Asian J Ophthalmol. 2018;16:035-050

Original Article

Changes in corneal properties and its effect on intraocular pressure measurement following phacoemulsification with intraocular lens implantation with or without trabeculectomy

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Abstract

Purpose: *To evaluate the changes in corneal biomechanical properties and their effect on pre- and postoperative differences in IOP measurement by each tonometer.*

Design: *Observational study.*

Methods: *The study was done in subjects who underwent phacoemulsification with intraocular lens (IOL) implantation (phaco-IOL) and combined phacoemulsification with IOL implantation and trabeculectomy (phaco-trab). IOP was measured by a single trained examiner using rebound tonometer (RBT), Ocular Response Analyzer (ORA), Goldmann applanation tonometer (GAT), dynamic contour tonometer (DCT), and Tono-Pen. Corneal hysteresis (CH) and corneal resistance factor (CRF) were measured using ORA, central corneal thickness (CCT) using ultrasonic pachymeter, and corneal curvature (CR) with manual keratometry. All measurements were done one week prior to surgery and after four weeks and six weeks of the two surgeries respectively. Only the operated eye was included for analysis.*

Results: *Twenty-nine eyes of 29 normal subjects who underwent phaco-IOL and 23 eyes of 23 glaucoma subjects who underwent phaco-trab were studied. Increase in CCT [10.2 ± 14.86 microns, $p = 0.001$], decrease in CH [0.82 ± 1.38 mmHg, $p = 0.003$] and CRF [0.97 ± 1.0 mmHg, $p < 0.001$] were found post-phaco-IOL, whereas post-phaco-trab decrease in CCT [16.61 ± 15.22 microns, $p < 0.001$], CRF [2.28 ± 1.93 mmHg, $p < 0.001$] with increase in CH [0.95 ± 1.89 mmHg, $p = 0.03$] were noted. Multiple linear regression analysis showed significant associations for change in CH and CRF with change in IOP and not with CCT and CR postoperatively.*

Conclusion: *Alterations in CH and CRF were associated with changes in IOP measured postoperatively by different tonometers. CH and CRF changes contribute to postoperative changes in measured IOP.*

Keywords*: Corneal biomechanics, intraocular pressure, phacoemulsification, trabeculectomy*

Introduction

Corneal viscoelastic properties depend on the corneal collagen fibrils. The arrangement of collagen fibrils varies directionally and regionally, which results in regional

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differences in elasticity.[1,2] Hjortdal showed that for a given intraocular pressure (IOP) radially the cornea is stronger at the center and circumferentially at the limbus. It is also known that both corneal and scleral fibrils are fused at the limbus.[3] Woo *et al.* found that the corneal biomechanical characteristics are approximately similar to that of the sclera.[4] The Ocular Response Analyzer (ORA; Reichert Inc., Depew, New York, USA), measures *in vivo* corneal biomechanical properties such as corneal hysteresis (CH) and corneal resistance factor (CRF) by analyzing corneal responses to indentation by a rapid air pulse. CH represents the corneal viscoelasticity and has been described as the ability of the tissue to absorb and dissipate energy. CRF represents overall corneal resistance and the ability to withstand the applanation force.[5,6] Eyes with a higher CH tend to have increased damping capacity, which buffers the harmful effect of IOP fluctuation on the optic nerve head. Studies have found that eyes with glaucoma have lower CH compared to normal eyes; this increases the risk for developing glaucomatous optic neuropathy and progression of the disease.[7-11]

Several studies reported the effect of corneal factors on IOP measurements by different tonometers, such as the Goldmann applanation tonometer (GAT), dynamic contour tonometers (DCT), ORA, Tono-Pen, and rebound tonometer (RBT) among normal and glaucoma subjects. It was reported that apart from the technical differences between tonometers, the variability is significantly associated with corneal properties such as central corneal thickness (CCT), corneal radius of curvature (CR), CH, and CRF.[12-18] Among all the corneal parameters, the effect of CCT was studied extensively. It is estimated that every ten micron increase in CCT results in 0.35 mmHg difference between GAT and ORA corneal compensated IOP (IOPcc) measurements and 0.80 mmHg between GAT and RBT measurements.[18]

The corneal properties are reported to be altered following refractive and phacoemulsification surgeries due to the incision created in the cornea.[19-25] In trabeculectomy surgery, a partial scleral flap thickness is created adjacent to the limbus. This may potentially modify the biomechanical properties of the ocular walls. To the best of our knowledge, there are no reports on alterations in corneal biomechanical properties and its effect on IOP measurement following combined phacoemulsification and trabeculectomy (phaco-trab) surgery.

The aim of this study was to evaluate the changes of corneal biomechanical properties and its effect on pre- and postoperative differences in IOP measurement by each tonometer.

