

# A Comparison of Three Techniques for Measurement of Intraocular Pressure in Normal Eyes

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## Abstract

**Objectives:** To compare the precision of intraocular pressure (IOP) measurements acquired using an ocular response analyser (ORA), Auto Kerato-Refracto-Tonometer (TRK-1P), and Goldmann applanation tonometer (GAT) in healthy eyes.

**Methods:** In this prospective study, one eye of each of 57 normal subjects was randomly selected for analysis. Measurements of the IOP were performed using ORA, TRK-1P, and GAT, and measurements of corneal hysteresis (CH), corneal resistance factor (CRF), and central corneal thickness (CCT) were performed using ORA. Repeatability was assessed by the coefficient of variation (CV) and interclass correlation coefficients (ICCs). Agreement among tonometers was assessed by Bland-Altman plots and one-way ANOVA.

**Results:** The average IOPs measured using Goldmann-correlated IOP (IOPg), corneal-compensated IOP (IOPcc), TRK-1P, and GAT ( $\pm$  SDs) were  $15.13 \pm 2.76$ ,  $14.39 \pm 2.59$ ,  $16.54 \pm 2.93$ , and  $15.21 \pm 2.54$  mmHg, respectively. Intra-observer agreement across all tonometers was strong and slightly higher for GAT and IOPg than for TRK-1P. The intra-observer CVs for GAT IOPg, and TRK-1P, were 4.22 (ICC=0.94), 4.99 (ICC=0.93), and 6.69 (ICC=0.86), respectively. Inter-observer agreement between various measurement methods was evaluated with Bland-Altman plots with multiple measurements per subject and ICCs. Results indicated fairly poor agreement across measurement methods, as supported by large limits of agreement and ICCs.

**Conclusion:** GAT, ORA, and TRK-1P are highly reliable methods for measurement of the IOP; however, the instruments cannot be used interchangeably.

**Keywords:** Goldmann applanation tonometer; TRK-1P; Ocular response analyser; Central corneal thickness; Corneal resistance factor; Corneal hysteresis; Normal eyes

## Introduction

Glaucoma is the second leading cause of blindness worldwide. Quigley and Broman (2006) estimated that by 2020, 6,18,718 individuals in the Middle East would have glaucoma; the corresponding estimate for 2020 is 2,295,407 individuals [1]. The intraocular pressure (IOP) measurement is vital for monitoring the effectiveness of treatment and evaluating the risk of glaucoma progression. Since IOP reduction is the objective of treatment, accurate IOP assessment is essential for monitoring the efficacy of therapy and for assessing the risk of glaucomatous progression [2,3].

The Goldmann applanation tonometer (GAT) has been considered the gold standard for measuring IOP for a number of decades [3]. However, GAT measurement of IOP is associated with calibration errors [4,5], contamination [6,7], and certain corneal features, such as central corneal thickness (CCT) [8,9], corneal curvature [10], and axial length [10]. Recently, advances in technology, including the dynamic contour tonometer (DCT; PASCAL, Ziemer Ophthalmic System, Port, Switzerland), ocular response analyser (ORA; Reichert Ophthalmic Instruments, Buffalo, NY, USA), and Auto Kerato-Refracto-Tonometer (TRK-1P); Topcon Corporation, Tokyo, Japan), have led to the

introduction of several instruments to increase the accuracy of IOP measurements and reduce the risk of infection [11]. However, it is unclear which of these instruments is best for precise measurement of IOP.

ORA analyses four variables: the Goldmann-correlated IOP (IOPg), corneal-compensated IOP (IOPcc), corneal hysteresis (CH), and corneal resistance factor (CRF) [3-6]. CH is an indication of viscous damping in the cornea; IOPcc is an IOP measurement that is less affected by corneal properties than GAT; and CRF is a measurement of the cumulative effects of both the viscous and elastic resistance encountered by the air jet while deforming the corneal surface. Various studies have compared GAT with DCT and ORA [11]. However, no comparisons have been made between GAT or ORA and TRK-1P.

