

TonoVet versus Tonopen in a high intraocular pressure monkey model

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Purpose: The purpose of this study is to evaluate the consistency of and deviation in intraocular pressure (IOP) measurements obtained by the TonoVet rebound tonometer and the Tonopen applanation tonometer in a primate model.

Methods: Twenty-four-hour IOPs (nine time points) were recorded in ten monkeys with normal IOP and eight monkeys with chronic high IOP (one eye was randomly selected for measurement in each animal) using a Tonopen and TonoVet device. Measurements obtained using both handheld devices were first compared in the healthy control group (90 readings). The monkeys with chronic ocular hypertension (COHT, 72 IOP readings) were divided into three subgroups according to the level of IOP. The consistency of and deviations in the measurements were analyzed using Bland–Altman plots, linear regression, and two-tailed Student *t* tests.

Results: In monkeys with normal IOP, the two devices produced similar IOP readings (mean IOP deviation, 0.06 ± 2.08 mmHg, $p = 0.761$), with 56.67% of the deviation between -1 mmHg and 1 mmHg and 91.12% between -3 mmHg and 3 mmHg. However, in the animal model group (23 – 60 mmHg), the readings obtained by the TonoVet tonometer were higher than those obtained by the Tonopen tonometer (mean deviation, 13.76 ± 9.19 mmHg); furthermore, 75.68% of the TonoVet measurements deviated by ± 5 mmHg from the Tonopen measurements.

Conclusions: In animals with normal IOP, the TonoVet and Tonopen tonometers produced consistent measurements. However, in a monkey model of chronic high IOP, the measurements obtained by these tonometers were inconsistent, with higher IOPs associated with larger measurement errors. Therefore, it is necessary to be aware that among different tonometers, there may be systemic errors and deviations in IOP measurements. These findings should facilitate efforts to obtain more accurate individualized diagnoses and prevent the utilization of misleading IOP values.

High intraocular pressure (IOP) is a major risk factor for the development and progression of glaucoma [1,2]. Currently, lowering IOP is the only approach confirmed to be efficient in preserving visual function in these patients [3,4]. To more accurately measure IOP, it is necessary to use reliable IOP measuring instruments in routine clinical practice. Presently, the Goldmann applanation tonometer (GAT) is the gold standard for IOP measurements [5,6]. However, in infants and patients with corneal disease, as well as in experimental research models, the Tonopen applanation tonometer and the TonoVet rebound tonometer have gradually gained attention, and they are now the most commonly used types of tonometers, because both devices are easy to use [7,8]. However, there is still some debate about the consistency of the tonometer measurements obtained using these devices. Most previous studies have reported that the TonoVet tonometer may be a more appropriate choice than the Tonopen tonometer [9-13]. Unfortunately, other researchers

have suggested that TonoVet measurements may not be accurate enough to replace the GAT; for example, in glaucomatous or ocular hypersensitive eyes, compared to the GAT, the TonoVet tonometer may overestimate IOP measurements somewhat [14,15]. In experimental studies, there is currently a lack of evidence regarding the level of consistency between TonoVet and Tonopen tonometer readings over a wide range of IOPs in animals with chronic high IOP. Thus, it remains unknown whether the inconsistency observed in humans exists in animal research models. This study was designed to calculate discrepancies between measurements obtained using the Tonopen and TonoVet devices in a monkey chronic ocular hypertension (COHT) model in animals with different IOP levels. The aim of this study is to provide guidance for studies exploring glaucoma.

METHODS

Animals and anesthesia: The study procedures were performed according to the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research and the guidelines developed by the Animal Care Committee at Zhongshan Ophthalmic Center (Permit Number: 2012-072). Twenty adult rhesus monkeys (4- to 6-year-old males weighing between 4

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and 8 kg) were purchased from Landao Biotechnology Co., Ltd. (Guangdong, China) and used to evaluate consistency between the two tonometers. The monkeys were raised in large cages with adequate room for activities and fed nutritious food and water. The rooms were illuminated on a 12 h:12 h light-dark cycle (daytime light intensity of approximately 200 lux) under controlled conditions, including humidity (50–55%) and temperature (24–25 °C). The health of the monkeys was monitored daily by animal care staff and veterinary personnel. All experimental procedures were performed under deep general anesthesia via an intramuscular injection of ketamine hydrochloride (5 mg/kg, Ketalar 50®, GuTian Pharmaceuticals Ltd., Fujian, China) plus chlorpromazine hydrochloride (2.5 mg/kg, chlorpromazine 50®, JiaoZuo Pharmaceuticals Ltd., Tianjin, China).