Methods and materials

Study design and subject selection

This was a single-center observational study. Subjects who underwent phacoemulsification and intraocular lens implantation (phaco-IOL) and subjects who underwent combined phacoemulsification with IOL implantation and trabeculectomy (phaco-trab) during September, 2013 to April, 2014 at a tertiary eye care center, were included in the study.

The study followed the tenets of the Declaration of Helsinki. The study was approved by the Institutional Review Board of Vision Research Foundation, Chennai, India. Subjects willing to participate in the study were informed in detail about the study and its objectives. Written informed consent was obtained from subjects before enrolling them into the study.

Inclusion criteria for the phaco-IOL group were age more than 30 years, clear cornea with normal fundus, and no previous history of ocular trauma, ocular surgery or refractive surgery. Eyes with any ocular pathology other than cataract were excluded.

Inclusion criteria for the phaco-trab group were age more than 30 years, clear cornea, diagnosed as glaucoma,[26] and no previous history of ocular trauma, ocular surgery or refractive surgery. Eyes with any other ocular pathology were excluded.

Baseline evaluation

Subjects underwent a comprehensive ophthalmic examination which included best corrected visual acuity (BCVA), IOP measured by GAT, slit-lamp bio-microscopy, gonioscopy, and stereoscopic dilated fundus evaluation on the slit lamp using a 90D lens. Subjects who had glaucomatous optic disc changes underwent standard automated visual field testing (SAP) (Humphrey Field Analyzer (HFA)) (model 750; Carl Zeiss Meditec). The axial length was measured by using ultrasound biometry (OcuScan® RxP Ophthalmic Ultrasound System, Alcon Laboratories, Inc. South Freeway, Fort Worth, Texas, U.S.A.).

Preoperative assessments

Preoperative measurements were done one week before the surgery. CR was measured using a keratometer (KMS-6; Appaswamy Associates, Chennai, India) before IOP measurements. IOP was measured using the following tonometers: RBT (Icare; Tiolat Oy, Helsinki, Finland), ORA (Reichert Ophthalmic Instruments, Buffalo, N.Y., U.S.A), Tono-Pen (Tono-Pen XL, Medtronic Solan, Southpoint Drive, North Jacksonville, U.S.A.), DCT (Swiss Microtechnology AG, Port, Switzerland), and GAT (AT-900; Haag Streit AG Gartenstadtstrasse, Koeniz, Switzerland). The RBT and ORA measurements were taken before instillation of topical anaesthesia. Tono-Pen, GAT, and DCT measurement were done after applying anaesthetic eye drops (proparacaine 0.5%, Paracain; Sunways India Pvt Ltd. Mumbai, India). The order of RBT and ORA measurements were randomized using a simple randomization method. Similarly the order of Tono-Pen, GAT, and DCT measurements were randomized for each subject. CCT was measured using an ultrasonic pachymeter (DGH-550 Pachette 2; DGH technology, Inc., PA, U.S.A.) after five minutes of the last IOP measurement. Repeated measurements were taken until a set of ten values differed by less than ten microns.

IOP measurement protocol

RBT

RBT was performed in the sitting position without instilling topical anaesthesia. Six measurements were acquired by lightly pressing the tonometer button. The instrument automatically averages the six measurements and the mean IOP is displayed.[27]

ORA

Subjects were asked to place their head against the head rest. Four air puffs within each measurement on each eye were taken; the signal with the highest waveform was automatically selected as the best signal value (BSV) for each eye. Those with poor-quality waveforms (multiple applanation spikes or asymmetric signals) were excluded. IOPcc, IOPg, CH, and CRF were recorded.[5]

Tono-Pen

The Tono-Pen was calibrated before each measurement. Tono-Pen measurements were taken after anaesthetising the eye. The cornea was applanated with the Tono-Pen tip several times until a reading was displayed. Measurements with a standard error of means (SEM) less than 5% were included. If successive measurements differed by more than 5 mmHg, the procedure were repeated. All Tono-Pen measurements were made with a disposable latex cover over the tip.[28]

GAT

Calibration for GAT was performed on a daily basis. Topical anaesthesia was instilled and the tear film stained using a sodium fluorescein strip. An average of two measurements was recorded for analysis; if they differed by more than 2.0 mmHg, a third reading was taken and the mean of the values was taken for analysis.[12]

DCT

DCT was performed after instilling topical anaesthesia. Each DCT IOP measurement usually requires five to eight seconds where the probe is placed to have continuous contact with the eye. The instrument gives a quality score that ranges from 1 to 5 (lower scores indicate better quality) and Ocular Pulse Amplitude (OPA) value along with IOP measurement. All measurements taken for this study had quality readings ranging from 1-3.[29]

Postoperative measurements

In addition to routine assessment, pachymetry and IOP were re-evaluated four weeks after performing phaco-IOL surgery and six weeks of phaco-trab using the same devices as mentioned earlier. Both pre- and postoperative CR, CH, CRF, IOP, and CCT measurements were performed by a single observer who was blinded to actual readings and the readings were read and recorded by the second examiner.

