



Comparison of Non-contact Tonometry and Goldmann Applanation Tonometry Measurements in Non-pathologic High Myopia

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Purpose: To compare intraocular pressure (IOP) values obtained using Goldmann applanation tonometry (IOP_{GAT}) and non-contact tonometry (IOP_{NCT}) in a non-pathologic high myopia population.

Methods: A total of 720 eyes from 720 Chinese adults with non-pathologic high myopia were enrolled in this cross-sectional study. Demographic and ocular characteristics, including axial length, refractive error, central corneal thickness (CCT), and corneal curvature (CC) were recorded. Each patient was successively treated with IOP_{NCT} and IOP_{GAT}. Univariate and multivariable linear regression analyses were conducted to detect factors associated with IOP_{NCT} and IOP_{GAT}, as well as the measurement difference between the two devices (IOP_{NCT-GAT}).

Results: In this non-pathologic high myopia population, the mean IOP_{NCT} and IOP_{GAT} values were 17.60 ± 2.76 mmHg and 13.85 ± 2.43 mmHg, respectively. The IOP measurements of the two devices were significantly correlated ($r = 0.681$, $P < 0.001$), however, IOP_{NCT} overestimated IOP_{GAT} with a mean difference of 3.75 mmHg (95% confidence interval: 3.60–3.91 mmHg). In multivariate regression, IOP_{NCT} was significantly associated with body mass index (standardized $\beta = 0.075$, $p = 0.033$), systolic blood pressure (SBP) (standardized $\beta = 0.170$, $p < 0.001$), and CCT (standardized $\beta = 0.526$, $p < 0.001$). As for IOP_{GAT}, only SBP (standardized $\beta = 0.162$, $p < 0.001$), CCT (standardized $\beta = 0.259$, $p < 0.001$), and CC (standardized $\beta = 0.156$, $p < 0.001$) were significantly correlated. The mean IOP_{NCT-GAT} difference increased with younger age (standardized $\beta = -0.134$, $p < 0.001$), higher body mass index (standardized $\beta = 0.091$, $p = 0.009$), higher SBP (standardized $\beta = 0.074$, $p = 0.027$), thicker CCT (standardized $\beta = 0.506$, $p < 0.001$), and lower IOP_{GAT} (standardized $\beta = -0.409$, $p < 0.001$).

Conclusion: In the non-pathologic high myopia population, IOP_{NCT} overestimated IOP_{GAT} at 3.75 ± 2.10 mmHg. This study suggests that the difference between the values obtained by the two devices, and their respective influencing factors, should be considered in the clinical evaluation and management of highly myopic populations.

Keywords: intraocular pressure, high myopia, non-contact tonometry, Goldmann applanation tonometry, axial length, central corneal thickness, corneal curvature

INTRODUCTION

High myopia is an extreme form of myopia, mainly characterized by excessive axial elongation and various pathological ocular lesions (1). A growing body of evidence suggests that high myopia is closely related to the occurrence of glaucoma (2–7). As intraocular pressure (IOP) is the most important target and the only treatable factor in glaucoma, accurate and reliable measurement as well as monitoring of IOP are essential in highly myopic populations.

Many types of devices have been proposed for IOP measurement, such as Goldmann applanation tonometry (GAT), non-contact tonometry (NCT), ICare rebound tonometer, and dynamic contour tonometer, each of which has advantages and disadvantages (8). The GAT is widely regarded as the gold standard for IOP measurement due to its accuracy and excellent reproducibility, while NCT is most widely used in outpatients and in ocular hypertension screening because of its non-invasive and convenient nature (9, 10). However, all measurements are influenced by the structure and biomechanical properties of the cornea, such as the cornea thickness and hysteresis, as well as systemic factors such as systolic pressure (11–13).

Due to excessive elongation of axial length (AL) in high myopia, which is accompanied by changes in scleral and corneal structures and their biomechanics, IOP values obtained may vary among different tonometers. Previous studies have reported the distribution of IOP values in high myopia populations, ranging from 9 to 27 mmHg, as measured by the GAT or NCT (14, 15). Comparative studies on IOP measurement with the NCT and GAT in high myopia populations are limited, and results from different measurements may not be comparable.

The present study aimed to evaluate the difference in IOP measurements obtained with the NCT and GAT in a population with non-pathologic high myopia, and the demographic and ocular characteristics that affect these measurements. The present findings may inform a more comprehensive and reliable management of IOP in highly myopic patients.

MATERIALS AND METHODS

Study Participants

This prospective cross-sectional study was conducted at the Zhongshan Ophthalmic Center (ZOC), Sun Yat-sen University, Guangzhou. Participants were recruited from a registry cohort study on the natural history of myopic neuropathy, which started from June 2019 to June 2021 (ClinicalTrials.gov identifier: NCT04302220) (16). This study was approved by the Ethics

Review Committee of the ZOC, and the study procedure conformed to the Declaration of Helsinki. Informed consent was obtained from all the participants prior to enrollment.