Establishment of a chronic ocular hypertension monkey model: Eight out of ten monkeys underwent successful induction of COHT (we randomly selected one eye in each animal for measurements). All of the animals were deeply anesthetized. The body was placed in the prone position, and the head was then held and adjusted to a nearly upright position suitable for measurement. The important steps of this procedure are described below. Tests performed before laser photocoagulation (to exclude existing ocular disease) included an IOP measurement, a slit-lamp examination, color fundus photography, and optical coherence tomography (OCT) of the retinal nerve fiber layer (RNFL) thickness. The pupils were sufficiently contracted (to 1 mm) with a 1% pilocarpine ophthalmic solution (Pilocarpine®, Zhongshan Ophthalmic Center, Guangdong, China), and the corneas were anesthetized with 0.5% proparacaine hydrochloride (Alcaine®, Alcon Pharma, Belgium). The entire circumference of the trabecular meshwork (TM) was ablated with the VISULAS Trion (Carl Zeiss Meditec AG, Jena, Germany) using a slit-lamp delivery system and laser gonioscope as previously described [16,17]. The laser parameters were slightly modulated as follows: 50 µm spot size, 0.5 s duration, 1,000 mW laser power, and 150–250 spots. The laser treatments were performed repeatedly to obtain a stable high IOP as previously described. Care was taken to indicate that the middle TM was photocoagulated. The presence of a vapor bubble signified that the TM was effectively ablated. Tobramycin dexamethasone and tropicamide eye drops (Alcon Laboratories Inc.) were used to alleviate any noninfectious inflammation during the immediate postlaser photocoagulation period. A single IOP measurement was obtained every week. If the IOP was not consistently higher than 21 mmHg, additional laser photocoagulation was performed at 3-week intervals until stable IOP was obtained.

Identification of a chronic ocular hypertension monkey model:

Color photography—A color fundus photograph of 35° of the eye was obtained weekly in anesthetized animals in the prone position (with the body placed in the prone position and the head then held and adjusted to a nearly upright position suitable for measurement) using a retinal camera (TRC-50DX Retinal Camera, Topcon, Tokyo, Japan) with a Nikon 200 D digital camera. Surface topical anesthesia was applied after the eye was opened. The pupils were sufficiently dilated (≥ 8 mm) with a 0.25% tropicamide ophthalmic solution (Mydrin®, Santen Pharmaceutical, Osaka, Japan). The clarity of the corneas was preserved with an ocular lubricating agent (Artificial tears®, Zhongshan Ophthalmic Center, Guangdong, China) during the examination. The narrowed neuroretinal rim and the enlarged optic cup were observed in the animal model.

Optical coherence tomography measurements of RNFL thickness—Cross-sectional images of the RNFL were scanned weekly with a circular scan (3.4 mm diameter) procedure using a Stratus OCT Instrument (Model 3000, Carl Zeiss Meditec, Dublin, CA). Deeply anesthetized animals were immobilized using a board to maintain the spine's posture and gently held in place by an operator. Surface topical anesthesia was applied after the eye was opened. The pupils were appropriately dilated, and the corneas were kept clear using a method similar to that used during color photography measurements. The RNFL thickness was then examined in the animal model.

Central corneal thickness assessment: Anterior segment optical coherence tomography (AS-OCT; Fourier OCT, Carl Zeiss Meditec, Dublin, CA) was used to measure the central corneal thickness (CCT) before the first laser photocoagulation to exclude the effect of corneal thickness on IOP measurements in each animal. The posture of the spine was maintained in a manner similar to that used for color photography during the examination in all anesthetized animals. Surface topical anesthesia and an ocular lubricating agent were also used. The procedure was performed using a four-line scan model of the cornea. The line was centered on the corneal vertex, and the scans were performed as horizontal, vertical, 45°, and 135° scans. Particular attention was paid to the eye position and scan lines through the central cornea.