Statistical analysis

The relevant information and test results were recorded in MS Office Excel 2007. Statistical analysis was carried out with SPSS statistical software (Version 14; SPSS Science Inc., Chicago, IL, USA), Med Calc Statistical software version 8.1, and MS-Excel 2007. Only data from the operated eye were considered for statistical analysis. Descriptive statistics were calculated for all parameters of all the groups. Tests for normality were carried out for each continuous variable and appropriate parametric/non-parametric analyses were performed. Type-I error was kept at 5%

level. Paired t-test was done to compare between pre- and postoperative measurements. Multiple linear regression was done to find the association between postoperative changes of corneal biomechanics and IOP. No comparison was done between phaco-IOL and phaco-trab group for postoperative measurements.

Results

Twenty-nine eyes of 29 normal subjects who underwent phaco-IOL and 23 eyes of 23 glaucoma subjects who underwent phaco-trab were included in this study. The mean age of the phaco-IOL and the phaco-trab group was 63.4 years (± 10.6) and 65.0 years (± 6.21), respectively, and no difference was noted ($p = 0.366$). The mean preoperative CH was significantly lower and OPA was higher in glaucomatous eyes (6.97 ± 2.22 mmHg and 3.04 ± 1.25 mmHg, respectively) as compared to normals (9.41 ± 1.67 mmHg, 1.92 ± 0.64 mmHg) ($p < 0.001$; Table 1).

Phaco-IOL group

Significant increase in CCT [10.48 microns (± 15.04), $p = 0.001$] and decrease in CH [0.79 mmHg (± 1.39), $p = 0.005$] and CRF [1.01 mmHg (± 1.00), $p < 0.001$] were noted post-phaco-IOL surgery. But there was no significant alteration in CR postoperatively ($p = 0.094$). There was no significant difference between pre- and postoperative IOP measured by different tonometers except DCT measurements [1.15 mmHg (± 2.87), $p = 0.039$] (Table 1).

Phaco-trab group

Significant decrease in CCT [16.61 microns (± 15.22), $p < 0.001$] and CRF [2.28 mmHg (± 1.93), $p < 0.001$] with increase in CH [0.95 mmHg, (± 1.89), $p = 0.026$] measurements were noted following phaco-trab surgery. There was no alteration in CR followed by phaco-trab surgery, similar to the phaco-IOL group. There was a significant decrease in IOP following phaco-trab surgery measured by all the tonometers ($p < 0.001$). No significant difference was found between pre and post CR measurements in the phaco-trab group ($p = 0.43$) (Table 1).

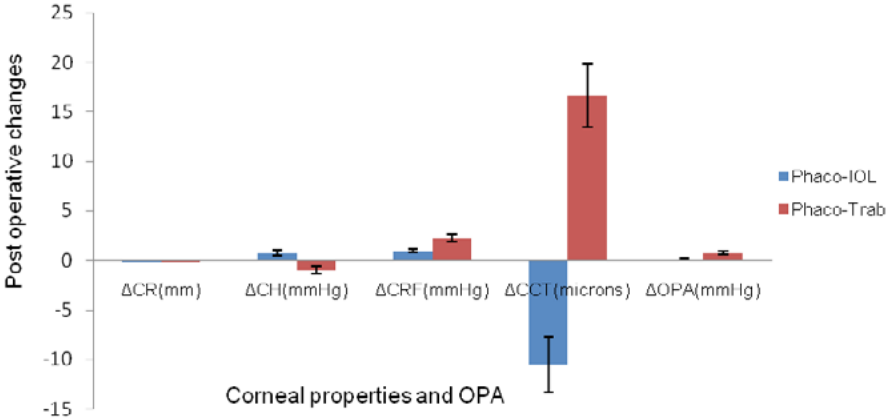

Fig. 1. Postoperative changes of corneal properties and OPA following phaco-IOL and phaco-trab surgeries. Δ = (preoperative measurements-postoperative measurements); CH: Corneal hysteresis, CRF: Corneal resistance factor; CR: Average corneal radius of curvature; CCT: Central corneal thickness; CI: Confidence interval.