High myopia adults aged 18–65 years were recruited, as previously reported (16). Briefly, patients were eligible for this study if either the left or right eye presented with myopic spherical equivalence (SE) of ≤ -6 diopters or AL of ≥ 26.5 mm, best corrected visual acuity (BCVA) of $\geq 6/12$, and myopic maculopathy category 0 or 1 [based on the International Photographic Classification and Grading System for Myopic Maculopathy (17)]. The right eye was chosen for analysis if both eyes met the inclusion criteria.

The exclusion criteria were as follows: (1) patients with severe systemic diseases such as malignant tumors, (2) a history of ocular surgery or laser treatment, and (3) ocular infection diseases that could not be measured by the GAT, such as corneal ulcers.

Demographic and Ocular Characteristics

In this study, blood pressure was measured twice using an automated blood pressure apparatus (Omron Healthcare Ltd., Japan), and the average value was recorded. Body mass index (BMI) was calculated as body weight (kg) divided by height (m) squared. Demographic and clinical characteristics such as age, sex, and other medical history data were collected through interviews.

All subjects underwent a comprehensive ophthalmic examination at the ZOC Clinical Research Center, including BCVA assessment, refractive error assessment with an autorefractor (KR-800, Topcon, Japan); slit lamp bio-microscopy (BQ-900, Haag-Streit, Switzerland), IOP measurement by both the NCT (mputeCT-1 Corized Tonometer, Topcon Ltd., Topcon) and GAT (Haag-Streit, Koniz, Switzerland); AL, central corneal thickness (CCT), and corneal curvature (CC) values were obtained using an IOL Master (IOL Master 700, Carl Zeiss Meditec, Germany); digital stereo fundus photography (Nonmyd WX3D, KOWA, Japan) was performed. All measurements were performed by well-trained technicians.

IOP Measurement

IOP was measured in all participants between 9:00 a.m. and 11:00 a.m. to minimize the influence of IOP circadian variations. Each participant was asked to calm down for at least 5 min before the measurement. The NCT assessment was performed 15 min before the GAT assessment; the

assessments were performed three times at 1-min intervals. Both instruments were periodically calibrated according to the manufacturer's guidelines, and the operations were conducted strictly following the manufacturer's instructions. During the GAT measurement, 0.5% proparacaine hydrochloride eye drops (Alcon, Fort Worth, TX, USA) were used for topical anesthesia, and fluorescein strips (Liaoning Meizilin Pharmaceutical Co., Ltd., China) were gently applied to the palpebral conjunctiva for corneal staining. The IOP measurement with the GAT was performed using a slit lamp mounted applanation tonometer and performed by the same experienced ophthalmologist twice, and the average values were recorded.

Statistical Analysis

In descriptive analysis, continuous variables were summarized as mean \pm standard deviation and range, and categorical variables were presented as frequency and proportion. The Bland-Altman analysis was performed to evaluate the agreement between IOP_{NCT} and IOP_{GAT} (18). The mean difference and limits of agreement (LOA) were calculated to quantify the extent of bias between the two measurements. Pearson's coefficient was used to assess the correlation between IOP_{NCT} and IOP_{GAT}. Linear regression analyses were conducted to determine the factors associated with IOP_{NCT}, IOP_{GAT}, and IOP_{NCT-GAT}. Variables with p -values of <0.1 in univariable linear regression were included in multivariable linear regression. All multivariable models were adjusted for age. Statistical significance was set at p -values of <0.05 . Statistical analyses were performed using Stata 16 software (Stata Corp., T.X., USA).

RESULTS

Participants' Characteristics

A total of 812 subjects were enrolled in this study; subsequently, 22 patients with a history of ocular surgery or laser treatment, 10 patients with ocular trauma or infection that could not complete a GAT measurement, 9 patients with severe systemic diseases, 34 patients using ocular hypotensive agents, and 17 patients with missing values of SE or IOL master measurement were excluded. Finally, a total of 720 subjects (720 eyes) with non-pathologic high myopia were included in the analysis. **Table 1** presents the clinical characteristics of the participants. The mean age was 31.10 ± 9.86 years (range 18 to 64 years), and 271 (37.64%) participants were male. The average AL, SE, CCT, and CC values were 26.90 ± 1.19 mm, -8.85 ± 2.22 diopter, 540.54 ± 32.03 μ m, and 43.80 ± 1.44 diopter, respectively.

