

Intraocular Pressure Calculation in Myopic Patients After Laser-Assisted In Situ Keratomileusis

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Hazem Helmy¹
Omar Hashem²

¹Glaucoma and Optic Nerve Disease Department, Research Institute of Ophthalmology, Giza, Egypt; ²Cornea and Refractive Surgery Department, Research Institute of Ophthalmology, Giza, Egypt

Background: Corneal refractive surgery is widely used worldwide. Myopia is the most common reason for laser-assisted corneal refractive surgery (LASIK) and one of the risk factors for glaucoma. Intraocular pressure (IOP) measurement becomes variable postoperatively as the results are affected by the decrease in corneal thickness and biomechanics. This prospective clinical case study attempted to establish a simple correction formula for the calculation of IOP in post-LASIK myopic patients.

Methods: This study included 300 eyes of 150 patients with myopia and myopic astigmatism as a refractive error who underwent LASIK. IOP was measured preoperatively and 6 months postoperatively. Preoperative and postoperative corneal thickness as well as ablation depth were measured. Statistical analysis was performed to detect the relationship between ablation depth and change in IOP. An attempt was made to construct a correction formula for the calculation of post-LASIK IOP.

Results: The age of the patients ranged between 18 and 50 (mean \pm SD 34.78 \pm 8.8) years. The spherical equivalent of refractive error ranged between -1.5 and -10 diopters. The mean IOP decreased significantly from 15.72 \pm 2.37 mmHg preoperatively to 11.71 \pm 2.24 mmHg postoperatively, with a mean difference of 4 \pm 1.75 mmHg ($p < 0.001$). A positive correlation was detected between corneal thickness and IOP difference among patients both preoperatively and postoperatively ($p < 0.001$). A positive correlation was identified between ablation depth and IOP change ($p < 0.001$). The correction formula for IOP was established: Real IOP = 4 + 0.7(preoperative IOP) - 0.3(ablation depth).

Conclusion: IOP measurements change after corneal refractive surgery with LASIK. A corrected formula may be a good option for the proper calculation of post-LASIK IOP.

Keywords: intraocular pressure calculation, post-LASIK glaucoma, Goldmann applanation tonometry, glaucoma, laser in situ keratomileusis

Introduction

Corneal refractive surgery is a valuable tool used worldwide.¹ A technique known as laser-assisted corneal refractive surgery (laser-assisted in situ keratomileusis [LASIK]) is most commonly used for the treatment of myopia.² Myopia is a key risk factor for glaucoma, and necessitates regular monitoring of intraocular pressure (IOP) to mitigate this risk.³ Indeed, IOP is a major consideration in both the detection and follow-up of glaucoma, with elevated IOP being the most modifiable risk factor for both glaucoma development and progression.⁴ Accurate measurement of estimated and corrected IOP is vital for the diagnosis, treatment, and

Correspondence: Hazem Helmy
Email hazem.helmy@yahoo.com

follow-up of glaucoma.^{5,6} Currently, the Goldmann applanation tonometer (GAT) is considered the gold-standard tool for IOP measurement.⁴

According to the literature, the GAT measures the force needed to flatten a given area of the cornea, which is affected by the central corneal thickness (CCT).⁵ However, following LASIK, scleral rigidity and hysteresis decrease, particularly in patients with myopia. These changes in corneal biomechanics after corneal refractive surgery tend to result in applanation and indentation-based tonometer readings that incorrectly underestimate IOP.⁷ Further research is required to study this phenomenon;^{8–10} however, the relevant studies have not so far been possible because of the lack of an appropriate tool for the reliable assessment of IOP following a LASIK procedure. Although correction formulae have previously been proposed to correct for the effects of surgery, these have not been sufficiently well documented to allow a valid assessment of the true IOP reading after corneal refractive surgery. Therefore, it seems appropriate to attempt to establish a correction formula to take into account the effect of surgery on GAT measurements.¹¹

Patients and Methods

The study was conducted in the Research Institute of Ophthalmology (RIO), Giza, Egypt. This study was performed under the tenets of the Declaration of Helsinki of 1975 (the 1983 revision). The research committee of the RIO approved the protocol of the study. All patients received a thorough explanation of the procedures entailed in the study and signed an informed consent form prior to enrollment. Preoperative IOP had to be less than 21 mmHg without any anti-glaucoma treatment either preoperatively or postoperatively.