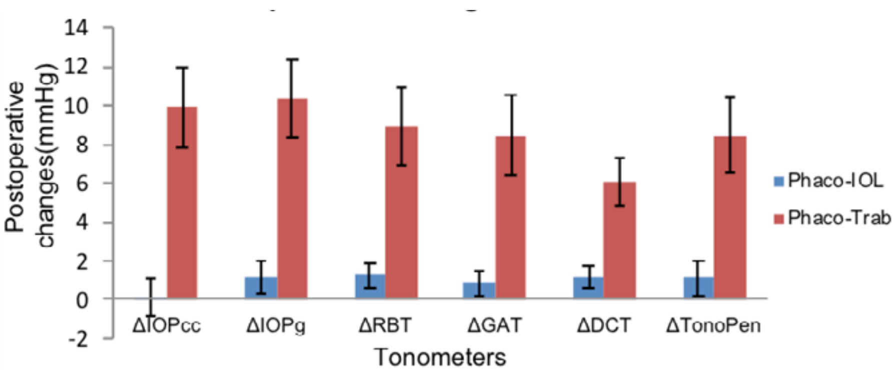

Fig. 2. Postoperative changes of IOP following phaco-IOL and phaco-trab surgeries. Δ = (preoperative measurements-postoperative measurements); GAT: Goldmann applanation tonometer; IOPcc: Corneal compensated IOP; IOPg: Goldmann correlated IOP; RBT: Rebound tonometer; DCT: Dynamic contour tonometer.

Effect of corneal properties on tonometers

Simple and multiple linear regression analysis were done with postoperative (phaco-IOL surgery) changes of corneal parameters (ΔCR, ΔCH, ΔCRF, and ΔCCT) as independent factors and ΔIOPs, *i.e.*, pre- and postoperative (phaco-IOL surgery) difference in IOP measured by different tonometers as dependent variable, which showed ΔIOPs were significantly associated with ΔCH ($p < 0.001$) and ΔCRF ($p < 0.001$) independently among all the corneal parameters. However, ΔIOPs measured by each tonometer were not significantly associated with ΔCCT ($p > 0.05$) and ΔCR ($p > 0.05$). Similarly, in the phaco-trab group, ΔIOPs were significantly associated with ΔCH ($p < 0.001$) and ΔCRF ($p < 0.001$) but not with ΔCCT ($p > 0.05$) nor ΔCR ($p > 0.05$) in the regression models.

Effect of axial length on corneal properties and tonometers

Simple linear regression was done using axial length (AXL) as independent variable and postoperative changes of corneal parameters (ΔCR, ΔCH, ΔCRF, and ΔCCT) and ΔIOP measurement by each tonometer as dependent variables. No significant association was found between AXL and postoperative changes of corneal parameters ($p > 0.05$) and postoperative changes in IOP ($p > 0.05$) measured by each tonometer following phaco-IOL and phaco-trab.

Discussion

Corneal properties were found to be significantly influenced by intraocular surgeries, with which the postoperative changes of IOP measured by each tonometer were explained by the changes of corneal properties.

Phaco-IOL group

In the phaco-IOL group, we found significant increase in CCT and decrease in CH and CRF after four weeks after the surgery. Recent studies reported that the decrease in CH measurement in spite of increased CCT one day after cataract surgery is attributable to corneal edema, which returned to normal values three months after the surgery.[22-25] In the present study, a significant increase in CCT and decrease in CH and CRF were noted even after one month after the surgery. This decrease in CH and CRF may be due to an incision made on the cornea that could weaken the strength of the eyeball, resulting in lower corneal biomechanics. Lu *et al.*[30] reported that there was no significant correlation between soft contact lens-induced corneal edema, CH and CCT, yet the effect of corneal edema induced by cataract surgery or contact lens on measurements of corneal biomechanics is not clear.

Phaco-trab group

In the phaco-trab group, we found significant increase in CH and decrease in CRF and CCT six weeks after the surgery. This increase in CH may be explained by the postoperative reduction of IOP. Similar finding were reported by Sun *et al.*[31] where IOP was reduced due to anti-glaucoma medications and surgery in subjects with chronic angle closure glaucoma. CH values significantly increased from 6.83 ± 2.08 mmHg to 9.22 ± 1.80 mmHg at two weeks and 9.50 ± 1.66 mmHg at four weeks after treatment. Neuberger *et al.*[32] suggested in an experimental study that ORA gives lower CH measurement in eyes with higher IOP due to limited indentation on the cornea. This reason could probably explain the increased CH with decreased IOP in post phaco-trab subjects. CH measurements were dependent on IOP level whereas CRF measurements were not influenced by IOP level. In the present study, we noted that CRF was significantly decreased both post-phaco-IOL and -phaco-trab, thereby concluding that the overall resistance of the cornea, *i.e.*, CRF, is altered following intraocular surgeries.

