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REVIEW

Reliability of Intraocular Pressure Measurement by Goldmann Applanation Tonometry After Refractive Surgery: A Review of Different Correction Formulas

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Abstract: Myopia is one of the main risk factors for the onset of open-angle glaucoma. One of the first steps to assess glaucoma occurrence is the measurement of the intraocular pressure (IOP) by the Goldmann applanation tonometry (GAT). Even if this device is considered to be the gold standard for such measurements, it is affected by several sources of errors. Among these, there are the corneal thickness and curvature, both modified by corneal refractive surgery (CRS), that nowadays has become a very popular method to treat refractive errors. Indeed, CRS, by modifying the corneal shape and structure, causes an underestimation of the IOP measurements. In the literature, several IOP correction formulas to utilize with different devices have been proposed to overcome this problem. This paper aims to review the various correction formulas applied to the GAT in the attempt to improve the reliability of this measurement.

Keywords: IOP measurement, corneal refractive surgery, GAT, laser in situ keratomileusis, photorefractive keratectomy

Introduction

An accurate evaluation of intraocular pressure (IOP) is very important both for an early diagnosis of glaucoma and to follow the evolution of the disease over the years.[1]

It has been demonstrated that even a difference of 1 mmHg can be relevant in the progression of this disease, especially in myopic patients, as the refractive error is one of the established risk factors for open angle glaucoma.[2]

Goldmann applanation tonometry (GAT) is currently considered the gold standard in measuring the IOP.[3] Several other instruments have been developed for such purpose and, to be validated, they all have been compared to GAT. Unfortunately, GAT is not very precise; in fact, it underestimates the IOP value, mainly when corneas are thinner, but also to a lesser extend when they are flatter or edematous.[4–9]

Corneal refractive surgery (CRS) techniques, such as Photorefractive Keratectomy (PRK), laser in situ keratomileusis (LASIK) or laser epithelial keratomileusis (LASEK), modifying corneal biomechanics[10] making corneas thinner and flatter.[11–14] Probably the most important effect of CRS on the cornea being its change in the buckling stress and stress redistribution under applanation.[15] For this reason, even using the GAT, a value lower than real will be obtained, and if one of these patients will develop glaucoma, the diagnosis can be delayed.[16,17]

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To overcome this problem, many authors have developed either formulas to correct the GAT IOP readings obtained after surgery[18–25] or they tried to utilize different methods.[26–36]

These methods can be divided in:

Methods based on knowledge of the patients clinical history

No history-based methods

Methods Based on Knowledge of the Patients' Clinical History

Knowledge of Preoperative IOP

Chihara et al[18] evaluated 93 right eyes of 93 patients that underwent LASIK. IOP was measured preoperatively and 3 months after surgery with GAT and air puff tonometer (Topcon CT90A); analyzing their data, authors elaborated a formula to obtain a correct IOP (IOPc) based on preoperative IOP (IOPpre):

Change in IOP (ΔIOP) = −6.455 + (0.596 x IOPpre).

The final formula is:

IOPc = postoperative IOP (IOPpost) + ΔIOP.

Knowledge of IOPpre, Ablation Depth and Age

Rashad & Bahnassy[19] performed a LASIK in 166 eyes of 93 patients with a mean age of 30.6 ± 8.0 years. Preoperatively and 12 months after surgery, IOP and Central Corneal Thickness (CCT) were measured, respectively, with GAT and ultrasound pachymeter (Teknar Ophthasonic pachymeter, Teknar Corporation, St. Louis, MO); they found a correlation between preoperative IOP, change in CCT (ΔCCT) and patient age in years and developed a multiple linear regression analysis:

IOPpost = 0.987 + 0.627 x IOPpre + 0.0143 x ΔCCT + 0.03044 x age

Knowledge of Ablation Depth

Munger et al[20] evaluated 481 eyes of 381 patients with a mean preoperative refractive error of –6,50 that underwent PRK. Twenty-four months after surgery, IOP was measured with GAT and CCT with Mentor Advent ultrasound pachymeter; they found a correlation between change in IOP and ΔCCT and proposed the following correction formula:

