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A regression model for correcting intraocular lens power after refractive surgery independent of preoperative data

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PURPOSE. *To find a method of calculating intraocular lens (IOL) power that may be independent of preoperative data in eyes that have previously undergone myopic laser in situ keratomileusis (LASIK).*

METHODS. *In 148 eyes of 75 patients, before and 6 months after LASIK, IOL power was calculated with SRK/T formula utilizing the spherical equivalent as the desired target refraction. Assuming that LASIK does not alter the crystalline lens refractive properties, IOL calculation error (CER) was estimated with this formula: CER = [pre-LASIK IOL power]/[post-LASIK IOL power]. Then the authors used postoperative biometry and Orbscan II corneal topography data in multiple regression models to find the best variables to predict the CER. Predicted amount of error which is calculated independent of preoperative data could be used to correct the post-LASIK calculated IOL: [corrected post-LASIK IOL power] = CER x [post-LASIK IOL power].*

RESULTS. *A regression model with these predictors was found: axial length in millimeters (L), radius of the anterior corneal surface best fitted sphere in millimeters divided by radius of the posterior corneal surface best fitted sphere in millimeters (AntBFS/PostBFS), corneal central 5 millimeters mean power in diopters divided by corneal central 3 millimeters mean power in diopters (mean 5 mm/mean 3 mm), the post-LASIK IOL power, and the post-LASIK simulated K reading. The model R square was 0.88.*

CONCLUSIONS. *There is correlation between post-LASIK biometry values and IOL power correction factor. This study presents a new model for further investigation. (Eur J Ophthalmol 2006; 16: 525-9)*

KEY WORDS. *Refractive surgery, LASIK, IOL power, Biometry*

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INTRODUCTION

As the current generation of patients who have undergone refractive surgery ages, the number of post-refractive surgery patients requiring cataract surgery and intraocular lens (IOL) implantation will increase within a few decades. Calculating the IOL power for an eye that has previously had keratorefractive surgery is a problem. The formulas and instruments make assumptions about the anatomy and refractive properties of the cornea that are no longer valid and may result in a “refractive surprise” after cataract surgery, which may require subsequent surgical correction (1).

After myopic laser in situ keratomileusis (LASIK), keratometry tends to overestimate the corneal power and consequently underestimate the IOL power (2-5). To overcome this problem several techniques have been proposed: history related methods require knowing the pre-

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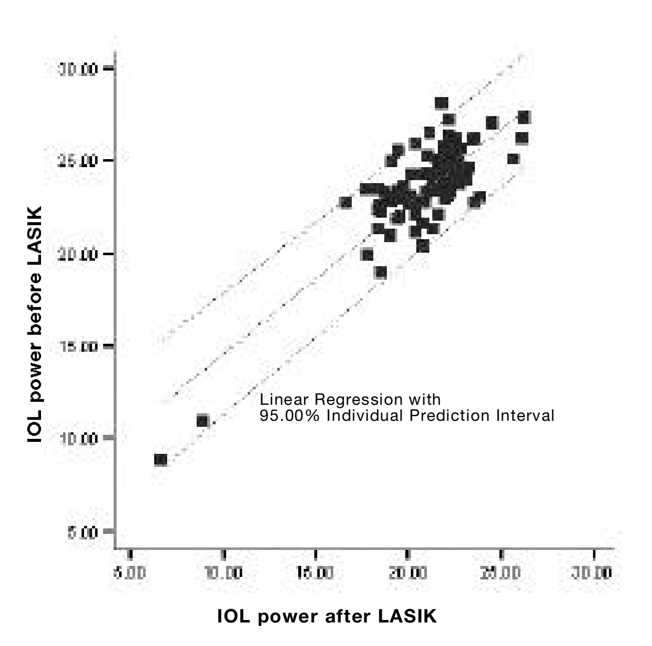

Fig. 1 - *Intraocular lens (IOL) power before laser-assisted* in situ *keratomileusis (LASIK) and IOL power after LASIK.*