The study included 300 eyes of 150 patients. Inclusion criteria were patients who were fit for corneal refractive surgery, older than 18 years, with stability of refraction for the past year (change ± 0.5 diopter) and no family history of glaucoma. Patients who appeared to have an elevation of IOP at any stage of follow-up, or had received any type of anti-glaucoma treatment, had undergone previous ocular surgery, or had corneal diseases, were excluded from the study.

Preoperative and postoperative IOP was measured with a GAT (Haag-Streit, Koeniz, Switzerland). Best corrected visual acuity, manifest and cycloplegic refraction were detected. Corneal topography was assessed and pachymetry was performed using a Pentacam (Oculus, Wetzlar,

Germany). CCT was measured with ultrasonic pachymetry, and the average of three consecutive readings was recorded. Corneal ablation depth was documented.

Patients were followed up at 1, 3, and 6 months postoperatively, and the 6-month reading was introduced along with the preoperative IOP reading for statistical analysis.

IOP was statistically described in terms of mean \pm SD and compared using the paired *t*-test. Correlations between variables were assessed using the Pearson moment correlation equation for linear relationships between normally distributed variables and the Spearman rank correlation equation for non-normal variables and non-linear monotonic relationships. Linear regression analysis was used to generate an equation to predict postoperative IOP (IOP post) using preoperative IOP (IOP pre) and ablation depth. Two-sided *p* values < 0.05 were considered statistically significant. All statistical calculations were done using IBM SPSS (IBM Corp, Armonk, NY, USA) release 22 for Microsoft Windows.

Results

Data from 150 patients (300 eyes) were composed and studied preoperatively and postoperatively. The average age of patients (mean \pm SD) was 34.8 \pm 8.8 years (range 18–50 years); 45% of patients were male while 55% were female. All patients underwent LASIK in both eyes. No family history of glaucoma was declared in any of the patients. All patients included in this study were Egyptian. The spherical equivalent (SE) of the 300 eyes ranged between 1.5 and 10 diopters. The corneal ablation depth for correction of refractive error fluctuated between 41 and 122 μ m, with a mean of 59.2 \pm 22 μ m. The mean preoperative pachymetry measurement was 546.9 \pm 31.8 μ m preoperatively and 480.4 \pm 29.3 μ m postoperatively. IOP decreased from 15.72 \pm 2.37 mmHg preoperatively to 11.71 \pm 2.24 mmHg postoperatively ($p < 0.001$) (Figure 1).

A strong positive correlation was noticed between SE and IOP both preoperatively and postoperatively ($p < 0.001$) (Figures 2 and 3). A positive correlation between both preoperative and postoperative pachymetry and IOP was detected ($p < 0.001$) (Figures 4 and 5, Tables 1 and 2). A positive correlation was identified between ablation depth and IOP changes ($p < 0.001$) (Figure 6, Tables 1–3). A strong positive correlation was detected between both preoperative IOP and ablation depth and postoperative IOP (Table 1). The greater the preoperative pachymetry, refractive error, and ablation corneal depth, the higher the IOP change (Table 1).

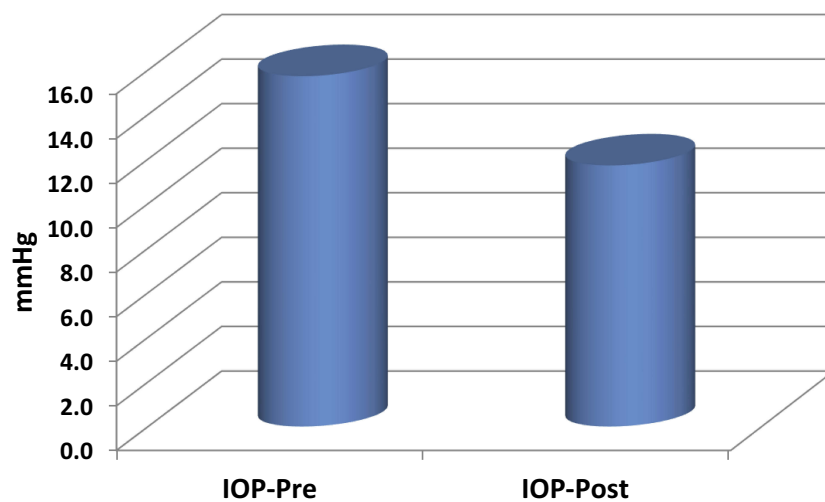


Figure 1 Mean preoperative and postoperative intraocular pressure (IOP pre and IOP post) in the study sample.

