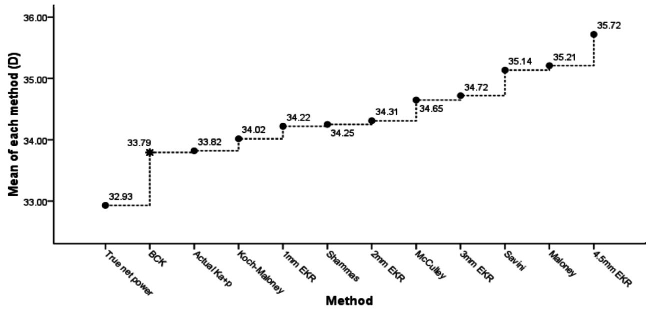

Figure 1 Comparison of the BCK to the estimated K value using different methods

agreement with the BCK, and 80% of the eyes were within ±0.5D and 100% were within ±1.0D from the BCK.

DISCUSSION

The number of patients who have had excimer laser refractive surgery and present for cataract surgery is sure to increase in the future. For these patients, an accurate IOL power calculation is critical to achieve high satisfaction postoperatively. The preoperative keratometric power and the exact amount of refractive correction may be regrettably unavailable for many cases. In some instances, patients may not even recall having LASIK when they present for cataract surgery years later.

Several methods to estimate the corneal power for patients lacking pre-LASIK data have been reported. The contact lens method has been recommended but the limitation of this method when applied in patients with reduced vision induced by the cataract and its low accuracy confirmed by clinical studies make it far from popular [1,6,7,19,21,22]. The aphakic refraction technique has been described by Ianchulev *et al* [8] and Mackool *et al* [10]. Using this technique, postoperative refractive results in small groups of patients seem excellent. The main disadvantages of the Mackool method are that the pause required for refraction interrupts the flow of the operating procedure and more time and effort is required on the part of surgical staff [15]. When neither the original K readings nor the corrected amount of myopia are known, we can also choose among the Shammas equation [18], Savini equation [14], McCulley equation [2], and the Maloney method based on separate consideration of anterior and posterior corneal curvature [14,21]. All these methods use post-LASIK corneal power data, and they use a similar formula: y=bx+k. Interestingly, most of the regression equations are very similar to the A+PCC formula. Many studies demonstrate that methods using the A+PCC formula may provide satisfactory results. The study by Savini *et al* [16] showed that the A+PCC method yielded the highest agreement with the clinical history method. In the study done by Wang *et al* [21], the Maloney method underestimated the IOL power and resulted in postoperative hyperopia. However, the variances in the IOL prediction error were significantly smaller than those found by the clinical history method, indicating that with appropriate modification, this method may provide more consistent results. In the study done by Savini *et al* [14], the Savini method provided the most accurate results. Because the posterior corneal curvatures were not available in those studies, the posterior corneal power in the A+PCC method is assumed to be fixed. In a study enrolling 263 normal participants, Seitz *et al* [17] used the Orbscan topography analysis system to measure *in vivo* the posterior surface keratometric diopters, finding a wide interindividual variability from -4.6D to -7.6D (-6.2±0.5). In our study using the Pentacam, *in vivo* measurements of the posterior surface keratometric diopters of post-LASIK eyes ranged from -5.31D to -8.60D (-6.29±0.99). This wide variation shows that simply adding the mean value of the posterior surface keratometric diopters to the anterior surface keratometric diopters may cause a considerable error in any given patient[18]. It also indicates that using a fixed constant for the posterior surface power may be inadequate.

Our data suggest that the Actual K_{a+p} method provides the highest accuracy in achieving postoperative emmetropia, as is demonstrated by the fact that 100% of the eyes were within ±1.0D and that 80% were within ±0.5D from the BCK. The fairly good results are not surprising, because we used the actual corneal back Km measured by the Pentacam in the A+PCC method, rather than using a constant for all eyes. The Pentacam uses a rotating Scheimpflug camera to ensure precise measurement of the anterior and posterior corneal surfaces. Using data provided by Pentacam is a logical approach to power calculation in eyes that have had corneal surgery, and it is an improvement over current methods[11].

There are three total corneal power measurements provided by the Pentacam: simulated keratometry (SimK), true net power, and EKR. The simulated K is higher than the real corneal power because it is calculated using the standard keratometric index (1.3375), which is known to overestimate corneal power after refractive surgery. The true net power was significantly lower than the values obtained with other methods and the BCK both in our study and in some former reports [4,16]. The reason may be that the true net power is calculated using the Gaussian optics formula that calculates the differences between the refractive indices of air (n =1), the cornea (n =1.376), and the aqueous humor (n =1.336). The negative posterior power of the cornea may not be taken into full account with the Gaussian optics formula [4]. In the theoretical study done by Savini *et al* [16], the EKR at 1.0mm, 2.0mm, and 3.0mm were more reliable than at 4.0mm and 4.5mm, with the 2.0mm EKR being closest to the clinical history method. Our clinical results revealed that the 1.0mm

EKR correlated best with the BCK compared to the EKR of other optical zones. The possible explanation for the discrepancy is that the sample sizes of both studies were not large enough.

The clinical history method has been used as the standard for true corneal power in many studies, and has been the suggested method to calculate IOL power post-LASIK when pre- and post-LASIK refractive data were available. However, it has also been reported to possibly lead to significant mistakes in IOL calculation [1,9,21]. In our opinion, we do not think this to be a perfect method, because a stable and precise refraction after refractive surgery is certainly not easy to obtain, and furthermore, one cannot promise that the cornea will maintain the same parameters until a cataract develops. With our Actual K_{a+p} method, the data obtained is fresh, and the corneal power calculated is very close to the back calculated true corneal power. We thus believe this method to be a superior option to those currently available. The corneal power measurement obtained with our method remains valid even in those patients who had greater than a 10D refractive correction and in those whose cataract surgery took place 10 years after the LASIK procedure, as is shown in Table 2.

For the K_{post} value, we opted to use the $ACCP_{3mm}$ measured by the Humphrey Atlas as opposed to the simulated keratometry value provided by the Pentacam because we have already successfully completed more than 10,000 IOL implantation surgeries using the $ACCP_{3mm}$ and the SRK/T formula and we are very familiar with its stable and repeatable data. Furthermore, the current IOL formulas are not based on data obtained from the Pentacam, but rather are based on keratometry data obtained with instruments that use a refractive index of 1.3375. If the keratometry system is altered, the constants within the IOL calculating formulas would subsequently need to be changed [11]. Thus, we prefer using the $ACCP_{3mm}$ value and the SRK/T formula instead of using simulated keratometry measured by Pentacam.

In our study, we employed the actual posterior surface curvature as measured by the Pentacam to calculate the intraocular lens power with a method based on the separate consideration of the anterior and posterior corneal curvatures. To our knowledge, this is the first time the Actual K_{a+p} method has been employed to calculate the intraocular lens power. Although our sample size was relatively small, we obtained encouraging results in most of these challenging patients. Further evaluation of this method in a larger series is needed to better gauge its validity.

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