Difference Between IOP_{NCT} and IOP_{GAT} Measurements

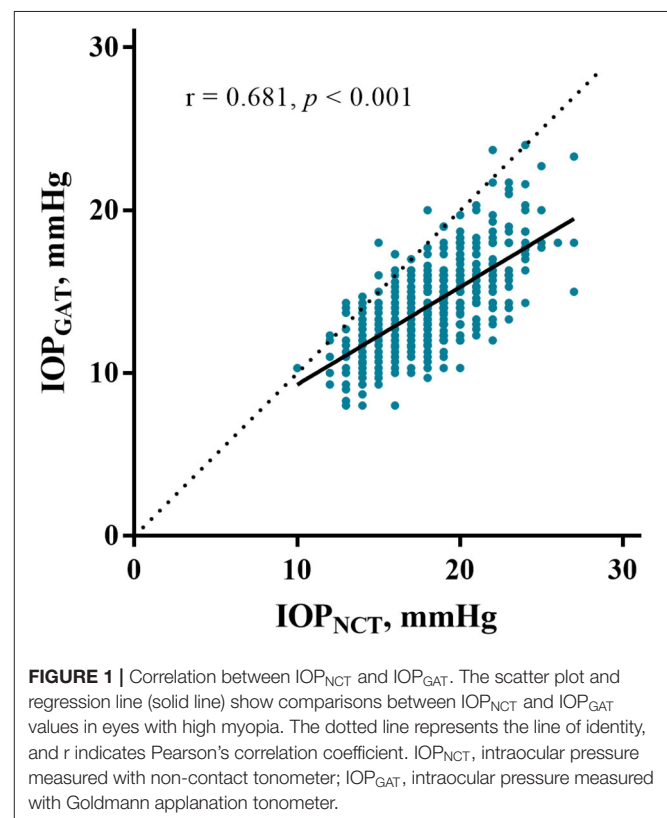
The average IOP_{NCT} and IOP_{GAT} values were 17.60 ± 2.76 mmHg and 13.85 ± 2.43 mmHg, respectively (**Table 1**). IOP_{NCT} and IOP_{GAT} values were significantly correlated ($r = 0.681$, $P < 0.001$) in linear regression analysis (**Figure 1**). The Bland-Altman scatter plot showed that the mean difference between

the two measurements was 3.75 mmHg, with LOA in the range of -0.35 to 7.86 mmHg. Only 5.14% (37/720) of IOP_{NCT-GAT} data points fell outside the LOA range (**Figure 2**).

TABLE 1 | Demographic and ocular characteristics of the high myopia participants.

Parameters	Mean \pm SD	Range
Systemic-related parameters		
Age (years)	31.10 \pm 9.86	18–64
Sex, male/female	271/449	
BMI (kg/m ²)	21.37 \pm 3.09	15.42–37.64
SBP (mmHg)	114.05 \pm 13.90	82–158
DBP (mmHg)	66.10 \pm 10.14	40–119
Ocular-related parameters		
Axial length (mm)	26.90 \pm 1.19	23.60–33.54
Central corneal thickness (μ m)	540.54 \pm 32.03	448.86–653.46
Corneal curvature (D)	43.80 \pm 1.44	39.51–49.05
Spherical equivalence (D)	-8.85 ± 2.22	-20.13 to -6.00
IOP (mmHg)		
IOP _{NCT}	17.60 \pm 2.76	10–27
IOP _{GAT}	13.85 \pm 2.43	8–24

Data are presented as mean \pm standard deviation and range unless stated otherwise. BMI, body mass index; D, diopter; DBP, diastolic blood pressure; IOP, intraocular pressure; IOP_{NCT}, intraocular pressure measured with non-contact tonometer; IOP_{GAT}, intraocular pressure measured with Goldmann applanation tonometer; SBP, systolic blood pressure; SD, standard deviation.



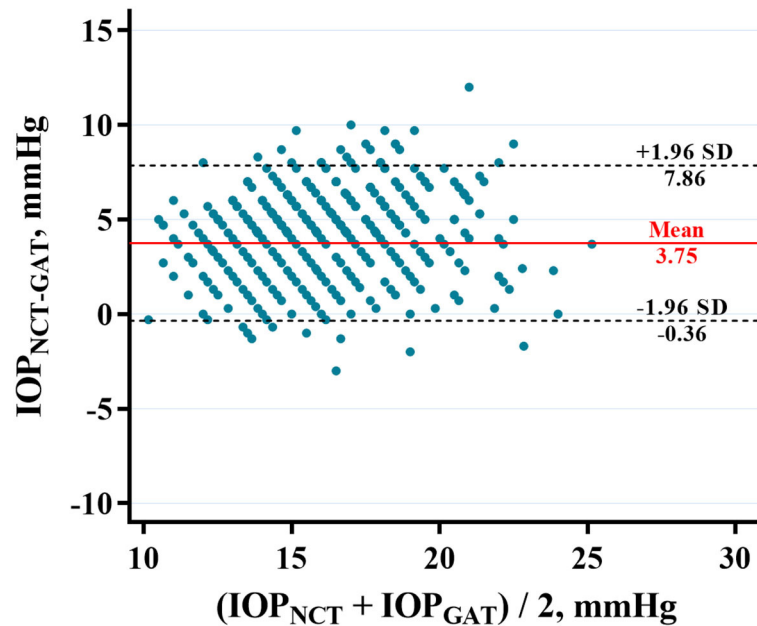


FIGURE 2 | Bland-Altman plot showing the agreement between IOP_{NCT} and IOP_{GAT} in highly myopic eyes. X axis, mean of IOP_{NCT} and IOP_{GAT} values. Y axis, the difference between IOP_{NCT} and IOP_{GAT} values. The two black dashed lines indicate mean difference \pm 1.96 standard deviation between IOP_{NCT} and IOP_{GAT} (-0.36 – 7.86 mmHg). The red line indicates the mean difference in IOP (3.75 mmHg). IOP_{NCT} , intraocular pressure measured with non-contact tonometer; IOP_{GAT} , intraocular pressure measured with Goldmann applanation tonometer.