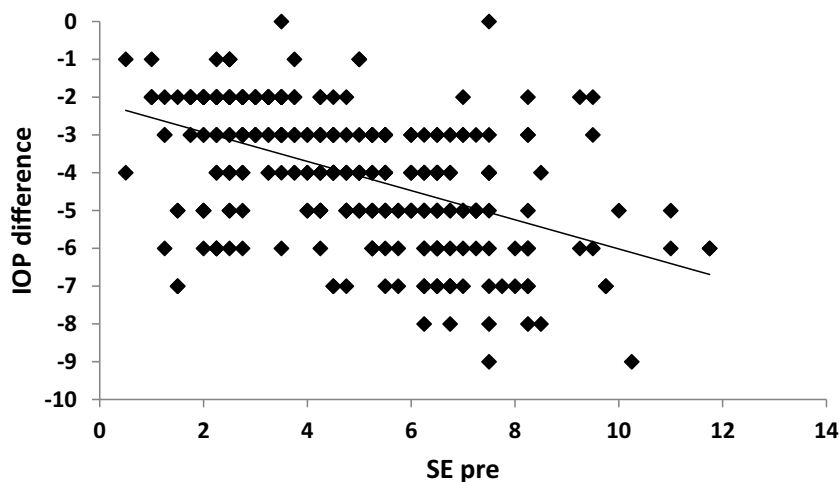


Figure 2 Correlation between preoperative spherical equivalent (SE pre) and intraocular pressure (IOP) difference in the study sample.

A scatterplot with regression line is plotted between preoperative spherical equivalent (SE pre) and IOP in [Figure 2](#), and between postoperative spherical equivalent (SE post) and IOP in [Figure 3](#). Scatterplots with regression lines between pachymetry and either preoperative or postoperative pachymetry are shown in [Figures 4](#) and [5](#), respectively. A scatterplot with regression line between ablation depth and IOP difference is shown in [Figure 6](#). Correlations between IOP pre and ablation depth and IOP post are presented in [Table 1](#). A regression analysis and correlations between IOP pre and ablation depth and IOP post are presented in [Table 2](#). Correlations between IOP difference and SE pre, SE post, preoperative pachymetry (pachy pre), postoperative pachymetry (pachy post), and ablation depth are presented in [Table 3](#).

After analyzing the consequential changes and correlations, a correction formula was created. The correction formula was: Real post-LASIK IOP=4+0.7(preoperative IOP)–0.3(ablation depth).

Discussion

The validity of GAT in measuring IOP depends upon a number of assumptions, including the notion that the corneal surface is infinitely thin and perfectly flexible and has a uniform thickness. Because these assumptions are fundamentally flawed, the identification of a more accurate technique for the measurement of IOP following laser surgery is necessary.^{7–10}

Multiple suggestions have been proposed to overcome the inherent inaccuracy of GAT measurements among