Therefore, the aim of this study was to assess the intra-observer repeatability and agreement of three tonometry instruments: ORA, TRK-1P, and GAT. To the best of our knowledge, this first study to compare TRK-1P with GAT and ORA.

## Subjects and Methods

Fifty-seven eyes from 57 healthy, oculovisually normal subjects (32 women and 25 men) were enrolled in this prospective study. The subjects were randomly selected from a clinical population. The mean age ( $\pm$  standard deviation [SD]) was  $24.50 \pm 5.85$  years (range, 19-40

years). Comprehensive anterior and posterior segment examinations of all subjects were performed using a slit lamp and direct ophthalmoscope. The exclusion criteria included contact lens wearers, positive history (or objective signs) of ocular disease, and systemic disease with ocular implications, such as diabetes mellitus. CCT measurements are affected by age and refractive error [12]. Thus, the spherical equivalent refractive error was  $\pm 4.00$  D or more, the corneal astigmatism was  $-3.00$  D or greater, and the corneal curvature was 48 D or greater. The corneal curvature was determined by an autorefractometer (Auto Kerato-Refracto-Tonometer [TRK-1P]; Topcon Corporation, Tokyo, Japan). The CCT measurements were obtained using Visante OCT from Zeiss (Carl Zeiss Meditec, Dublin, CA, USA). To eliminate the disadvantages of ultrasound pachymetry, such as physical contact with the cornea, topical anesthesia was used; the accuracy of measurements was dependent on the perpendicularity of the probe's application to the cornea, and reproducibility relied on precise probe placement on the corneal centre [13].

For each subject, one eye was randomly selected using a table of random numbers generated in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). An unmasked single investigator conducted all measurements of the IOP, CCT, CRF, and CH. All IOP, CCT, CRF, and CH measurements were collected between 10:00 and 14:00 h [14].

The Auto Kerato-Refracto Tonometer (TRK-1P) is a new instrument ideal for screening that combines four measurements: autorefractometry, keratometry, noncontact tonometry, and pachymetry. Using rotary prism technology, the TRK-1P provides unmatched accuracy and reliability. The innovative optical design incorporated into the TRK-1P allows for accurate and reliable measurements with a pupil as small as  $\phi 2$  mm. The TRK-1P is easy to operate. A significant advantage of noncontact tonometry is the elimination of possible risks related to all contact tonometry, such as corneal abrasion, use of topical anaesthetic or fluorescein, and spread of infection.

Three consecutive measurements were performed using each method for each subject. However, three subjects dropped out of the study as they were apprehensive about being examined with GAT; these subjects were excluded. The purpose of the study was explained to all subjects, and informed consent was obtained from each subject before beginning the examination. The study was conducted in accordance with the ethical principles described in the 2008 Declaration of Helsinki, and the study protocol was approved by the research ethics review board of the College of Applied Medicine Science at King Saud University.

### Three IOP instruments

The first measurements were conducted with noncontact tonometers followed by GAT to eliminate the possible effects of applanation on the hysteresis value. The IOPg, IOPcc, CRF, and CH measurements were obtained using ORA, followed by measurement of IOP with TRK-1P. All ORA measurements were obtained at wave scores 6 and above [15]. The mean of the three readings from each tonometer was recorded. Then, CCT measurements were obtained using Visante OCT. There was a resting interval of around 15 min between noncontact tonometry and GAT. Finally, the IOP was measured with GAT after instillation of one drop of 0.5% proparacaine in the lower conjunctival sac, along with one drop of fluorescein sodium (0.25%). Three readings were obtained from GAT, and the mean was recorded.

### Statistical methods

Demographic data for all subjects and repeatability were assessed by determining the coefficient of variation (CV), interclass correlation coefficient (ICC), and 95% confident intervals (CIs). Bland-Altman analysis was performed to determine agreement between methods of measurement with multiple observations per individual, and the average of agreement between methods was used to assess the limits of agreement using Medcalc software version 11.4.4.0.

### Results

The study included 57 normal subjects (34 right eyes and 23 left eyes). The mean spherical equivalent of refractive error was  $-0.36 \pm 0.67$  D. Data for GAT, TRK-1P, IOPg, IOPcc, CH, CRF, and CCT are summarised in Table 1.