Factors Associated With IOP_{NCT} and IOP_{GAT}

Univariate linear regression revealed that IOP_{NCT} was strongly associated with sex, BMI, SBP, and CCT. Multivariable regression analysis, which included IOP_{NCT} as the dependent variable, and age, sex, BMI, SBP, AL, and CCT as independent variables, showed that age (standardized $\beta = -0.115$, $p < 0.001$) was negatively associated with IOP_{NCT} , while BMI (standardized $\beta = 0.075$, $p = 0.033$), SBP (standardized $\beta = 0.170$, $p < 0.001$), and CCT (standardized $\beta = 0.526$, $p < 0.001$) were positively correlated with IOP_{NCT} (Table 2). The related regression plots (Figure 3) showed that the R^2 values of SBP and CCT on IOP_{NCT} were 0.047 and 0.279, respectively.

Univariate linear regression showed that IOP_{GAT} was significantly positively associated with sex, BMI, SBP, CCT, and CC (Table 3). Multivariable regression confirmed the results of univariate linear regression and revealed that only SBP (standardized $\beta = 0.162$, $p < 0.001$), CCT (standardized $\beta = 0.259$, $p < 0.001$), and CC (standardized $\beta = 0.156$, $p < 0.001$) were significantly associated with IOP_{GAT} . However, age, sex, and BMI were not associated with the IOP_{GAT} . The related regression plots (Figure 4) showed that the R^2 values of SBP, CCT, and CC on GAT were 0.036, 0.062, and 0.009, respectively.

Factors Affecting $IOP_{NCT-GAT}$

$IOP_{NCT-GAT}$ values can be influenced by specific systemic and ocular factors. In the high myopia group, univariate linear

regression showed that $IOP_{NCT-GAT}$ was positively associated with BMI, AL, and CCT, and negatively associated with CC and IOP_{GAT} (Table 4). Multivariable regression confirmed that $IOP_{NCT-GAT}$ was positively associated with BMI (standardized $\beta = 0.091$, $p = 0.009$), SBP (standardized $\beta = 0.074$, $p = 0.027$), and CCT (standardized $\beta = 0.506$, $p < 0.001$), and negatively associated with age (standardized $\beta = -0.134$, $p < 0.001$) and IOP_{GAT} (standardized $\beta = -0.409$, $p < 0.001$). The related regression plots (Figure 5) showed that the R^2 values of CCT and IOP_{GAT} on $IOP_{NCT-GAT}$ were 0.167 and 0.069, respectively.

DISCUSSION

To the best of our knowledge, this is the first study to comprehensively compare the differences between the GAT and NCT measurements and factors that affect them in a non-pathological high myopia population. Among the high myopia participants with a mean age of 31.10 years and IOP of <30 mmHg, although the IOP measurements of the two devices were significantly correlated ($r = 0.681$, $P < 0.001$), IOP_{NCT} overestimated IOP_{GAT} by 3.75 ± 2.10 mmHg. SBP and CCT were the main factors influencing both measurements. Younger age, higher BMI, higher SBP, thicker CCT, and lower IOP_{GAT} significantly broadened the difference in $IOP_{NCT-GAT}$.

In this cross-sectional study, the mean IOP_{NCT} and IOP_{GAT} values were 17.60 and 13.85 mmHg, respectively. Li et al. showed that IOP_{GAT} was 15.1 ± 2.4 mmHg in highly myopic population with a mean age of 22.8 years (14), and a Spanish study suggested that IOP_{GAT} was 15.54 ± 2.78 mmHg in a population with a

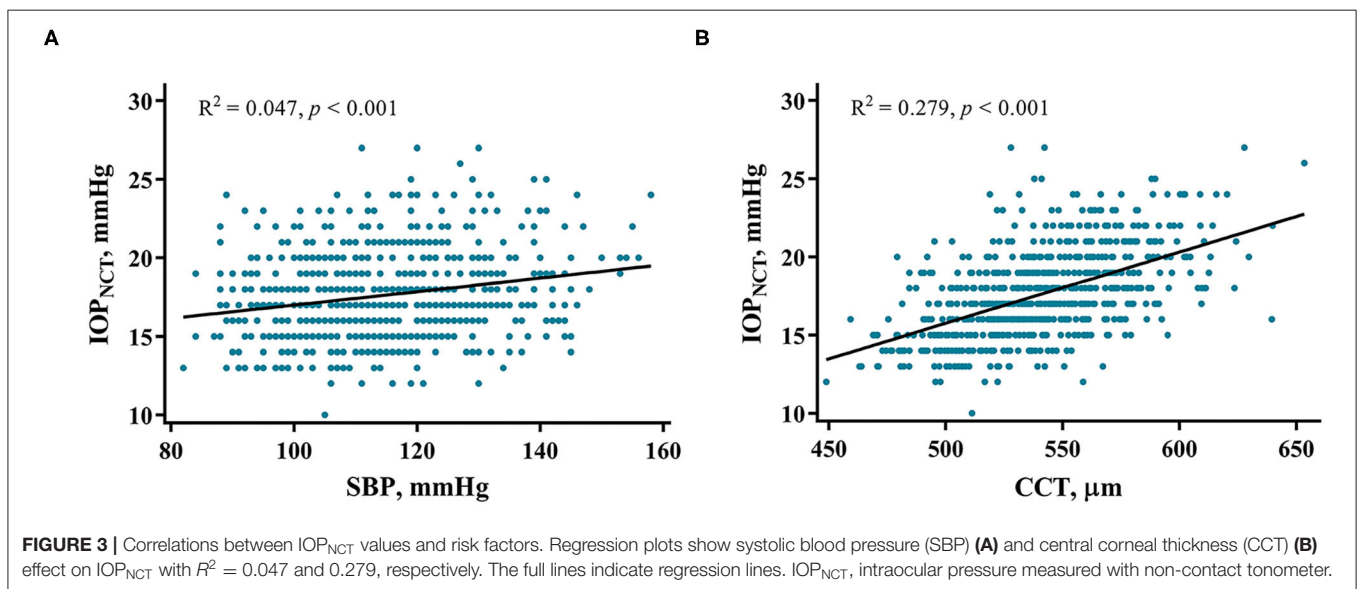
TABLE 2 | Univariate and multivariable linear regression analyses of factors that affect IOP_{NCT}.