Measurement of intraocular pressure: IOP was measured in ten healthy monkeys (one eye was randomly selected in each animal) and eight monkeys with COHT (eyes with high IOP) using the TonoVet® rebound tonometer (Finland, TV01) and the Tonopen XL® applanation tonometer (Reichert, Depew, NY) in compliance with the manufacturers' recommended

procedures. All experimental monkeys were placed under deep general anesthesia, but topical eye anesthetics were avoided during this measurement. The animals were seated and gently held in place at a desk by one operator while another experienced operator obtained all IOP measurements with the two tonometers. Both tonometers were calibrated before each measurement. The TonoVet tonometer was used first and was followed by the Tonopen tonometer 1 min later. The reasoning behind this order was that the TonoVet tonometer requires a smaller area of contact with the cornea; however, measurement error can be reduced by recording the measurements with both tonometers 1 min apart.

Due to the limited number of subjects, nine IOP measurements were obtained in each animal; to obtain more digital differential pressure data, these times were based on a 24 h pattern observed in IOP fluctuations [18]. According to our previous study, the monkeys' high IOP was sustained for 3–6 weeks [19]. Some problems, such as transient IOP increases and corneal edema, were observed during the previous post-laser photocoagulation period. To reduce measurement bias caused by these problems as much as possible, 24 h IOP levels were measured after the high IOP and ocular conditions were stabilized. To maintain a high IOP, every monkey underwent multiple laser procedures, and some monkeys experienced severe spikes in IOP. Extra laser photocoagulation was not performed in the COHT animal models once a stable high IOP was achieved, and laser-induced ocular noninfectious inflammation and corneal edema then gradually disappeared. The fifth week after the first photocoagulation was chosen as the time point for IOP measurement; at this time, single IOP measurements had gradually dropped to approximately 21 mmHg, and different IOP levels were observed during the 24 h span because of fluctuations in the model animals' IOP. The 24 h IOP measurement points were obtained at 1:30, 3:30, 6:30, 9:30, 12:30, 15:30, 18:30, 21:30, and 23:30, because of the general anesthesia used on the monkeys [20].

According to the individual properties of both tonometers, six consecutive IOP readings were obtained using the TonoVet rebound tonometer, and ten consecutive IOP readings by the Tonopen tonometer were acquired for each measurement. The average IOP value of each tonometer was automatically calculated for each measurement. An average IOP value for several measurements obtained at each time point was used for the statistical analyses. Only consecutive readings that showed little value variation (<3 mmHg) at each time point were regarded as valid measurements.

Statistical analysis: Statistical analyses were performed using SPSS software (Version 13.0, SPSS, Chicago, IL). Pearson's r coefficient of correlation was used to evaluate the CCT and

IOP measurements. Bland–Altman plots constructed to assess consistency for both tonometers. The deviations between the Tonopen applanation tonometer and the TonoVet rebound tonometer were analyzed with linear regression and two-tailed Student t tests in the model. Data are expressed as the means \pm standard deviation (SD). Deviation were considered statistically significant when the p value was less than or equal to 0.05.

RESULTS

Corneal thickness and IOP measurements: The average CCT values obtained in the ten healthy monkeys and the eight monkeys with high IOP were $500.00 \pm 10.95 \mu\text{m}$ and $496.25 \pm 19.23 \mu\text{m}$ (mean \pm SD), respectively. The correlation coefficients between the IOPs obtained using the Tonopen and TonoVet tonometers and the CCT values in the healthy control group were 0.15 ($p = 0.66$) and -0.30 ($p = 0.37$), respectively. Similarly, there was no statistically significant correlation between the CCT and IOP values in the animal model group (Spearman correlation coefficient: -0.33 and -0.30 , respectively, and $p = 0.42$ and $p = 0.47$, respectively).