Parameters	Mean $\pm$ SD**
Age (years)	24.50 $\pm$ 5.85
GAT*	15.21 $\pm$ 2.54
TRK-1P*	16.54 $\pm$ 2.93
IOPg*	15.13 $\pm$ 2.76
IOPcc*	14.39 $\pm$ 2.59
CRF*	11.10 $\pm$ 1.80
CH*	11.40 $\pm$ 1.40
CCT ( $\mu$ m)	546.43 $\pm$ 31.54

Table 1: Characteristics of normal individuals.

### Intra-observer repeatability of IOP measurements

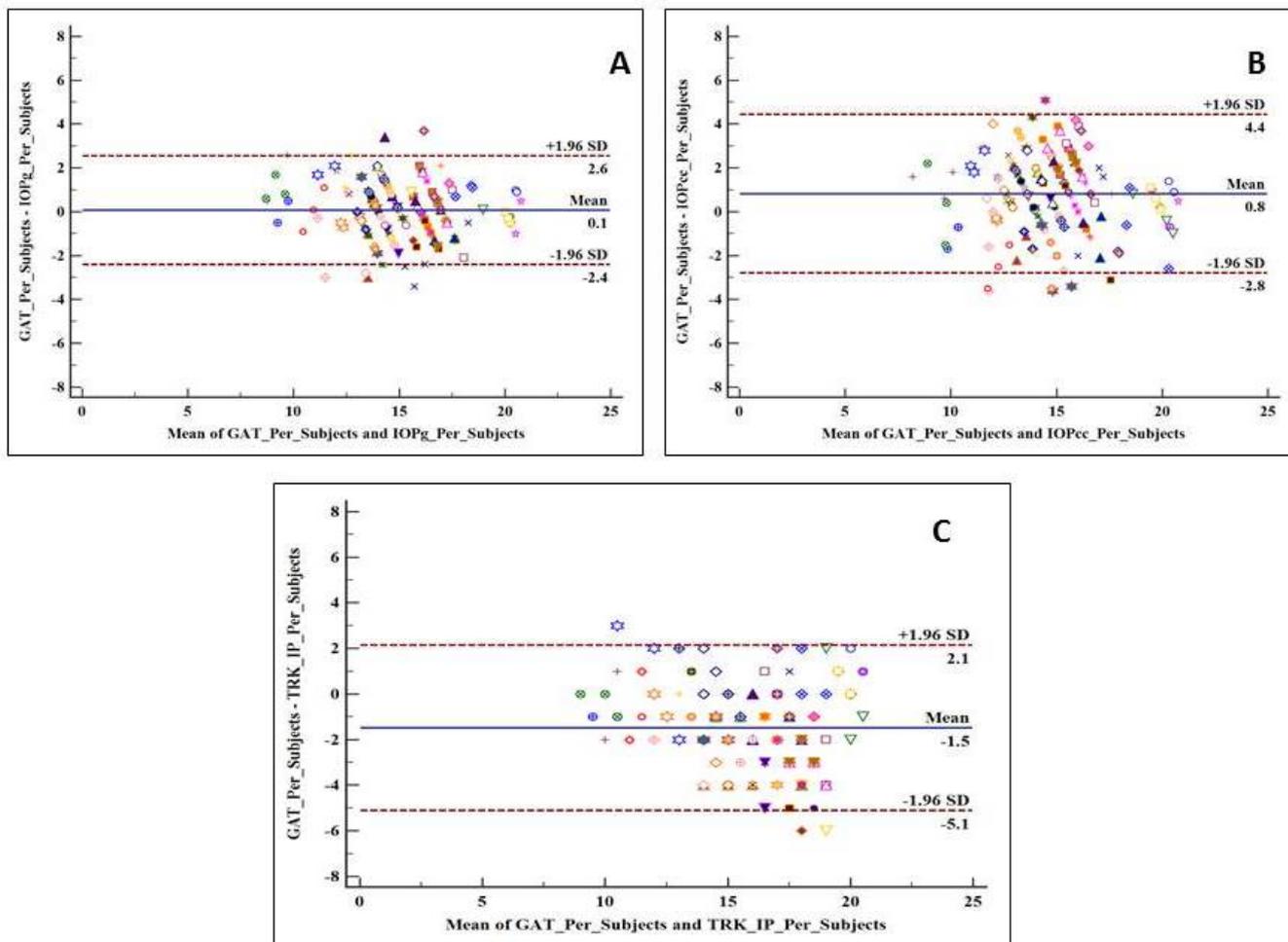
Intra-observer repeatability of IOP measurements obtained with the three instruments is summarised in Table 2. The results indicated acceptable agreement between measurements of the GAT and IOPg, as shown by the semisymmetrical distribution of the Bland-Altman plot and an ICC in the high agreement range (ICC=0.941). The remainder of measurement combinations did not yield sufficient agreement, as shown by the widely distributed Bland-Altman plots and ICCs below the critical value of 0.80.