Postoperative changes in IOP

A study by Kucumen *et al.* showed no significant difference pre- and post-1-month IOPcc and IOPg measurements following phaco-IOL.[22] In the present study, we found no significant difference in pre- and postoperative (one month) IOP measurements obtained by all tonometers in the phaco-IOL group except DCT ($p = 0.04$). Several studies reported that DCT underestimates IOP in eyes with high IOP compared to GAT and overestimates IOP in eyes with low IOP.[33, 34] In the present study, we noted that DCT underestimated IOP (0.1 ± 4.4 mmHg, $p < 0.05$) in preoperative eyes (phaco-trab) as compared to GAT, similar to Tonnu *et al.*[34] However, postoperatively (phaco-trab) mean DCT-IOP was 2.2 mmHg ($\pm$ 2.9) ($p > 0.05$) higher than GAT-IOP. Hamilton *et al.*[35] and Oh *et al.*[36] have also reported that DCT underestimates IOP in eyes with contact lens-induced corneal edema. The reason for this difference in IOP measured by DCT following post-one-month phaco-IOL was not clear. However, the least mean difference was noted [6.12 mmHg ($\pm$ 5.85), $p < 0.001$] between pre- and postoperative IOP obtained by DCT following phaco-trab among all the tonometers. In our pilot study, we found that DCT overestimated IOP measurement as compared to GAT in eyes with IOP less than 20 mmHg, whereas this pattern reverses in eyes with IOP greater than 20 mmHg.

Effect of corneal properties on tonometers

CH is significantly lower in glaucomatous eye as compared to non-glaucomatous eyes. Similar findings were noted in the present study.[7-9] Luce[5] reported that CH and CRF are direct measurements of corneal biomechanical properties and more completely describe the effect of corneal biomechanics on IOP measurements than CCT. Hence, we studied the postoperative changes in corneal biomechanics and its effect on IOP measured by all the tonometers.

CH: In the present study, ΔCH was negatively associated with ΔIOPs both in the phaco-IOL and phaco-trab groups. Multiple linear regression analysis showed postoperative increase in CH results decrease IOP following phaco-IOL and phaco-trab.

CRF: ΔCRF was positively associated with ΔIOPs. Multiple linear regression analysis showed postoperative decrease in CRF results decrease IOP following phaco-IOL and phaco-trab.

Our findings indicate that corneal biomechanics (CH and CRF) independently influenced all tonometers. DCT measurement was less influenced by corneal biomechanics compared to other tonometers. DCT measures IOP by a sensor tip which does not applanate the corneal surface, so theoretically it is not affected by any force-to-pressure translations. The variability between GAT and DCT decreased by 0.7 mmHg for every ten micron increase in CCT.[37] Doyle *et al.*[38] reported that the mean difference between GAT-IOP and DCT-IOP was -2.6 mmHg in thin corneas and -0.06 mmHg in thick corneas. According to Kotecha *et al.*[16] GAT significantly underestimates IOP compared to DCT and ORA IOPcc in eyes with low CRF, whereas Wang *et al.*[17] reported that GAT underestimates IOP compare to DCT eyes with low CH. Those two previous studies did not consider both CH and CRF as influential factors for IOP measurement. Hence, the variability in IOP measurement among various tonometers can be explained in a better manner by considering all the corneal properties.

In the present study, OPA was significantly higher in glaucomatous eye as compared to non-glaucomatous eyes, which significantly decreased in the phaco-trab group but not in the phaco-IOL group. This suggests that OPA is dependent on the level of IOP, a finding similar to that reported by Knecht *et al.*[39] In the present study, from the simple and multiple linear regression model we did not find any association between postoperative changes of OPA and ΔIOP measured by all tonometers (Table 4). Even after removing OPA from the multiple regression models, we found no difference in the strength of association.

IOP reduction after cataract surgery ranged from 1.3 to 2.05 mmHg at one year follow-up in a few studies.[40] Issa *et al.*[41] reported that the preoperative anterior chamber depth was inversely related to the postoperative IOP reduction, whereas Bhallil *et al.*[42] and Huang *et al.*[43] reported that postoperative IOP reduction was associated with the lens thickness and axial length, not with preoperative and postoperative anterior chamber depth. In the present study we did not find association between axial length and the reduction of IOP following phaco-IOL and phaco-trab. There was also no association between postoperative changes in corneal parameters (ΔCR, ΔCH, ΔCRF, and ΔCCT) with axial length in our study.

This study was done on limited subjects and may not reflect population data. We did not look into the variability of surgeon factor, which could be a confounder of the outcome. Hence, we need quantitative and longitudinal assessment of the corneal biomechanical parameters in eyes that undergo intraocular surgery and its effects on IOP measurements.

Acknowledgement

We thank Dr Aditya Neog, Consultant, Glaucoma Services, Sankara Nethralaya, for his guidance and support.

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Tables

Table 1. Pre- and postoperative changes in corneal biomechanical properties and IOP measured by different tonometers.