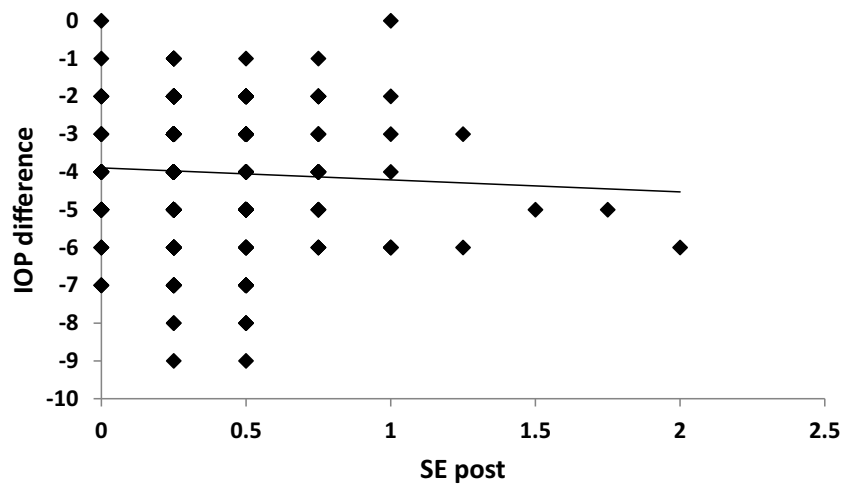


Figure 3 Correlation between postoperative spherical equivalent (SE post) and intraocular pressure (IOP) difference in the study sample.

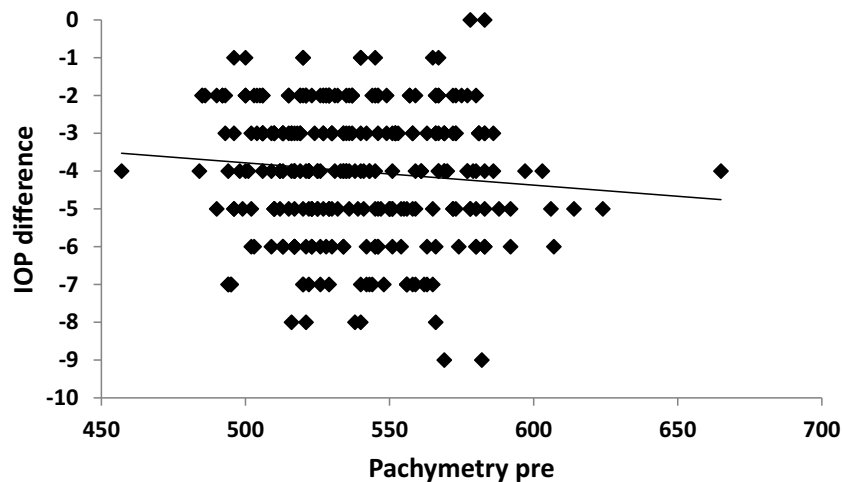


Figure 4 Correlation between preoperative pachymetry (pachymetry pre) and intraocular pressure (IOP) difference in the study sample.

myopic patients following LASIK correction surgery. Some authors have suggested measuring IOP by the application of GAT on the peripheral cornea to correct for alterations in corneal thickness and biomechanics;² however, another study has refuted the benefit of this approach.¹²

Newer devices have been introduced for the measurement of IOP that are based on dynamic rather than static applanation, such as the ocular response analyzer (ORA), Pascal dynamic contour tonometer, and indentation tonometer. These devices may be valid alternatives for the measurement of IOP in post-refractive surgery patients, but results have been mixed. The unsatisfactory results of these approaches may be attributed to changes in biomechanics, which are considered basic parameters for these devices.^{13–20}

Because of the inaccuracy of GAT measurements following LASIK, there is an argument for the development of a correction formula to address this issue. The development of a correction formula has been suggested by several authors previously, but none of the proposals has so far gained wide acceptance or been considered suitable for application.

In the development of our correction formula, we studied the changes that may appear with LASIK, and assessed their effects on GAT readings. Our results revealed a reduction in CCT that correlates with ablation depth. Because CCT is a major factor contributing to the reliability of GAT readings, we considered it necessary to study the correlation between ablation depth and change in IOP reading (as shown in Tables 1–3).

In the current study, we observed a correlation between decrease in postoperative IOP and both preoperative IOP and