Comparisons	Limits of agreement	CV%	ICC	95% CI†
GAT vs. IOPg	-2.40 to 2.60*	4.24	0.941	0.902 to 0.965
GAT vs. IOPcc	-2.80 to 4.40*	8.01	0.796	0.590 to 0.892
GAT vs. TRK-1P	-5.10 to 2.10*	9.35	0.729	0.167 to 0.890
TRK-1P vs. IOPg	-1.70 to 4.80*	9.04	0.768	0.081 to 0.918
TRK-1P vs. IOPcc	-2.80 to 7.40*	14.65	0.473	0-.015 to 0.734

\*mmHg, †confident intervals

Table 2. Measurements of the mean differences  $\pm$  SDs and limits of agreement between the three instruments.

Comparisons of the TRK-IP and the IOPcc yielded the poorest agreement. Overall, these results suggested that while each tonometer method was by itself reliable and consistent, scores obtained using different clinical methods may not be directly comparable.



**Figure 1:** Bland-Altman plots of agreement showing the mean differences and limits of agreement of IOP measurements with multiple observations per subject. (A) GAT versus IOPg, (B) GAT versus IOPcc, and (C) GAT versus TRK-IP.

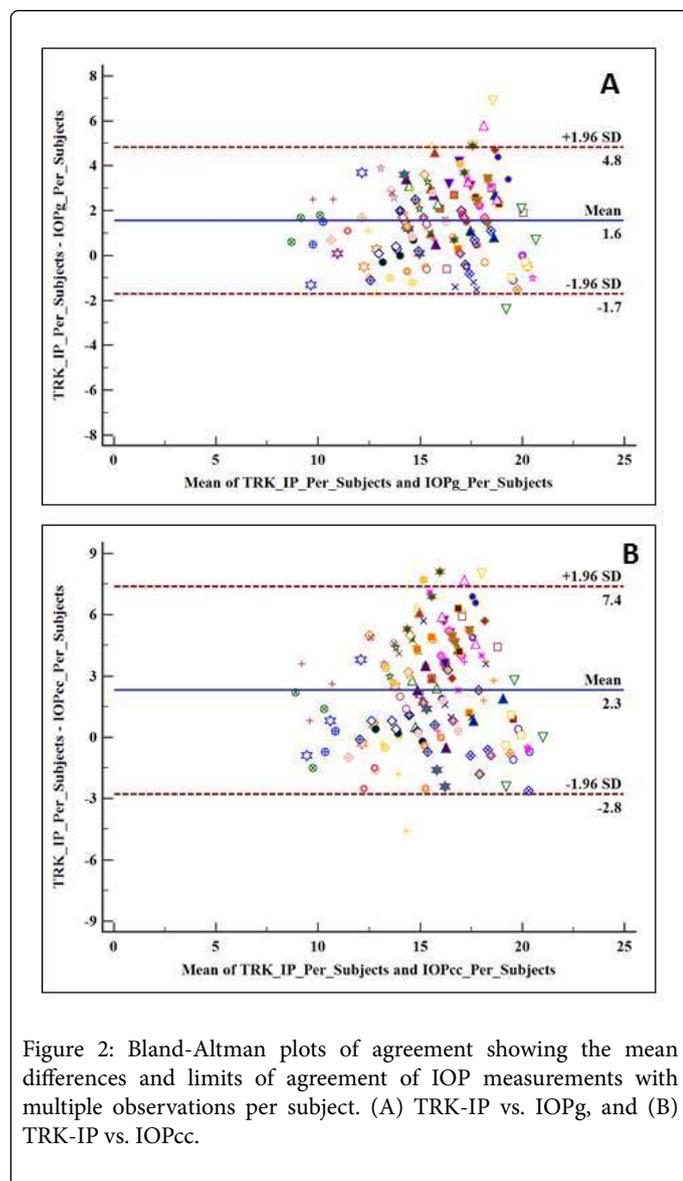