Phaco-IOL (n = 29)				Variables	Phaco-trab (n = 23)			
p value[¥]	Postoperative difference (Mean ± SD) (95%CI)	Postoperative (Mean ± SD)	Preoperative (Mean ± SD)		Preoperative (Mean ± SD)	Postoperative (Mean ± SD)	Postoperative difference (Mean ± SD) (95%CI)	p value[¥]
0.094	(-0.01 ± 0.04) (-0.03, 0.003)	7.73 ± 0.27	7.72 ± 0.27	**CR (mm)**	7.60 ± 0.30	7.62 ± 0.31	(-0.02 ± 0.10) (-0.06, 0.03)	0.448
0.001	(-10.48±15.04) (-16.20, -4.76)	532.41 ± 45.29	521.93 ± 41.49	**CCT (microns)**	505.96 ± 35.54	489.35 ± 38.95	(16.61 ± 15.22) (10.02, 23.19)	< 0.001
0.005	(0.79 ±1.39) (0.26, 1.31)	8.63 ± 1.57	9.41 ± 1.67	**CH (mmHg)**	6.97 ± 2.22*	7.92 ± 1.08	(-0.95 ± 1.89) (-1.77, -0.13)	0.026
< 0.001	(1.01 ± 1.00) (0.63, 1.39)	8.19 ± 1.89	9.20 ± 1.97	**CRF (mmHg)**	8.82 ± 1.97	6.54 ± 1.60	(2.28 ± 1.93) (1.44, 3.11)	< 0.001
0.223	(0.10 ± 0.45) (-0.07, 0.27)	1.81 ± 0.63	1.92 ± 0.64	**OPA (mmHg)**	3.04 ± 1.25*	2.28 ± 0.95	(0.76 ± 0.71) (0.45, 1.06)	< 0.001
0.858	(0.18 ± 5.24) (-1.82, 2.17)	15.68 ± 4.86	16.04 ± 4.45	**IOPcc (mmHg)**	23.44 ± 9.64*	13.53 ± 5.55	(9.90 ± 9.89) (5.63, 14.19)	< 0.001
0.189	(1.18 ± 4.73) (-0.62, 2.98)	13.13 ± 5.01	14.31 ± 4.68	**IOPg (mmHg)**	19.87 ± 9.09*	9.54 ± 5.77	(10.33 ± 9.58) (6.19, 14.47)	< 0.001
0.056	(1.28 ± 3.44) -0.03, 2.58)	13.79 ± 4.20	15.07 ± 3.44	**RBT (mmHg)**	21.04 ± 10.24*	12.13 ± 5.90	(8.91 ± 9.83) (4.66, 13.16)	< 0.001
0.215	(0.86 ± 3.66) (-0.53, 2.25)	13.03 ± 4.08	13.90 ± 3.50	**GAT (mmHg)**	19.70 ± 9.07*	11.26 ± 5.99	(8.43 ± 1.00) (4.11, 12.76)	0.001
0.039	(1.15 ± 2.87) (0.06, 2.24)	14.15 ± 2.45	15.31 ± 2.49	**DCT (mmHg)**	19.63 ± 5.12*	13.50 ± 4.51	(6.12 ± 5.85) (3.59, 8.65)	< 0.001
0.231	(1.10 ± 4.85) (-0.74, 2.94)	13.24 ± 4.05	14.34 ± 3.71	**Tono-Pen (mmHg)**	18.65 ± 8.71*	10.22 ± 5.58	(8.43 ± 9.21) (4.45, 12.42)	< 0.001

[¥]Paired t-test; phaco-IOL: phaco- emulsification with IOL implantation; phaco-trab: Combined phaco-emulsification with IOL implantation and trabeculectomy (phaco-trab); GAT: Goldmann applanation tonometer; IOPcc: Corneal compensated IOP; IOPg: Goldmann correlated IOP; RBT: Rebound tonometer; DCT: Dynamic contour tonometer; CH: Corneal hysteresis; CRF: Corneal resistance factor; CR: Average corneal radius of curvature; CCT: Central corneal thickness; SD: standard deviation; CI: Confidence interval. *Comparison between preoperative phaco-IOL and phaco-trab groups: *Independent t-test; significant level p < 0.05.

Table 2. Simple linear regression on changes of corneal properties and changes in IOP measurements by each tonometer, following phaco-IOL.