	Univariable linear regression			Multivariable linear regression		
	<i>B</i> (95% CI)	β (95% CI)	<i>p</i> -value	<i>B</i> (95% CI)	β (95% CI)	<i>p</i> -value
Age, years	-0.006 (-0.027, 0.014)	-0.022 (-0.095, 0.051)	0.555	-0.032 (-0.050, -0.014)	-0.115 (-0.180, -0.051)	<0.001
Sex	-0.718 (-1.132, -0.304)	-0.126 (-0.199, -0.053)	0.001	0.177 (-0.231, 0.586)	0.031 (-0.041, 0.103)	0.394
BMI (kg/m ²)	0.121 (0.056, 0.185)	0.135 (0.062, 0.208)	<0.001	0.067 (0.006, 0.128)	0.075 (0.006, 0.143)	0.033
SBP (mmHg)	0.043 (0.028, 0.057)	0.214 (0.142, 0.286)	<0.001	0.034 (0.020, 0.048)	0.170 (0.098, 0.242)	<0.001
DBP (mmHg)	0.061 (0.041, 0.080)	0.223 (0.152, 0.295)	<0.001			
AL (mm)	0.169 (-0.001, 0.338)	0.073 (-0.001, 0.146)	0.052	-0.040 (-0.188, 0.108)	-0.017 (-0.081, 0.047)	0.596
SE (D)	-0.086 (-0.177, 0.005)	-0.069 (-0.142, 0.004)	0.064			
CCT (μ m)	0.046 (0.040, 0.051)	0.528 (0.466, 0.590)	<0.001	0.045 (0.040, 0.051)	0.526 (0.464, 0.588)	<0.001
CC (D)	-0.050 (-0.191, 0.091)	-0.026 (-0.099, 0.047)	0.487			

SBP and DBP, AL and SE were correlated; therefore, only SBP and AL were included in multivariable regression.

Boldface values indicate statistical significance.

AL, axial length; B, non-standardized beta; BMI, body mass index; β , standardized beta; CC, corneal curvature; CCT, central corneal thickness; CI, confidence interval; D, diopter; DBP, diastolic blood pressure; GAT, Goldmann applanation tonometer; IOP_{NCT}, intraocular pressure measured using a non-contact tonometer; SBP, systolic blood pressure; SD, standard deviation; SE, spherical equivalence.



mean age of 33.8 years (19); these values were slightly higher than those in the present study. Studies regarding IOP_{NCT} in the high myopia population are limited (20). In normal young subjects, IOP_{NCT} usually overestimates IOP_{GAT} by 1–2 mmHg (21–23). Compared with that in our study, the mean difference between IOP_{NCT} and IOP_{GAT} in the present study was greater, which might be related to the different measuring principles and corneal biomechanics in high myopia populations.

The GAT is based on the area of flattened cornea (approximately 7.35 mm²), which is converted in mmHg following the Imbert-Fick law (24). The pneumatic system of the NCT generates a puff of air and flattens the central cornea (approximately 10.17 mm²), and the time required for applanation is measured and converted to the IOP value (25). We believe that the flattening of the corneal area by the NCT is larger than that by the GAT, and air flattening is more sensitive to ocular surface conditions and corneal structural properties. In our study, the Bland-Altman consistency analysis revealed that

the mean difference between the two measurements was 3.75 mmHg, and the 95% upper LOA was 7.86 mmHg. Although there was a correlation between the values obtained by the two devices, their measurement difference was not acceptable from a clinical point of view, as it can affect the correct assessment of IOP, especially in those high myopia patients with a greater probability of combining glaucoma. In general, IOP_{NCT} cannot simply substitute IOP_{GAT} in patients with high myopia.

IOP measurements are affected by various factors. The present study demonstrated that CCT and SBP are the most important factors that can significantly affect IOP_{NCT}, IOP_{GAT}, and IOP_{NCT-GAT}. The effect of CCT was expected, which is in line with most other reports (14, 26–30). Because the slope estimate in NCT is slightly steeper than that in GAT (Figures 3, 4), CCT had a greater influence on IOP_{NCT} than on IOP_{GAT}. Thus, it is easy to understand that IOP_{NCT-GAT} increases as the CCT increases. This finding is in good agreement with those of other studies (26, 28, 29).