Figure 2: Bland-Altman plots of agreement showing the mean differences and limits of agreement of IOP measurements with multiple observations per subject. (A) TRK-IP vs. IOPg, and (B) TRK-IP vs. IOPcc.

Repeatability			
Instruments	GAT	IOPg	TRK-1P
CV%	4.22	4.99	6.69
ICC	0.94	0.93	0.86
95% CI†	0.905 to 0.961	0.890 to 0.954	0.789 to 0.9012

†Confident interval

Table 3: Intra-observer repeatability of IOP measurements with the three instruments.

### Agreement between instruments

Consistency across repeated trials within each method was examined using CVs and Cronbach's alpha intra-class correlations (Table 3). Across all tonometers, consistency and reliability was in the excellent range ( $\alpha > 0.90$ ; ICCs  $> 0.90$ ). GAT and IOPg had slightly better consistency compared with TRK-IP; however, these differences were not meaningfully different. These results indicated that measurements within a single tonometer instrument were consistent and reliable.

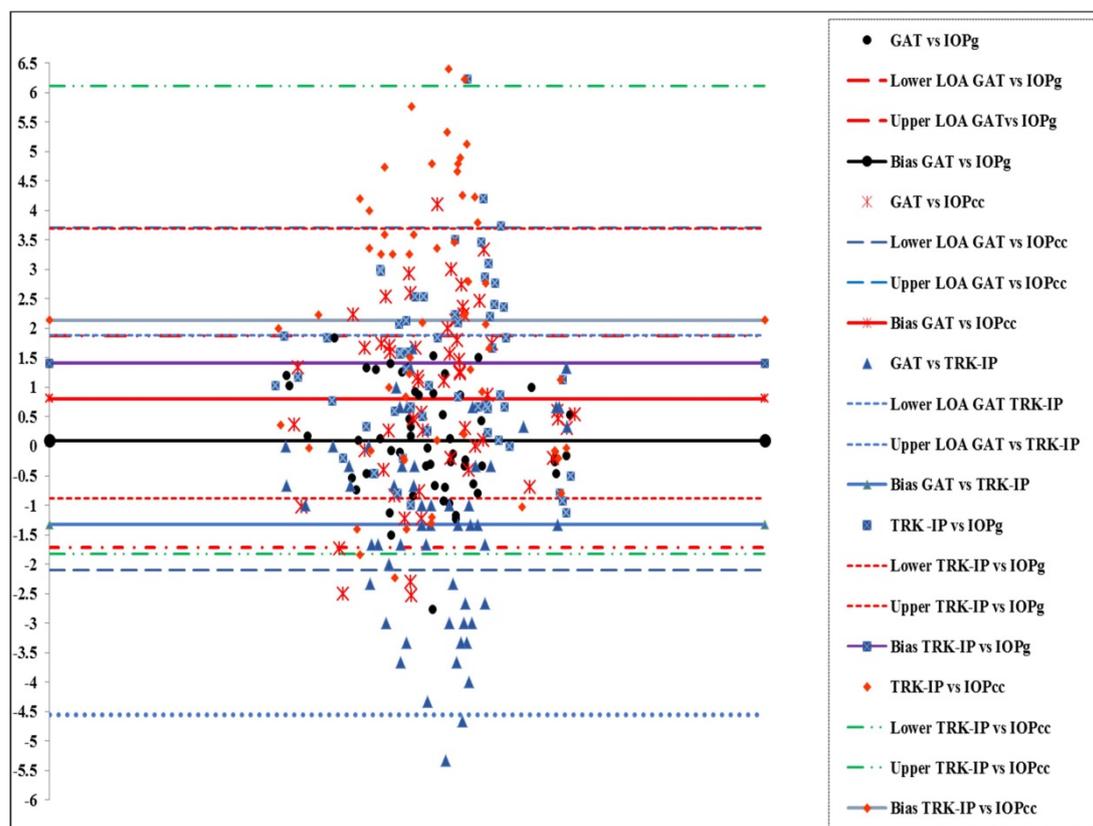
Bland-Altman plots of the mean differences and limits of agreement (LOAs) of IOP measurements using GAT versus IOPg, IOPcc, and TRK-IP and using TRK-IP versus IOPg and IOPcc are shown in Figure 3.