IOPc = IOPpost + 2.1 x ΔCCT/100

Emara et al[21] studied 85 eyes of 50 myopic patients evaluating IOP with GAT and CCT with Sonogage Corneo-Gage Pulse 2 pachymeter before undergoing LASIK 3 months after. They found a correlation between decrease in IOP and ablation depth. The post-LASIK slope was 0.027 mmHg/µm or a decrease of 1 mmHg per 37.8 µm reduction in CCT:

IOPc = IOPpost + ΔCCT/37.8

Duch et al[22] evaluated 118 eyes of 60 patients that underwent LASIK. Before and 3 months after surgery, they measured IOP with GAT and contact Pneumotonometer (Mentor Modular One Pneumotonometer, Mentor O & O), CCT with ultrasound pachymeter (DGH 2000, DGH Technology, Frazer, PA). They found a correlation between ΔIOP and ΔCCT with a mean decrease of 2.9 mmHg per 70µm of reduction in CCT; they exposed also a correlation between ΔIOP and ΔCCT with the following formula:

ΔIOP = 1.59 + 0.019 x Δ CCT;

Then the final formula developed is:

IOPc = IOP post + Δ IOP

Knowledge of Ablation Depth and Effective Treatment

Rosa et al.[23] Studied 87 eyes of 87 patients, with a mean dioptric error of −7.6 ± 4.1, that underwent PRK and the fellow eyes were used as controls; they measured IOP with GAT 12 months after PRK. They developed a correction formula for IOP based on IOPpost, ablated cornea (A) and effective treatment in diopters (D):

IOPc = IOPpost + (0.025 x A) + (0.34 x D)

Knowledge of Ablation Depth and Preoperative K Readings

Svedberg et al[24] evaluated 40 eyes in 40 patients divided into 2 groups of 20 eyes, 1 with 20 eyes that underwent PRK/LASEK and 1 with 20 eyes who underwent LASIK. IOP was assessed with GAT, while CCT and K values with Orbscan. The authors did not specify when the postoperative measurement was performed. They developed two correction formulas, taking into account their measurement and the correlation between ΔIOP, ΔCCT and differences in corneal power (ΔK):

Δ IOP = 2.765–0.001 x ΔCCT - 0.424 x Δ K (PRK/LASEK)

Δ IOP = 4.340 + 0.018 x ΔCCT - 0.440 x Δ K (LASIK)
In the end the final formula is:

IOPc = IOPpost + Δ IOP

No History-Based Methods

Kohlhaas et al[25] examined 101 eyes of 59 patients before and 6 months after LASIK; IOP was measured with GAT, CCT with ultrasound pachymeter (Ultrasonic Pachymeter DGH-500 Pachette; TechnoMed Inc, Wallace, NC) and K values with topography (TechnoMed); evaluating their data, authors found a correlation between IOP, CCT and postoperative K values (k post) and derived a correction formula:

IOPc = IOP post + (540 – CCT post)/71 + (43 – K post)/2.7 + 0.75 mmHg

Discussion

The IOP is routinely measured during the ophthalmological examination; however, the finding of low IOP values could be misleading and could delay the diagnosis of glaucoma, mainly in myopic eyes where the optic disc examination and the visual field can be difficult to evaluate.

It is well known that after CRS, several changes occur in the anterior eye segment[37,38] and some measurements become unreliable.[39–41]

Among these, there is an IOP underestimation. In the attempt to find a reliable method in measuring the IOP after CRS, several devices have been tested, such as pneumotonometer, Tono Pen (TP), non-contact tonometer (NCT), such as TonoPachymeter, dynamic contour tonometer (DCT), Ocular Response Analyzer (ORA), Corvis ST and CATS Tonometer and only the last four has been proven to be as reliable as GAT.[42–52]

Schipper,[26] to rehabilitate the GAT, in 2000 suggested to measure the IOP with GAT and TP in the corneal periphery because they found a higher IOP of 1.8–2.3 mmHg in the corneal periphery compared to the values measured in the central corneal region.