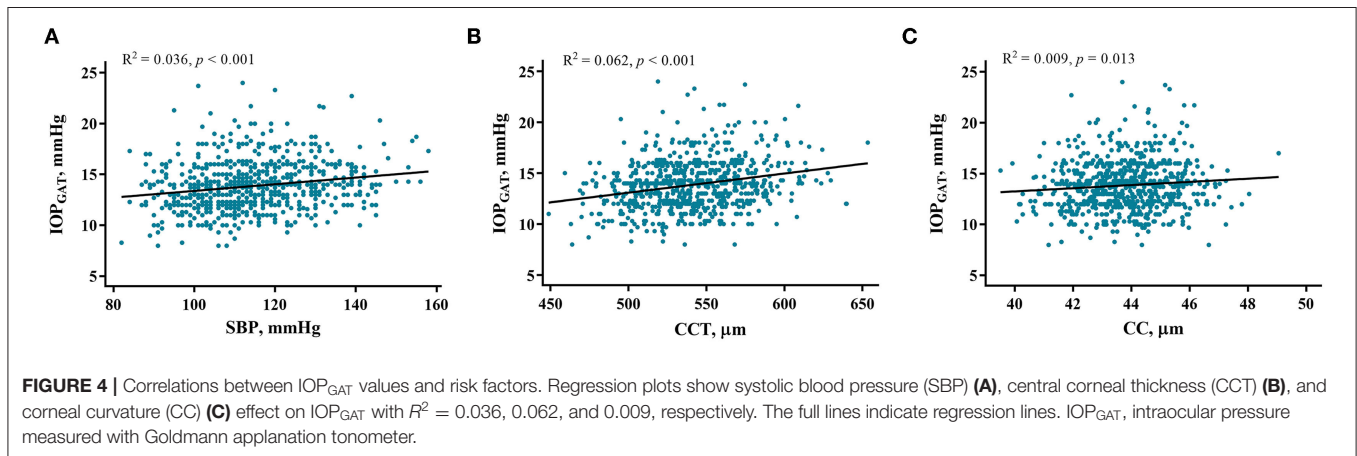
TABLE 3 | Univariate and multivariable linear regression analyses of factors that affect IOP_{GAT}.

	Univariable linear regression			Multivariable linear regression		
	<i>B</i> (95% CI)	β (95% CI)	<i>p</i> -value	<i>B</i> (95% CI)	β (95% CI)	<i>p</i> -value
Age, years	0.003 (−0.015, 0.022)	0.014 (−0.059, 0.087)	0.709	−0.011 (−0.030, 0.007)	−0.046 (−0.120, 0.028)	0.223
Sex	−0.577 (−0.942, −0.212)	−0.115 (−0.188, −0.042)	0.002	−0.162 (−0.565, 0.241)	−0.032 (−0.113, 0.048)	0.429
BMI (kg/m ²)	0.058 (0.001, 0.115)	0.074 (0.001, 0.147)	0.048	0.014 (−0.048, 0.076)	0.018 (−0.061, 0.096)	0.657
SBP (mmHg)	0.033 (0.021, 0.046)	0.190 (0.118, 0.262)	<0.001	0.028 (0.014, 0.043)	0.162 (0.080, 0.244)	<0.001
DBP (mmHg)	0.042 (0.025, 0.060)	0.176 (0.104, 0.248)	<0.001			
AL (mm)	−0.062 (−0.212, 0.088)	−0.030 (−0.104, 0.043)	0.416			
SE (D)	−0.028 (−0.108, 0.052)	−0.025 (−0.099, 0.048)	0.496			
CCT (μm)	0.019 (0.014, 0.024)	0.249 (0.178, 0.320)	<0.001	0.020 (0.014, 0.025)	0.259 (0.188, 0.330)	<0.001
CC (D)	0.156 (0.033, 0.280)	0.092 (0.019, 0.165)	0.013	0.265 (0.143, 0.386)	0.156 (0.084, 0.228)	<0.001

SBP and DBP were correlated; therefore, only SBP was included in multivariable regression.

Boldface values indicate statistical significance.

AL, axial length; B, non-standardized beta; BMI, body mass index; β , standardized beta; CC, corneal curvature; CCT, central corneal thickness; CI, confidence interval; D, diopter; DBP, diastolic blood pressure; IOP_{GAT}, intraocular pressure measured with Goldmann applanation tonometer; SBP, systolic blood pressure; SD, standard deviation; SE, spherical equivalence.



Blood pressure is another risk factor that has been widely investigated in the context of IOP measurements. Higher SBP may increase aqueous humor drainage by increasing capillary pressure and decreasing outflow by elevating episcleral venous pressure (31). The Japanese Kumejima Study, the European Prospective Investigation into Cancer-Norfolk Eye Study, and the Northern Ireland Cohort for the Longitudinal Study of Aging (NICOLA) reported that higher SBP was a strong determinant of higher IOP (32–34); this finding is consistent with that of the present study. Clinicians should consider the potential effects of CCT and SBP on both types of IOP measurements.