Comparison of Tonopen and TonoVet measurements in healthy monkeys: The average IOP measurements obtained using the TonoVet and Tonopen devices were 12.99 ± 3.04 mmHg (range, 8 to 21 mmHg) and 12.92 ± 2.31 mmHg (range, 6 to 20 mmHg), respectively. There was no statistically significant difference between the measurements obtained for the average IOP between the two instruments (two-tailed Student t test: 0.06 ± 2.08 mmHg, $p = 0.761$). The Tonopen and TonoVet readings were strongly and linearly correlated in the normal IOP monkey eyes, as shown in Figure 1A. The Bland–Altman analysis with 95% limit of agreements (LoAs) is shown in Figure 1B. The 95% LoA width was between -4.13 and 4.00 mmHg. Table 1 indicate that there were small deviations in IOP for both tonometers. Furthermore, 56.67% of the deviations were concentrated between -1.00 and $+1.00$ mmHg, and 91.12% were located between -3.00 and $+3.00$ mmHg. There was good consistency in the IOP measurements obtained using both tonometers in healthy monkeys with normal IOPs.

Comparison of Tonopen and TonoVet measurements obtained in monkeys with COHT: A COHT monkey model was established according to the ocular manifestations (Figure 2). The average IOP measurements obtained using the Tonopen and TonoVet tonometers were 23.49 ± 7.67 mmHg (range, 12.00 to 47.00 mmHg) and 32.88 ± 14.93 mmHg (range, 16.00 to 71.00 mmHg), respectively. There was a strong corresponding linear regression between the TonoVet and Tonopen measurements in the COHT monkey group (linear regression: $Y =$

TABLE 1. EVALUATION OF THE CONSISTENCY BETWEEN THE TONOPEN AND THE TONOVELT MEASUREMENT IN CONTROL HEALTHY MONKEYS.

Tonometers	IOP ≤21 mmHg (n=90 readings)	
	Tonopen	TonoVet
Mean ± SD	12.92±2.31	12.99±3.04
Range	6-20	8-21
Δ Mean ± SD	0.06±2.08	
Δ Range	-5-7	
95% CI	-4.13 – 4.00	
Δ < ±1 mmHg*	56.67%	
Δ < ±3 mmHg†	91.12%	
P	0.761	

Δ Mean ± SD: mean and standard deviation of difference (TonoVet minus Tonopen) * IOP difference smaller than ± 1 mmHg † IOP difference smaller than ± 3 mmHg

1.62X + -5.24), as shown in Figure 3A. The mean deviation in IOP measurements between the TonoVet and Tonopen devices was calculated as the TonoVet reading minus the Tonopen reading, and was found to be 9.39 ± 8.22 mmHg (range, -1.00 to +30.0 mmHg). The same strong linear regression was observed in the mean IOP deviations between the two tonometers (linear regression: $Y = 0.62X + -7.96$), with higher IOP values associated with larger deviations between the two tonometer measurements (Figure 3B).

According to the International Organization Standardization standard for human eye tonometers (ISO 8612) [21], the 72 IOP readings obtained in the COHT model group were divided into three subgroups based on the differences in the Tonopen readings (the Tonopen readings were selected because they had a smaller standard deviation), as follows: 13 readings were placed in the low-pressure group (range,

7.0–16 mmHg), 22 were placed in the medium-pressure group (range, 17–22 mmHg), and 37 were placed in the high-pressure group (range, 23–60 mmHg). In the low-pressure group (IOP: 7–16 mmHg), the IOP readings deviated by $4.46 ± 1.66$ mmHg, as shown in Figure 4A; 23.08% of the IOP measurements acquired using the TonoVet tonometer deviated by ± 5.00 mmHg from the Tonopen measurements, and this difference was statistically significant (two-tailed Student *t* test: $p < 0.001$; Table 2). For eyes with higher IOPs ranging from 17 to 22 mmHg, 36.36% of the TonoVet measurements deviated by ± 5.00 mmHg from the Tonopen measurements, and the mean difference calculated as the mean TonoVet reading minus the mean Tonopen reading was $4.95 ± 3.57$ mmHg, indicating a statistically significant difference (two-tailed Student *t* test: $p < 0.001$) (Table 2 and Figure 4B). In the high-pressure group (IOP: 23–60 mmHg),