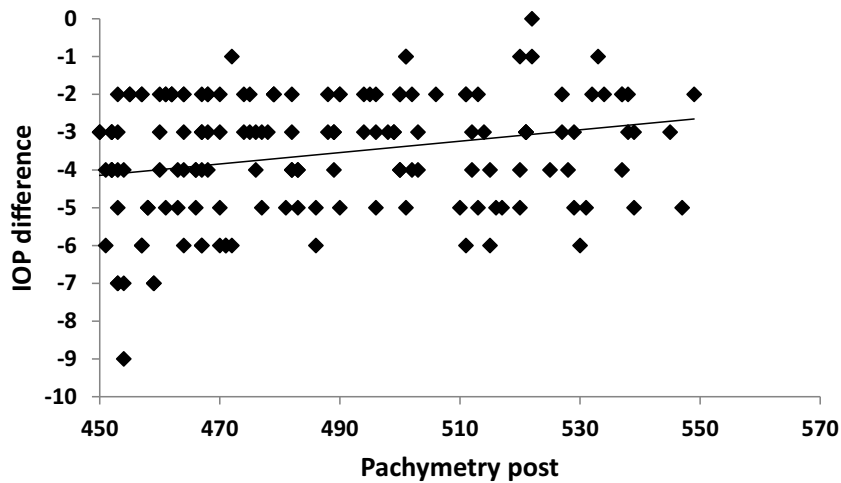


Figure 5 Correlation between postoperative pachymetry (pachymetry post) and intraocular pressure (IOP) difference in the study sample.

Table 1 Correlation Between Preoperative Intraocular Pressure (IOP pre) and Ablation Depth

Model		Unstandardized Coefficients		Standardized Coefficients	t	p	95% CI for B	
		B	Std. Error	Beta			Lower	Upper
1	(Constant)	4.024	0.539		7.469	0.000	2.964	5.084
	IOP pre	0.658	0.031	0.694	21.378	0.000	0.597	0.718
	Ablation depth	-0.034	0.003	-0.422	-13.000	0.000	-0.039	-0.029

Notes: ^aPredictors: (constant), ablation depth, IOP pre. ^bDependent variable: IOP post.

Table 2 Correlation Between Postoperative Intraocular Pressure (IOP Post) and Ablation Depth

ANOVA ^b						
Model		Sum of Squares	df	Mean Square	F	p
1	Regression	1,039.475	2	519.737	327.127	0.000 ^a
	Residual	471.872	297	1.589		
	Total	1,511.347	299			

Notes: ^aPredictors: (constant), ablation depth, IOP pre. ^bDependent variable: IOP post.

change in corneal thickness, as well as ablation depth (Tables 1 and 2). In accordance with our findings, Rashad and Bahnassy reported a mean change in GAT readings of 1.63–3.69 mmHg, as well as a strong correlation between reduction in IOP and both preoperative IOP and change in corneal thickness.¹² The small number of cases (102 eyes) and the restriction of cases to include myopic astigmatism only may be limiting factors in this previous study compared with the current study.¹²

Our results indicate a clear linear correlation between ablation depth and change in IOP. This is consistent with multiple studies that have also reported a change in IOP reading following LASIK corrective surgery, ranging from a minimal change in some studies to a more marked change of up to 5 mmHg in others^{2,7,10} (Table 3 and Figures 2–6).

After taking into account the correlation between spherical equivalent and preoperative or postoperative IOP difference and the correlation between pachymetry and preoperative or postoperative IOP difference, our proposed correction formula may be stated as: Real IOP=4+0.7(pre-operative IOP)–0.3(ablation depth).

Our formula is not the first correction formula to be developed in this way. Kohlhaas et al also reported the inaccuracy of IOP measurement post-LASIK, and attempted a correction formula for IOP calculation. These authors found a significant correlation between the measured IOP and CCT in addition to a k-reading. However, this formula considered postoperative IOP as a main element, which may be a source of error as it is the most likely factor to be changed. The small number of