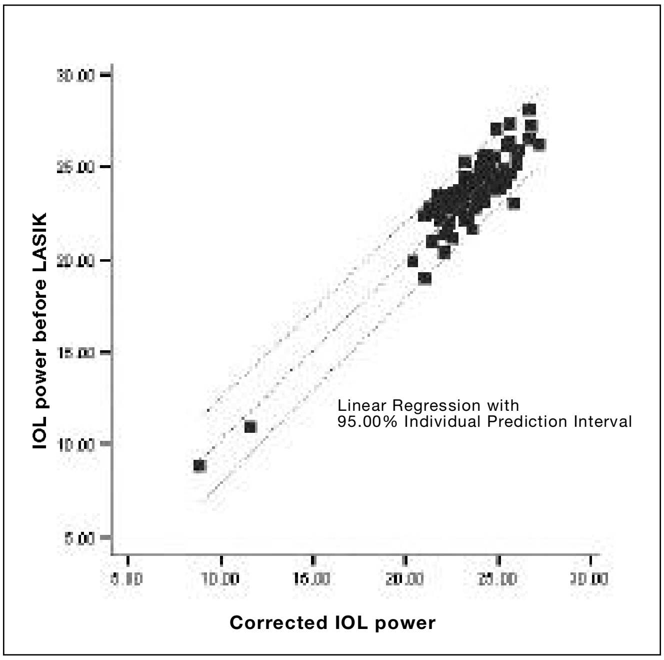

Fig. 2 - *Intraocular lens (IOL) power before laser-assisted* in situ *keratomileusis (LASIK) and corrected IOL power after LASIK.*

operative corneal power and the amount of refractive treatment on cornea that may be inaccessible in some cases, they depend on the accuracy of the refractive data; a plano hard contact lens over refraction, which has the limitation of availability, difficulty in obtaining an accurate refraction in presence of a cataract, and the residual myopia induced by the cataract. Computerized simulation of ocular refractive media and numerical ray-tracing may help in the future.

The purpose of this study was to develop a mathematical correction procedure for IOL power prediction that may be independent of preoperative data in eyes after myopic LASIK.

METHODS AND MATERIALS

A total of 148 eyes of 75 patients (30 men and 45 women) consecutively underwent LASIK for myopia or myopic astigmatism in a non-randomized, prospective clinical study. The age of the patients ranged between 19 and 39 years with mean ± SD age of 27.5 ± 6.4 years (Tab. I).

Patients were included if they were willing to participate in the study and returned for follow-up visits. They were asked to discontinue wearing contact lenses for at least 1 month before the refractive evaluation. Written informed consent was used routinely. Patients who had a previous ophthalmic surgery or ocular surface disorders were excluded from the study, as were patients with diabetes, uveitis, corneal and lens opacities.

Tetracaine 0.5% ophthalmic drops were instilled for topical anesthesia before surgery. Corneal flaps were created with Hansatome microkeratome (Bausch & Lomb, Rochester, NY); standard LASIK surgery was performed with Technolas® 217 z excimer laser (Bausch & Lomb). Patients received gentamicin 3% and betamethasone 0.1% ophthalmic drops four times daily for 1 week after surgery. Artificial tear drops were also used in the first week every 8 hours as needed.

Patients underwent a complete ophthalmic examination preoperatively, and 6 months after LASIK. Objective and subjective refraction achieving the best visual acuity in each visit was used to determine the refractive error. Combined slit-scanning and Placido-disk corneal video keratography with the Orbscan II corneal topography system (Bausch & Lomb-Orbtek Inc., Salt Lake City, UT) provided the corneal curvature data in pre- and postoperative visits; the diameter of the anterior and posterior best fitted sphere determination was 10 mm. We measured axial lengths in postoperative visits by ultrasound contact biometry (Nidek Echoscan US-1800, Nidek Inc.); the automatic phakic mode was used with 1532 m/sec ultrasound speed for the anterior chamber and vitreous and 1641 m/sec for the normal lens.