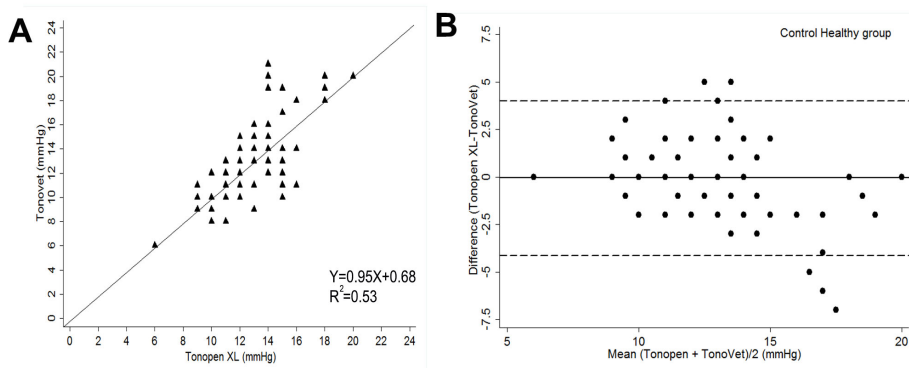


Figure 1. Consistency analysis in monkey eyes with normal intraocular pressure (IOP). **A:** Regression analysis between TonoVet rebound and Tonopen applanation tonometer readings (n= 90 readings) demonstrated that the tonometer readings obtained using these two devices were strongly and linearly correlated; **B:** Consistency between

TonoVet and Tonopen readings was evaluated using Bland-Altman analysis, with the means plotted against the deviations between TonoVet and Tonopen readings.