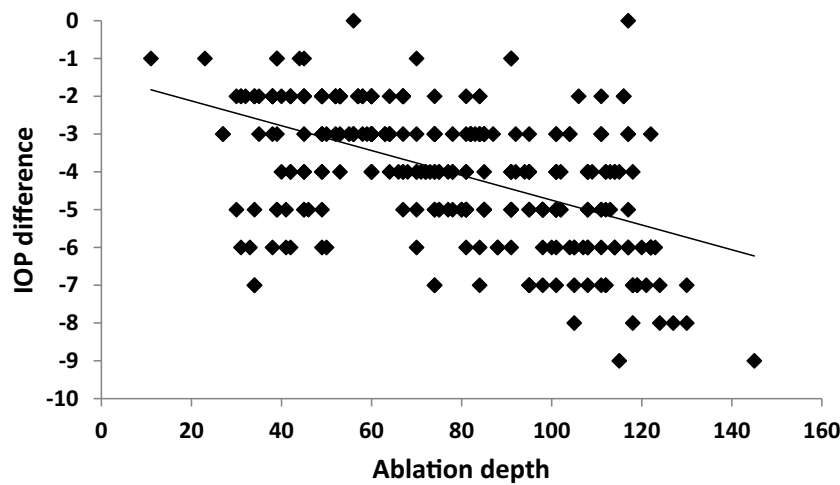


Figure 6 Correlation between ablation depth and intraocular pressure (IOP) difference in the study sample.

cases (n=101) in their study may be a further point of weakness, and was corrected in the current study. Furthermore, in our formula, we consider preoperative IOP to be the main element in the equation, which we firmly believe makes our proposal stronger and more robust to the no touched form of the cornea.¹¹

The Kohlhaas formula contains multiple parameters that make it more complex and impractical in application, while our formula is simpler and more applicable, and has one

factor (preoperative IOP) that needs to be fitted. Furthermore, our formula is based on processing the effect of ablation depth on the resulting reading of IOP. The Kohlhaas formula also differs from ours in that it must be applied at every patient visit, whereas our formula has a clear role, which is the conclusion of the most nearly accurate IOP of the patient to be post-LASIK. This number can be documented in the patient's file, and any follow-up documentation of IOP may be compared with this number.

One weak point in our formula in comparison with the Kohlhaas formula is the necessity to preserve and document preoperative IOP.

In our study, change in k-readings was not included as this is not considered a sharp parameter and its measurement may be subject to errors. This is consistent with a study performed by Silva et al in 2011, which found a weak correlation between average simulated keratometry and change in IOP readings.²¹

Our result is also consistent with a study by Yin Lin et al that explored the factors that may alter IOP measurements following LASIK. These authors reported that CCT and central ablation depth are the main parameters to be considered. This fact was confirmed in a femtosecond laser or microkeratome flap created by LASIK.²²

In the current study, the IOP calculation started 6 months postoperatively, when all postoperative treatments including steroids had been completed and discontinued to avoid steroid-induced glaucoma. This coincides with the observation of authors that steroid-induced glaucoma and pressure-induced keratopathy may appear as acute or late-onset events, and may disrupt the reliability of readings and subsequent equations.^{23,24}

Table 3 Correlations Between Intraocular Pressure Difference (IOP Diff.) and Preoperative Spherical Equivalent (SE Pre), Postoperative Spherical Equivalent (SE Post), Preoperative Pachymetry (Pachy Pre), Postoperative Pachymetry (Pachy Post), and Ablation Depth

		IOP Diff.
SE pre	Pearson correlation	-0.499
	pvalue	0.000
	N	300
SE post	Pearson correlation	-0.049
	p value	0.403
	N	300
Pachy pre	Pearson correlation	-0.098
	pvalue	0.089
	N	300
Pachy post	Pearson correlation	0.318
	p value	0.000
	N	300
Ablation depth	Pearson correlation	-0.520
	p value	0.000
	N	300

A study by Corenemberger et al showed that both eyes of the same patient may have different refraction corneal thicknesses, and consequently different ablation depth;²⁵ therefore, we studied both eyes of the same patient to ensure that the eye chosen had no negative effect on the results.

A limitation of this study may be the restriction to and selection of myopias and myopic astigmatism among patients following LASIK. This may be justified by the strong association between myopia and glaucoma, as reported by many authors. Myopia is an independent risk factor for glaucoma incidence and progression, which mandates early diagnosis and treatment. Moreover, laser correction in myopias affects the central cornea, which is the main concern for GAT.^{26–29}

Conclusion

GAT is the gold standard for IOP measurement, but requires a correction formula for proper assessment post-LASIK. A simple and easily applicable correction formula, such as $\text{Real IOP} = 4 + 0.7(\text{preoperative IOP}) - 0.3(\text{ablation depth})$, may be a good option for the proper assessment and follow-up of post-LASIK IOP.

Disclosure

The authors report no conflicts of interest in this work.

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