### Discussion

Precise, reliable assessment of IOP measurements is important for maintaining ocular visual function, decision-making regarding treatment modalities in patients with glaucoma, and improvements in treatment regimens [16].

Intra-observer repeatability of IOP measurements obtained with the three instruments demonstrated that GAT and IOPg had higher levels of reliability and repeatability and good agreement for multiple observations per individual. The ICCs of GAT and IOPcc, GAT and TRK-IP, and TRK-IP and IOPg showed good levels of reliability and repeatability below 0.80, yet did not yield sufficient agreement for multiple observations per individual, as shown by the wide distributions of the Bland-Altman. In contrast, the ICC TRK-IP and IOPcc measurements yielded poor levels of reliability, repeatability, and agreement of multiple observations per individual. In general, the results suggested that measurements of IOP obtained using different techniques may not be directly comparable.

Furthermore, the results showed that GAT and IOPg had higher levels of reliability and repeatability (as indicated by CVs and ICCs) than TRK-IP. Statistical analysis revealed that there was high intra-observer repeatability for GAT and IOPg, but high intra-observer variability for TRK-IP. Bland-Altman analyses of IOP measurements showed poor LOAs between GAT and TRK-IP, TRK-IP and IOPg, and TRK-IP and IOPcc, as shown by the wide distributions of the Bland-Altman plots. However, good agreement was noted between GAT and IOPg and between GAT and IOPcc, with mean differences of 0.1 and 0.81 mmHg, respectively. Overall, these results suggested that each tonometer was in and of itself reliable and consistent.



**Figure 3:** Bland-Altman plot of agreement showing the mean differences and limits of agreement of IOP measurements using GAT versus IOPg, IOPcc, and TRK-IP and using TRK-IP versus IOPg and IOPcc.

Several of studies have reported high intra-observer repeatability of IOP measurements obtained using GAT and IOPg in normal eyes [17-19]. Our results show high intra-observer consistency and repeatability of IOP measurements obtained with GAT and IOPg. However, Wang et al. [20] reported higher CVs (9.70 and 7.0, respectively) and ICCs (0.79 and 0.79, respectively) for GAT and IOPg. This discrepancy could be due to the sample size used in their study. No previous reports have examined the relative performance of TRK-IP. This study demonstrated that the TRK-IP instrument showed good intra-observer consistency and repeatability of IOP measurements.

In this study, the 95% limits of agreement of the between GAT and IOPg, GAT and TRK-IP, TRK-IP and IOPg, and TRK-IP and IOPcc were outside the accepted limits, indicating that they were not interchangeable. For GAT and the noncontact tonometer, this may be because noncontact tonometry tended to overestimate the GAT at high IOPs and underestimate GAT at low IOPs due to the CCT effect [20,22,23]. However, comparisons between noncontact tonometers could be explained by the use of different calculation methods to obtain the IOP [22].

## Conclusion

GAT, ORA, and TRK-IP are highly reliable for measurement of the IOP; however, the instruments cannot be used interchangeably.

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