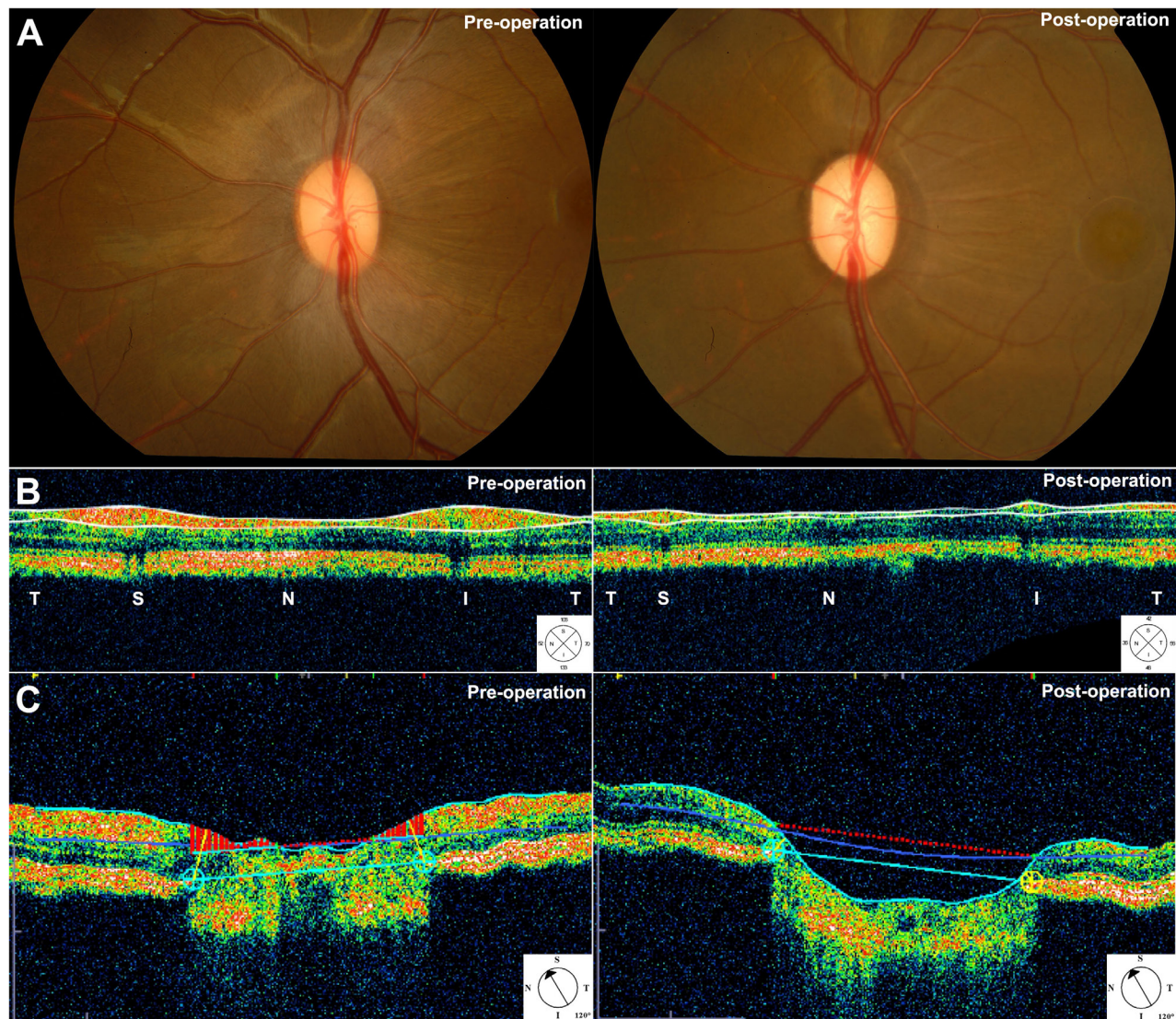


Figure 2. A monkey model of chronic ocular hypertension was established. **A:** Fundus: The enlarged optic cup. **B:** Optical coherence tomography (OCT): The damaged retinal nerve fiber layer. **C:** OCT: The enlarged optic cup.

the deviation in IOP readings between the two devices was 13.76 ± 9.19 mmHg, and 75.68% of the measurements deviated by ± 5.00 mmHg; indicating instrumental systemic error (two-tailed Student *t* test: $p < 0.005$) (Table 2 and Figure 4C).

DISCUSSION

The TonoVet rebound tonometer and the Tonopen applanation tonometer are the most commonly used IOP measuring instruments in experimental research studies. At present, most published studies acknowledge that there is some level of consistency between these devices in eyes with normal

IOP [9-12]. However, under high IOP conditions, not enough evidence is available to support the notion that measurements are consistent between the two tonometers. The most important finding of this study is that the TonoVet measurements were consistent with the Tonopen measurements in monkey eyes with normal IOP; however, as the IOP gradually increased, the readings produced by the TonoVet tonometer were larger than those produced by the Tonopen tonometer. Additionally, there was a quantitative relation between the tonometer measurements when the deviations and the IOP levels were investigated.

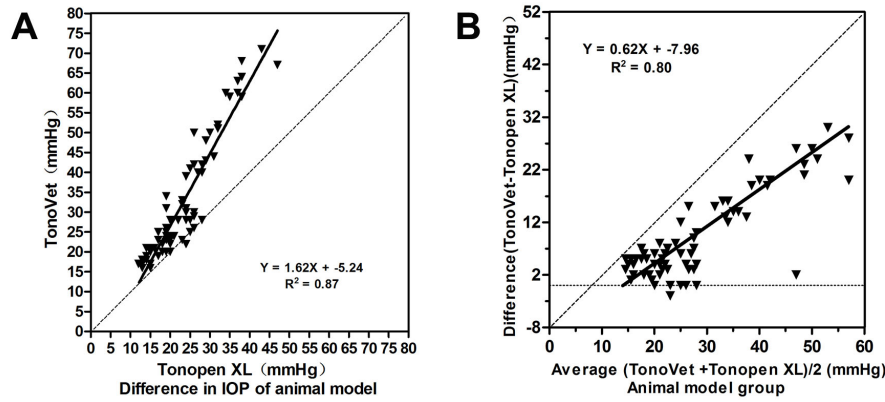


Figure 3. Consistency analysis in COHT monkey models. **A:** Regression analysis between TonoVet rebound and Tonopen applanation tonometer readings (n= 72 readings); **B:** Deviations in IOP values (calculated as TonoVet minus Tonopen) are shown plotted against the average IOP ((TonoVet plus Tonopen)/2). The solid line represents the regression line, and the dotted lines represent 95% confidence interval limits. Duplicates were distributed in the graph.