This proposal was supported by Abbasoglu et al[43] that, utilizing GAT and Pneumotonometer, noticed an underestimation by GAT of a mean of 2.40 mmHg in central corneal region; this underestimation was not present with evaluations by Pneumotonometer neither in central corneal nor in the peripheral cornea.

Nevertheless, these findings were not confirmed by other studies:

Zadok et al[53] found no statistically significant difference between pre and post-operative evaluations in central IOP versus peripheral IOP measured by pneumotonometry.

Rashad & Bahnassy[19] in their study concluded that there was no difference between central corneal IOP measurements and peripheral corneal measurements both before and after surgery.

Park et al[54] found that the IOP measurements in the nasal cornea region were statistically lower than at baseline, although the drop in nasal cornea was not so high as the IOP difference in central cornea between preoperative and postoperative evaluations.

The problem, that was born in the years and has made Schipper's proposal difficult to apply, is that corneal ablations were initially made with a diameter of 3–4 mm but currently, to get less regression and less night vision problems, the ablation can reach the 7–9 mm diameter.

Therefore, it is almost impossible to find, in the periphery, a non-treated corneal area, considering that the GAT tip is about 3 mm in diameter.

Most of the authors tried to overcome the problem, describing correcting factors to apply to IOP readings. These correcting factors are related to different data such as: ΔCCT alone;[20–22] or to the IOPpre, the ΔCCT and the age of the patient;[19] or to the A and D;[23] or only to the IOP value measured before surgery;[18] or to the ΔCCT and the ΔK[24] or to the CCT and the Kpost.[25]

Mardelli et al tried to explain the IOP reduction post CRS and found no correlation between ΔIOP and ΔCCT or keratometry.[55] They related this loss of correlation with the removal of the Bowman's membrane that causes the production of new collagen tissue, affecting corneal resistance to applanation. Their study, however, is based on small ablated areas in which the pachymetric difference before and after surgery does not exceed the average value of 23 μ.

Montes-Micò et al[56] disagree with the findings of Mardelli et al because they found the same difference post PRK and post LASIK (where the Bowmann's layer is not ablated) concluding that Bowman's membrane does not play a significant role in corneal rigidity. They agreed with a study by Patel and Aslanides[57] that explains the reduction in IOP after PRK based on a general softening of the cornea during healing process.

De Bernardo et al tested several of these formulas in 121 eyes of patients that underwent PRK and concluded that the best results were obtained by using Rashad, Chihara and Rosa formulas (R^2 = 0.8593, <0.001; R^2 = 0.5389, 0.128; R^2 =0.2489, <0.001, respectively).[58]

The reliability of these studies is influenced by several factors:

1. The real IOP is unknown, because the direct measurement, for ethical reasons, can be realized only during cataract surgery.

2. It had been shown that if single tonometry readings are used by the same observer, they must differ by at least 4.5 mmHg before it can be said that the IOP is different; for variations of smaller magnitude, there is only a 10% chance that this difference is due to a change alone.[59]

3. Whitacre and Stein recommended not to ascribe any clinical significance to changes in the IOP measured across two different measurement sessions that were smaller than 2–3 mmHg.[4]

4. In most of these studies, the modified IOP was compared with preoperative values and it is not sure that no change in real IOP is present after 6 months.

Regrettably, to date, it is impossible to measure the real IOP, but, on the other hand, several authors who published a study on this topic utilized the preoperative values to test the reliability of the proposed formulas.[18–24]

It is said that when there are too many ways to solve a problem it means that none of them is reliable. We think the real problem is that so far, as it is evident from the above, only a few methods have been tested in a sufficient number of patients, while most of them are just theoretical and have been verified in few patients. The other problem is that several methods are clinical history based and, unfortunately, in most of the patients the preoperative keratometry values and the exact refractive treatment are not available, so we can conclude that nowadays there are not reliable and immediate methods to apply to assess IOP post corneal refractive surgery.

Pending further studies comparing the IOP measurements with real IOP, the suggestion of the present study is that further studies are necessary to establish a method that could make GAT measurements reliable in patients that underwent CRS.

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