We reported that younger age and higher BMI were significantly correlated with higher IOP_{NCT} but not IOP_{GAT}, which is in line with previous studies (13, 14, 31, 32, 35–37). However, the Anyang Childhood Eye Study and NICOLA Study found that IOP increased with older age (34, 38). It has been proposed that both corneal hysteresis and corneal resistance factor values decrease with aging (39). In high myopia populations, corneal hysteresis was reported to be lower than that in normal subjects (40–42). Overall, age-dependent changes in corneal biomechanical properties as well as changes in high myopia may account for our results.

In multivariable analysis, higher CC was a risk factor for increased IOP_{GAT} but not for IOP_{NCT}. This result is consistent

with that of a previous study (43). Theoretically, a steeper cornea may require greater flattening and deformation to reach a standard contact area; thus, more pressure and higher IOP_{GAT} readings were generated. However, other studies reported that CC affected IOP measurement with dynamic contour tonometry but not with GAT (44, 45). At present, the influence of CC on IOP measurements is inconclusive, and further research is needed to elucidate the reasons for this discordance. Findings on the association between myopia and IOP have also been inconsistent (3, 14, 37, 46). Due to the strong association between AL and SE, and given that SE is affected by more factors than AL, only AL was incorporated into multivariable analysis. However, there was no significant association between AL and IOP in our study; although AL was longer in patients with high myopia, it did not affect the IOP readings. Differences in mechanical strain of the sclera and organizational compliance may explain these findings (37).

Moreover, the present findings suggest that IOP_{NVT–GAT} values increased as IOP_{GAT} values decreased (Table 4), indicating that with the lowering of IOP, the measurement accuracy of IOP_{NCT} decreased. This finding is consistent with that of a previous study, which reported that NCT overestimated IOP in the lower value range and underestimated IOP in the higher value range (22). However, some studies reported opposite findings,

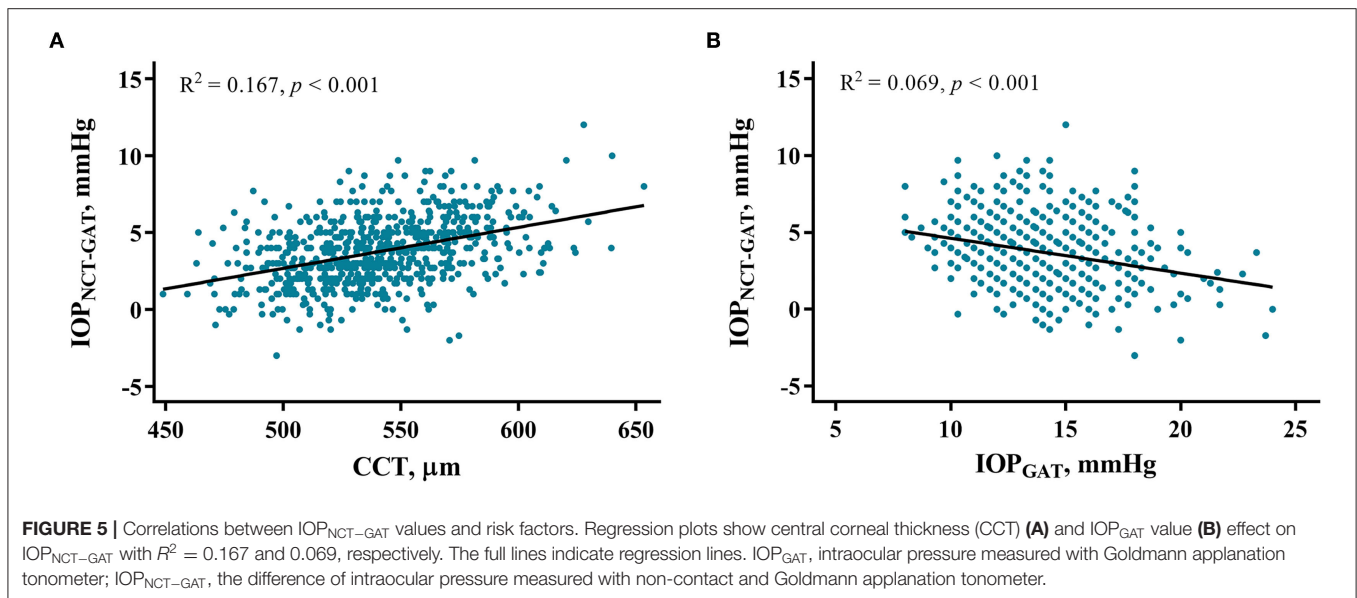
TABLE 4 | Univariate and multivariable linear regression analyses of factor that affect $IOP_{NCT-GAT}$.