We reviewed previously published clinical papers that explored consistency in IOP measurements. Munkwitz compared the rebound tonometer and the GAT in 75 eyes of 75 patients, and reported that the deviations in IOP values were similar between these two tonometers (range, 7.0–22 mmHg). However, the deviations were almost twice as large in the higher IOP range (23–60 mmHg), where they deviated by 12.56 ± 11.98 mmHg [14]. Martinez-de-la-Casa also found that compared to the GAT, the rebound tonometer tended to overestimate IOPs, and the deviation between the two instruments reached as high as 7.7 mmHg in eyes with high IOP [15]. These reports led us to question the consistency between TonoVet and Tonopen measurements. In this study, we first compared measurements obtained using both handheld devices in a healthy control group. As previously reported [22], in monkeys, the IOP readings were similar between the Tonopen and TonoVet tonometers in eyes with

normal IOP, with 56.67% of the deviations between -1 and $+1$ mmHg, and 91.12% of the deviations below 3 mmHg ($p = 0.761$). In the normal IOP group, therefore, the range of deviations was “acceptable.” Subsequently, the deviations in measurements obtained using the TonoVet and Tonopen devices were investigated in animals with different IOP levels. When the IOP was above 23 mmHg, 75.68% of the TonoVet measurements deviated by ± 5.00 mmHg from the Tonopen measurements, and the deviation between the tonometers reached as high as 13.76 ± 9.19 mmHg. The standard deviation for the TonoVet measurements was higher for eyes in the high IOP range (23–60 mmHg). These results suggest that in monkeys with normal IOP, the IOP readings obtained using the TonoVet tonometer agreed with those obtained using the Tonopen device, whereas the IOP readings were not always in agreement in the high IOP range.

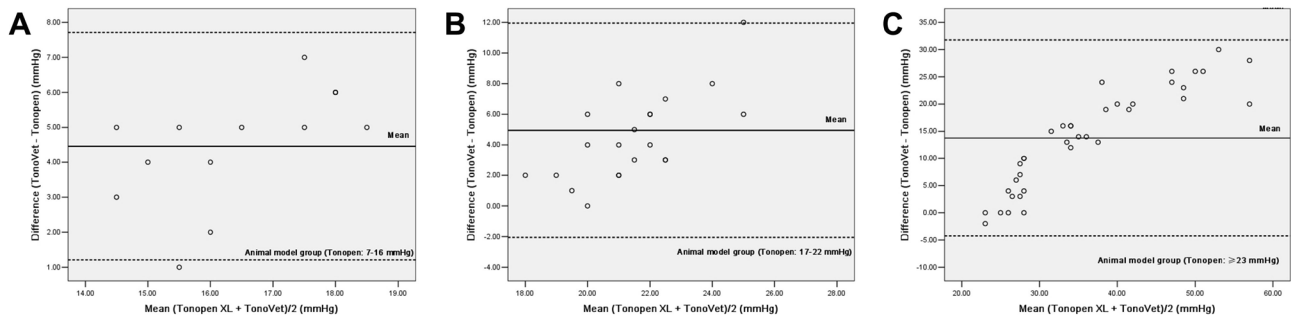


Figure 4. Consistency between TonoVet and Tonopen measurements was evaluated using the Bland–Altman analysis in animals with different IOP levels in the COHT monkey group. The averages are shown plotted against the deviations. Higher intraocular pressure (IOP) values were associated with worse consistency for both tonometers. The solid line represents the average deviation, and the dotted lines indicate the 95% limits of the confidence intervals.

Thus far, few publications have explored the consistency in evaluations obtained using these two tonometers in monkeys with chronic high IOP over a wide range of IOP values. Some researchers have reported that these two convenient handheld tonometers have excellent consistency when used in monkey eyes with normal IOP and in monkey eyes with regulated IOP in which IOP was adjusted by modifying the height of a connected perfusate reservoir [12,23,24]. The novel finding presented in this study appears to be the comparison of monkeys with chronic experimentally induced high IOP. These models closely mimic open angle glaucoma, in which IOP is gradually and chronically elevated, and does not sharply increase. The animal model used in this study presented with stable high IOP and an anterior eye segment condition. This model allowed us to avoid acute corneal edema, anterior chamber inflammation, and ciliary body dysfunction, which can be caused by acute high IOP. It has been suggested that a laser-induced COHT monkey model could be useful for comparing deviations in tonometer measurements.