ΔIOP	Independent variables	ΔCR	ΔCH	ΔCRF	ΔCCT	ΔOPA
ΔIOPcc	R^2	0.003	0.706	0.165	0.000	0.012
	Constant	0.263	2.663	-1.969	0.160	0.045
	beta	5.975	-3.164	2.130	-0.002	1.265
	95% CI	-39.565 to 51.515	-3.969 to -2.358	0.240 to 4.021	-0.139 to 0.136	-3.336 to 5.867
	p value	0.790	< 0.001	0.029	0.982	0.577
ΔIOPg	R^2	0.002	0.513	0.336	0.002	0.023
	Constant	1.244	3.100	-1.581	1.028	1.017
	beta	4.226	-2.438	2.745	-0.015	1.603
	95% CI	-36.970 to 45.421	-3.376 to -1.501	1.220 to 4.269	-0.139 to 0.109	-2.534 to 5.740
	p value	0.835	< 0.001	0.001	0.809	0.433
ΔRBT	R^2	0.002	0.448	0.193	0.002	0.002
	Constant	1.320	2.578	-0.248	1.178	1.245
	beta	3.033	-1.656	1.513	-0.009	0.299
	95% CI	-26.914 to 32.981	-2.382 to -0.931	0.292 to 2.737	-0.100 to 0.081	-2.741 to 3.339
	p value	0.837	< 0.001	0.017	0.834	0.841
ΔGAT	R^2	0.002	0.360	0.292	0.001	0.003
	Constant	0.814	2.103	-1.133	0.783	0.817
	beta	-3.304	-1.578	1.981	-0.008	0.432
	95% CI	-35.160 to 28.552	-2.410 to -0.747	0.764 to 3.198	-0.104 to 0.089	-2.800 to 3.664
	p value	0.833	0.001	0.002	0.873	0.786
ΔDCT	R^2	0.007	0.472	0.122	0.021	0.059
	Constant	1.078	2.267	0.149	0.866	0.994
	beta	-5.313	-1.415	1.000	-0.028	1.557
	95% CI	-30.179 to 19.554	-2.006 to -0.824	-0.061 to 2.061	-0.102 to 0.047	-0.900 to 4.015
	p value	0.665	< 0.001	0.064	0.454	0.204
ΔTono-Pen	R^2	0.002	0.419	0.192	0.001	0.000
	Constant	1.178	2.878	-1.037	0.985	1.105
	beta	5.085	-2.257	2.126	-0.011	-0.020
	95% CI	-37.096 to 47.267	-3.306 to -1.208	0.404 to 3.848	-0.139 to 0.116	-4.306 to 4.267
	p value	0.806	< 0.001	0.017	0.857	0.993

Table 3. Multiple linear regression on changes of corneal properties and changes in IOP measurements by each tonometer, following phaco-IOL.

ΔIOP	Independent variables	ΔCR	ΔCH	ΔCRF	ΔCCT
ΔIOPcc	R2	0.998			
	Constant	0.022			
	beta	-1.085	-3.477	2.866	0.001
	95% CI	-3.094 to 0.925	-3.543 to -3.411	2.774 to 2.959	-0.005 to 0.008
	p value	0.276	< 0.001	< 0.001	0.643
ΔIOPg	R2	0.998			
	Constant	0.033			
	beta	-0.616	-2.801	3.341	0.002
	95% CI	-2.689 to 1.457	-2.869 to -2.734	3.245 to 3.436	-0.004 to 0.008
	p value	0.546	< 0.001	< 0.001	0.532
ΔRBT	R2	0.748			
	Constant	0.799			
	beta	-0.250	-1.867	1.898	-0.003
	95% CI	-16.567 to 16.067	-2.400) to -1.334	1.146 to 2.649	-0.053 to 0.047
	p value	0.975	< 0.001	< 0.001	0.907
ΔGAT	R2	0.775			
	Constant	-0.093			
	beta	-6.763	-1.846	2.388	0.009
	95% CI	-23.147 to 9.620	-2.381 to -1.311	1.633 to 3.142	-0.041 to 0.060
	p value	0.403	< 0.001	< 0.001	0.710
ΔDCT	R2	0.714			
	Constant	0.801			
	beta	-7.296	-1.602	1.249	-0.024
	95% CI	-21.768 to 7.177	-2.075 to -1.129	0.582 to 1.916	-0.068 to 0.021
	p value	0.309	< 0.001	0.001	0.281
ΔTono-Pen	R2	0.714			
	Constant	0.417			
	beta	0.559	-2.547	2.658	-0.002
	95% CI	-23.942 to 25.061	-3.347 to -1.747	1.529 to 3.787	-0.078 to 0.074
	p value	0.963	< 0.001	< 0.001	0.957

*Δ = (preoperative measurements-postoperative measurements); GAT: Goldmann applanation tonometer; IOPcc: Corneal compensated IOP; IOPg: Goldmann correlated IOP; RBT: Rebound tonometer; DCT: Dynamic contour tonometer; CH: Corneal hysteresis; CRF: Corneal resistance factor; CR: Average corneal radius of curvature; CCT: Central corneal thickness CI: Confidence interval.

Table 4. Simple linear regression on changes of corneal properties and changes in IOP measurements by each tonometer, following phaco-trab.