Before and 6 months after LASIK, IOL power was calculated with SRK/T formula. The formula was programmed into a spreadsheet program (Microsoft® Office Excel 2003) using the corrected version of the formula (6). We used simulated K reading (Sim K) of corneal topography, ocular axial length, the arbitrary A constant of 119, and the spherical equivalent of the eye at the time of examination as the desired target refraction to calculate the IOL (e.g., if a patient had a spherical equivalent refraction of -4.5 diopters before LASIK and -0.25 D after LASIK, we used as target -4.5 D before LASIK and -0.25 D after LASIK). Through this method we actually determine the subjects' own lens power. Assuming that LASIK does not alter the crystalline lens refractive properties, the pre- and post-refractive surgery powers should be the same unless errors in calculations ensue because of the surgery. Comparing pre- and post-surgery powers in this way reveals the calculation error as previously used to derive the correcting factor by Rosa et al (7, 8).

The calculation error (CER) was estimated with this formula:

CER = [pre-LASIK IOL power]/[post-LASIK IOL power]

Then we used postoperative biometry and Orbscan II corneal topography data in stepwise multiple regression model analysis with the goal to determine the best variables to predict the "CER" given in a generalized form as:

CER = a + bx + cy + …

where "CER" represents a dependent variable; "a" represents a constant term; "b," "c," … represent weighting factors, and "x," "y," … represent independent variables. To find better independent variables we also tried multiple products of the corneal topography values in the regression model. Thereafter, CER, which is calculated independent of preoperative data, could be used to correct the post-LASIK calculated IOL:

[Corrected post-LASIK IOL power] = CER x [post-LASIK IOL power]

Statistical analysis included stepwise regression model fitting made with the PC software program SPSS (SPSS Inc., Chicago, IL, USA) for Windows release 10.0.5.

TABLE I - PATIENT CHARACTERISTICS

	Male	Female	Total
Age <20 y	0 (0)	1 (1.3)	1 (1.3)
20–30 y	18 (24)	32 (42.6)	50 (66.6)
31–40 y	10 (13.3)	9 (12)	19 (25.3)
>40 y	2 (2.6)	3 (4)	5 (6.6)
Total n	30 (40)	45 (60)	75 (100)
Mean age, y	28.7	26.8	27.5

Values are n (%)

TABLE II - REFRACTION DIOPTERS (Mean ± SD)

	Sphere	Cylinder	Spherical equivalent
Before LASIK	-4.69±2.16	-1±1.16	-5.19±2.41
After LASIK	-0.25±0.61	-0.36±0.24	-0.45±0.64

LASIK = Laser-assisted *in situ* keratomileusis

TABLE III - CHARACTERISTICS OF REGRESSION MODEL PREDICTORS

	Coefficients	Beta
Constant	1.0474	
Axial length*	-0.01785	0.36
AntBFS/PostBFS†	0.54336	0.30
Mean 5 mm/mean 3 mm‡	2.47424	0.50
Post-LASIK IOL power§	-0.02097	0.66
Post-LASIK Sim K**	-0.00403	0.19

*Ocular axial length in millimeters
†Radius of the anterior corneal surface best fitted sphere in millimeters divided by radius of the posterior corneal surface best fitted sphere in millimeters
‡Corneal central 5 mm mean power in diopters divided by corneal central 3 mm mean power in diopters
§Post LASIK calculated intraocular lens power in diopters
**Simulated K reading of corneal topography after LASIK
LASIK = Laser-assisted *in situ* keratomileusis; IOL = Intraocular lens

RESULTS

Before LASIK, the spherical equivalent refraction of the patients ranged between -12 and -2.75 D (-5.19 ± 2.41, mean ± SD). Six months after LASIK the spherical equivalent ranged between -2.25 and +1 D (-0.45 ± 0.64, mean ± SD) (Tab. II).

Linear regression revealed a tiny correlation between IOL power before and after LASIK (R-square = 0.61); scatter plot of the powers before and after LASIK is shown in Figure 1.

Amount of error in calculation with postoperative values (CER) ranged between 0.96 and 1.36 (1.12 ± 0.08, mean ± SD). Postoperative biometry and Orbscan II corneal topography data were used in multiple regression models to predict the amount of error (CER).