Additionally, because the number of animals was limited, and it is difficult to establish a chronic high IOP model, we chose to use 24 h IOP measurements as a solution, to obtain more differential digital pressure data for this experimental study, although this decision represents a flaw. To our knowledge, higher IOP values are associated with higher IOP fluctuations. There is some evidence indicating that monkeys exhibit large variations in IOP values from day to day and hour to hour, especially under high IOP conditions [18,25]. Thus, in this study, we used 18 monkeys (ten with normal IOP and eight with COHT) to measure 24 h IOP values (nine times for each eye). The 24 h IOP measurements were measured during the 15th week after the first photocoagulation. At that time, although the single IOP measurements had gradually

dropped to approximately 21 mmHg, there were large fluctuations in the 24 h IOP values. Thus, different IOP levels were obtained to guarantee proper data analysis. Moreover, laser-induced transient IOP increases and corneal edema were avoided, and did not influence the IOP measurements. The total number of IOP readings was in line with the statistical sample size estimation.

The GAT is the international gold standard for IOP measurement. It is difficult for monkey to complete the GAT measurement because the position of the monkey's eye (a mild upshift) causes the corneal center to shift under general anesthesia. It cause the two semicircles of the flattened corneal surface to be unequal or, in some cases, two semicircles do not form, affecting IOP measurements. Although it is regrettable that the GAT could not be used as a control, in this study, we focused on the comparison between the TonoVet rebound tonometer and the Tonopen applanation tonometer, as these two tonometers are the instruments most commonly used to measure IOP in experimental research studies. It remains to be determined which tonometer is the most precise and reliable. The quantitative relation between the IOP levels and the deviations observed for both IOP measurement apparatuses was investigated. The present results could play a role in glaucoma studies that use experimental animals. Additionally, the Tonopen and TonoVet tonometers need only a small area of contact with the cornea; the fact that it is not necessary to form a semicircular ring to obtain an IOP value during the measurement process represents an obvious advantage for measuring IOP in animals. The TonoVet tonometer might be more useful in small animals that have normal or slightly high IOP, such as rats and other animals used to study corneal disease, because this device requires only a small contact area. The Tonopen tonometer might be more suitable than the TonoVet tonometer in cases in which moderate to advanced

TABLE 2. EVALUATION OF THE CONSISTENCY BETWEEN THE TONOPEN AND THE TONOVET MEASUREMENT IN COHT MONKEY MODELS.

Tonometers	IOP 7–16 mmHg (n=13 readings)		IOP 17–22 mmHg (n=22 readings)		IOP 23–60 mmHg (n=37 readings)	
	Tonopen	TonoVet	Tonopen	TonoVet	Tonopen	TonoVet
Mean ± SD	14.15 ± 1.14	18.62 ± 1.98	19.23 ± 1.31	24.18 ± 3.62	29.3 ± 6.12	43.05 ± 14.29
Range	12-16	16 - 21	17 - 22	19 - 34	23 - 47	22 - 71
Δ Mean ± SD	4.46±1.66		4.95±3.57		13.76±9.19	
Δ Range	1-7		0 - 15		-32	
95% CI	3.46 - 5.47		3.37 - 6.54		10.69 - 16.82	
Δ > ±5 mmHg*	23.08%		36.36%		75.68%	
P	0		0		0.003	

Δ Mean ± SD: mean and standard deviation of difference (TonoVet minus Tonopen) * IOP difference bigger than ± 5 mmHg

high IOP values must be measured, because the Tonopen tonometer has a more stable standard deviation.

The use of anesthetized animals as experimental subjects is one flaw of this study. In a clinical setting, IOP is likely to be influenced by anesthetics and anesthetic drugs [26-28]. In addition, anesthesia causes IOP to increase in rabbits, cats, and Syrian hamsters [29-31]. However, no previous study explored how anesthesia acts on IOP in nonhuman primates. Anesthesia is difficult to avoid in animal research. In this study, IOP measurements were obtained in anesthetized monkeys without topical anesthesia. The animals were reanesthetized before each IOP measurement obtained during the study. Thus, all of the IOP measurement results were affected by anesthesia, and it may have had a small effect on the conclusions regarding the IOP measurements obtained in this study.

In summary, the results of this study suggest that TonoVet measurements are consistent with Tonopen measurements for normal IOP samples. However, in monkey models with chronic high IOP, inconsistencies were observed between results obtained using these two tonometers. We found that higher IOP values could be associated with larger measurement error. Therefore, it is necessary to be aware of the systemic error that can be observed in IOP measurements, and the deviations among different tonometers, to facilitate accurate individualized diagnoses and prevent the utilization of misleading IOP values.

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