ΔIOP	Independent variables	ΔCR	ΔCH	ΔCRF	ΔCCT	ΔOPA
ΔIOPcc	R2	0.048	0.709	0.546	0.065	0.043
	Constant	9.558	5.747	1.294	7.154	7.725
	beta	-21.623	-4.390	3.781	0.166	2.887
	95% CI	-65.177 to 21.931	-5.666 to -3.115	2.218 to 5.345	-0.119 to 0.451	-3.292 to 9.066
	p value	0.314	< 0.001	< 0.001	0.240	0.342
ΔIOPg	R2	0.058	0.583	0.675	0.056	0.037
	Constant	9.959	6.677	1.057	7.863	8.372
	beta	-22.894	-3.854	4.070	0.149	2.588
	95% CI	-64.866 to 19.079	-5.334 to -2.375	2.788 to 5.352	-0.129 to 0.426	-3.415 to 8.592
	p value	0.269	< 0.001	< 0.001	0.278	0.380
ΔRBT	R2	0.060	0.708	0.396	0.020	0.083
	Constant	8.525	4.783	1.628	7.385	5.891
	beta	-23.929	-4.358	3.198	0.092	3.995
	95% CI	-66.937 to 19.079	-5.628 to -3.088	1.405 to 4.990	-0.198 to 0.382	-2.013 to 10.003
	p value	0.260	< 0.001	0.001	0.517	0.181
ΔGAT	R2	0.068	0.589	0.762	0.044	0.028
	Constant	8.014	4.604	-0.540	6.137	6.643
	beta	-25.945	-4.042	3.939	0.138	2.369
	95% CI	-69.503 to 17.613	-5.575 to -2.508	2.420 to 5.459	-0.153 to 0.430	-3.923 to 8.661
	p value	0.229	< 0.001	< 0.001	0.334	0.442
ΔDCT	R2	0.031	0.600	0.495	0.022	0.065
	Constant	5.957	3.858	1.273	5.173	4.530
	beta	-10.171	-2.389	2.128	0.057	2.104
	95% CI	-36.169 to 15.828	-3.273 to -1.505	1.153 to 3.104	-0.115 to 0.230	-1.507 to 5.716
	p value	0.425	< 0.001	< 0.001	0.498	0.239
ΔTono-Pen	R2	0.048	0.048	0.671	0.047	0.075
	Constant	8.110	5.245	-0.457	6.251	5.744
	beta	-20.021	-3.365	3.903	0.132	3.556
	95% CI	-60.616 to 20.574	-4.955 to -1.776	2.662 to 5.145	-0.137 to 0.400	-2.103 to 9.216
	p value	0.317	< 0.001	< 0.001	0.319	0.205

Table 5. Multiple linear regression on changes of corneal properties and changes in IOP measurements by each tonometer, following phaco-trab.

ΔIOP	Independent variables	ΔCR	ΔCH	ΔCRF	ΔCCT
ΔIOPcc	R2	0.999			
	Constant	-0.043			
	beta	-1.487	-3.623	2.831	0.003
	95% CI	-3.197 to 0.222	-3.717 to -3.529	2.740 to 2.923	-0.009 to 0.014
	p value	0.084	< 0.001	< 0.001	0.636
ΔIOPg	R2	0.999			
	Constant	-0.030			
	beta	-1.842	-2.965	3.284	0.002
	95% CI	-3.668 to -0.015	-3.066 to -2.865	3.187 to 3.382	-0.010 to 0.014
	p value	0.050	< 0.001	< 0.001	0.702
ΔRBT	R2	0.904			
	Constant	1.352			
	beta	-6.235	-3.908	2.175	-0.072
	95% CI	-21.751 to 9.280	-4.763 to -3.053	1.343 to 3.006	-0.176 to 0.031
	p value	0.410	< 0.001	< 0.001	0.160
ΔGAT	R2	0.930			
	Constant	-1.440			
	beta	-5.466	-3.231	3.052	-0.014
	95% CI	-18.898 to 7.965	-3.971 to -2.491	2.333 to 3.772	-0.103 to 0.076
	p value	0.404	< 0.001	< 0.001	0.749
ΔDCT	R2	0.878			
	Constant	1.038			
	beta	1.511	-2.036	1.655	-0.036
	95% CI	-8.882 to 11.903	-2.609 to -1.463	1.098 to 2.212	-0.105 to 0.034
	p value	0.764	< 0.001	< 0.001	0.294
ΔTono-Pen	R2	0.917			
	Constant	-1.390			
	beta	0.049	-2.493	3.263	0.002
	95% CI	-13.490 to 13.588	-3.239 to -1.747	2.537 to 3.989	-0.088 to 0.092
	p value	0.994	< 0.001	< 0.001	0.968

*Δ = (Preoperative measurements- Postoperative measurements); GAT: Goldmann applanation tonometer; IOPcc: Corneal compensated IOP; IOPg: Goldmann correlated IOP; RBT: Rebound tonometer; DCT: Dynamic contour tonometer; CH: Corneal hysteresis; CRF: Corneal resistance factor; CR: Average corneal radius of curvature; CCT: Central corneal thickness CI: Confidence interval.