A regression model with these predictors was found: ocular axial length in millimeters (L), radius of the anterior corneal surface best fitted sphere in millimeters divided by radius of the posterior corneal surface best fitted sphere in millimeters (AntBFS/PostBFS), corneal central 5 mm mean power in diopters divided by corneal central 3 mm mean power in diopters (mean 5 mm/mean 3 mm), the calculated IOL power after LASIK itself (post-LASIK IOL power), and the simulated K reading (post-LASIK Sim K) of corneal topography after LASIK. The model R square was 0.88, standard error of the estimate was 0.04. The coefficients are shown in Table III. Scatter plot of the IOL power before LASIK versus corrected IOL power after LASIK is shown in Figure 2. The regression formula was:

CER = -1.0474 -0.0178*[L] -0.0040*[post-LASIK Sim K] + 0.5433*[AntBFS/PostBFS] + 2.4742*[mean 5 mm/mean 3 mm] -0.0209*[post-LASIK IOL power]

We also analyzed other mathematical models of multiple regression, such as quadratic, cubic, or exponential regression formulas, which did not yield superior predictive results. Analyzing the subtracted value between pre and post LASIK IOL powers to calculate the error instead of CER ratio revealed a low predictive value using postoperative biometry and Orbscan II corneal topography data.

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 those persons, accurate IOL power calculation is critical to achieve high satisfaction postoperatively. The transformation of the cornea from a prolate into an oblate shape causes errors in the measurements of corneal vertex radii using a standard keratometer based on Gaussian optics. Keratometric power calculations are currently on the basis of Gullstrand's model eye and the refraction of a fictitious single refractive surface representing both the anterior and the posterior surface of the cornea. After refractive surgery, especially LASIK, a misrelation between anterior and posterior curvature of the cornea in comparison with the model eye causes corneal power overestimation correlated with the intended depth of ablation (9). The inaccurate radii measurement translates into overestimation of corneal refractive power, and leads to an underestimation of IOL power.

The preoperative keratometric power and the exact amount of refractive correction may be regrettably unavailable for some cases. In these cases, however, it is impossible to calculate the IOL power without error by means of the standard formulas.

There is a direct association between corneal shape, axial length, and refractive status. Refractive surgery systematically alters corneal shape to make change in the refractive status. We hypothesized that there may be some clues after LASIK to estimate the amount of induced systematic error in calculations. The error prediction model may not be simple. Different corneal shape factors and axial length should come into account to find a model.

We measured axial lengths only in postoperative visits assuming that the procedure does not alter the axial length. Two studies analyzing axial length before and after refractive procedure have found no significant differences (10, 11).

There is correlation between post-LASIK biometry values and IOL power correction factor. Axial length and radius of posterior corneal surface best fitted sphere are correlated with preoperative refractive status. Corneal topography values may be a representative for anterior corneal shape alteration due to LASIK. Although corneal power measurements including 5 and 3 mm mean power and Sim-K after LASIK are not accurate, they are shown to be correlated with the error of IOL calculation and could be utilized as correction factors to improve the predictive value of the regression model while they are related to the systematic corneal modification by refractive surgery. Finding a better corneal shape factor will improve the formula.

Rosa et al (7, 8) have revealed a correcting factor for calculating corneal radius according to axial length of the eye after photorefractive keratectomy; the method is independent of preoperative data; the corneal data are not used to improve the accuracy of results. The double-K method by Aramberri (12) is a rational solution to the problem; its limitation is the availability of the pre-refractive surgery K-value. Ferrara et al (13) have proposed a theoretical variable refractive index correlated with axial length, providing the correct keratometric power after refractive surgery. Feiz et al (14) suggested a nomogram-based power adjustment according to the change in spherical equivalent induced by refractive surgery. The clinical history method and its subsequent modification (15-17) is easy to calculate when preoperative data are available.

It seems possible to find a way to correct the IOL power when preoperative data are unavailable. It can be useful whether it is used as a primary or just as a second check method. Our results are not complete and practical, they need to be refined and confirmed with larger sample size in different centers. On the other hand, evaluating the actual outcome in patients who have already undergone cataract surgery after LASIK is another essential task. This study presents a new successful model for further investigation. There is still a need for a large prospective investigation to validate the authors' findings and to understand all factors and to find the best variables. Further prospective studies with patients who will undergo cataract surgery might demonstrate the validity of our findings. After validation of the regression parameters in a large representative study this correction may enhance the predictability of refraction results after cataract surgery in this group of patients.

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