	Univariable linear regression			Multivariable linear regression		
	<i>B</i> (95% CI)	β (95% CI)	<i>p</i> -value	<i>B</i> (95% CI)	β (95% CI)	<i>p</i> -value
Age, years	-0.010 (-0.025, 0.006)	-0.045 (-0.118, 0.028)	0.226	-0.029 (-0.042, -0.015)	-0.134 (-0.199, -0.070)	<0.001
Sex	-0.141 (-0.458, 0.175)	-0.033 (-0.106, 0.041)	0.381			
BMI (kg/m ²)	0.063 (0.013, 0.112)	0.092 (0.019, 0.165)	0.013	0.062 (0.016, 0.108)	0.091 (0.023, 0.159)	0.009
SBP (mmHg)	0.009 (-0.002, 0.020)	0.062 (-0.011, 0.135)	0.096	0.011 (0.001, 0.021)	0.074 (0.008, 0.139)	0.027
DBP (mmHg)	0.019 (0.003, 0.034)	0.090 (0.017, 0.163)	0.016			
AL (mm)	0.231 (0.103, 0.359)	0.131 (0.058, 0.203)	<0.001	0.084 (-0.047, 0.214)	0.048 (-0.026, 0.122)	0.207
SE (D)	-0.058 (-0.127, 0.011)	-0.061 (-0.134, 0.012)	0.100			
CCT (μ m)	0.027 (0.022, 0.031)	0.407 (0.340, 0.474)	<0.001	0.033 (0.029, 0.037)	0.506 (0.442, 0.570)	<0.001
CC (D)	-0.206 (-0.312, -0.100)	-0.141 (-0.214, -0.069)	<0.001	0.040 (-0.070, 0.149)	0.027 (-0.048, 0.102)	0.474
IOP_{GAT} (mmHg)	-0.227 (-0.287, -0.166)	-0.263 (-0.334, -0.192)	<0.001	-0.352 (-0.407, -0.297)	-0.409 (-0.473, -0.345)	<0.001

SBP and DBP, AL and SE were correlated; therefore, only SBP and AL were included in multivariable regression.

Boldface values indicate statistical significance.

AL, axial length; B, non-standardized beta; BMI, body mass index; β , standardized beta; CC, corneal curvature; CCT, central corneal thickness; CI, confidence interval; D, diopter; DBP, diastolic blood pressure; GAT, Goldmann applanation tonometer; IOP_{GAT} , intraocular pressure measured with Goldmann applanation tonometer; $IOP_{NCT-GAT}$, the difference in IOP measured by non-contact and Goldmann applanation tonometer; SBP, systolic blood pressure; SD, standard deviation; SE, spherical equivalence.



suggesting that IOP_{NCT} values were approximately equal to IOP_{GAT} values in the group with low IOP, while they were overestimated in that with high IOP (10, 23). Larger sample sizes are required to validate these results.

Our study has several strengths. First, this was a large cross-sectional study of non-pathologic high myopia patients. Second, the variables of interest included demographic characteristics, AL, SE, CCT, and CC values. Third, we used the NCT and GAT, which are most commonly used in clinical practice, and we examined factors that affect the accuracy of their measurements. The present results highlight the following: (1) CCT and SBP have a strong effect on IOP_{NCT} , IOP_{GAT} , and $IOP_{NCT-GAT}$ measurements in high myopia patients; (2) younger age and higher BMI values contributed to higher IOP_{NCT} and

$IOP_{NCT-GAT}$; (3) CC positively affected IOP_{GAT} measurement; (4) $IOP_{NCT-GAT}$ increased in the higher IOP_{GAT} range; and (5) sex and excessive AL in high myopia patients were not associated with IOP measurements.

There are some limitations to this study. First, this cross-sectional study examined correlations among the relevant factors; however, no causal inferences can be made from the presented findings. Further longitudinal studies are required to confirm these findings. Second, corneal biomechanical properties were not accounted for, including corneal hysteresis and corneal resistance factor, which may greatly affect IOP measurements. Other risk factors, such as smoking and drinking, should also be included in future studies. Third, a control group of age-matched healthy subjects should be included in the

analysis. It remains unclear whether the present findings are unique to patients with high myopia. Fourth, the range of IOP_{GAT} in our subjects was 8 to 24 mmHg, and the number of patients with higher IOP values was relatively small. High myopia patients with higher IOP levels may be underrepresented in our sample. Studies involving larger samples with a wide range of IOP values or population-based study are required to provide reliable evidence on IOP measurements obtained with different methods in patients with high myopia.

In conclusion, we believe that IOP_{NCT} cannot simply substitute IOP_{GAT} in high myopia populations, in particular, in patients with thicker CCT and lower IOP values, which are the main factors that broaden the difference in IOP_{NCT-GAT}. Moreover, the difference between IOP_{NCT} and IOP_{GAT} and the factors that affect it, including demographic and ocular characteristics, should be considered when evaluating the IOP values. Further studies involving more participants and accounting for corneal biomechanical properties are needed to determine the reliability of different IOP measurements in highly myopic patients.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

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ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Review Committee of the Zhongshan Ophthalmic Center, Sun Yat-sen University, Guangzhou. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PW: design and data screening and manuscript drafting. PW, YS, FL, XG, and WC: acquisition, analysis, and interpretation of data. ZW: statistical analysis. MC, YP, and YL: collected and measured data. XZ and SC: study concept and design, project supervision, and manuscript revision. All authors discussed the results and approved the submitted version.

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