Original Article

Central corneal thickness and tonometric intraocular pressure in healthy young Malaysian Chinese adults

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ABSTRACT

Background: Central corneal thickness (CCT) can influence intraocular pressure (IOP) readings, but the relationship varies across tonometers and populations. This study examined the associations between CCT and uncorrected IOP measured using Canon TX-F non-contact tonometry (NCT) and AccuPen contact applanation tonometry in healthy young Malaysian Chinese adults.

Methods: This cross-sectional comparative study was conducted at UCSI University, Kuala Lumpur, Malaysia, between July and October 2019. Participants aged 18–25 years were recruited through voluntary, non-probability sampling. Eligibility required best-corrected visual acuity of 6/6 or better in each eye and clinically healthy anterior segments and optic nerve heads. A single optometrist performed bilateral examinations between 12:00 and 17:00 in a fixed sequence: NCT, ultrasonic pachymetry using AccuPach VI, and AccuPen tonometry. Three valid measurements per eye were averaged for each instrument. IOP readings were analysed without CCT correction.

Results: Of 98 individuals screened, 84 were enrolled, including 30 (35.7%) men and 54 (64.3%) women. Mean (standard deviation [SD]) age was 21.61 (1.88) years, and mean (SD) CCT was 570.11 (36.50) μm. Mean (SD) IOP was 15.50 (2.13) mmHg with NCT and 13.00 (2.35) mmHg with AccuPen. NCT readings were higher by a mean paired difference of 2.50 mmHg (95% confidence interval [CI], 2.11–2.89; $P < 0.001$). CCT was positively correlated with NCT readings ($r = 0.339$; 95% CI, 0.134–0.516; $P < 0.05$) and AccuPen readings ($r = 0.310$; 95% CI, 0.103–0.491; $P < 0.05$). CCT accounted for 11.5% and 9.6% of the variance in NCT and AccuPen readings, respectively. The regression slopes were numerically similar, corresponding to approximately 0.20 mmHg higher measured IOP per 10-μm greater CCT.

Conclusions: Greater CCT was associated with higher uncorrected IOP readings from both tonometers, while NCT yielded higher mean readings. These findings support considering CCT and instrument type when interpreting IOP in this population, without establishing device interchangeability or equivalent CCT sensitivity. Future studies in larger, more representative samples should examine how closely IOP readings from Canon TX-F NCT and AccuPen agree and how consistent repeated measurements are with each device.

KEYWORDS

corneal pachymetry, intraocular pressure, tonometry, ocular; young adult, cross-sectional studies.

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How to cite this article: Selvarayar V, Othman SF. Central corneal thickness and tonometric intraocular pressure in healthy young Malaysian Chinese adults. Med Hypothesis Discov Innov Optom. 2026 Fall; 7(3):154-163. DOI: https://doi.org/10.51329/mehdioptometry256
Received: 03 October 2026; Accepted: 31 October 2026

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INTRODUCTION

Intraocular pressure (IOP) measurement is important for assessing glaucoma risk and monitoring the response to treatment. However, tonometric readings are influenced by corneal properties and the measurement technique, which should be considered when interpreting the results [1]. Central corneal thickness (CCT) can influence applanation measurements and is also relevant to glaucoma risk assessment in patients with ocular hypertension. In the Ocular Hypertension Treatment Study (OHTS), thinner corneas were associated with a higher risk of developing primary open-angle glaucoma [2, 3]. Understanding how CCT relates to readings obtained with different tonometers can therefore help clinicians interpret IOP measurements in otherwise healthy eyes.

In patients with ocular hypertension or glaucoma, positive associations have been reported between CCT and IOP measured using the Canon TX-10 non-contact tonometer (NCT) and Tono-Pen XL [4]. However, a study using the same NCT model in young healthy subjects found no statistically significant CCT–IOP association [5]. A systematic review also found that agreement with Goldmann applanation tonometry varied among tonometers and between studies [6]. In Singapore, a population-based study documented differences in CCT and IOP among Chinese, Malay and Indian adults [7]. In a large Chinese university cohort, greater CCT remained associated with higher NCT after adjustment for other measured factors [8].

Evidence from one tonometer model cannot automatically establish the behaviour of another. The Canon TX-F has been included in clinical instrument comparisons [9], and AccuPen has been used in human studies of posture-related IOP variation [10]. However, these applications do not resolve how uncorrected readings from the Canon TX-F and AccuPen relate to CCT in healthy young Malaysian Chinese adults. Describing this relationship within a defined population may help distinguish a mean difference between instruments from the extent to which each instrument's readings covary with corneal thickness.

This study examined the associations between CCT and uncorrected IOP measured by Canon TX-F NCT and AccuPen contact applanation tonometry in healthy Malaysian Chinese adults aged 18–25 years. It also compared mean IOP readings between the instruments and estimated the device-specific linear associations between CCT and measured IOP using one right eye per participant.

METHODS

This cross-sectional comparative study was conducted at the Outpatient Optometry Clinic, School of Optometry, Faculty of Medicine and Health Sciences, UCSI University (formerly University College Sedaya International), Kuala Lumpur, Malaysia, between July and October 2019. The study was approved by the UCSI University Institutional Ethics Committee before participant recruitment and was conducted in accordance with the Declaration of Helsinki. Before enrolment, all participants received a written information sheet explaining the study purpose, examination procedures, potential risks and discomforts, and measures to protect data confidentiality. Written informed consent was obtained from all participants before examination.

Sample size was calculated using G*Power (version 3.1.9.4; Heinrich-Heine-Universität Dusseldorf, Dusseldorf, Germany) [11] for a two-sided test of a Pearson correlation under the bivariate normal model. Assuming a correlation coefficient of 0.30, representing a conventional medium effect size [12], against a null correlation of zero, with a significance level of 0.05 and 80% power, the required sample size was 84 participants. Each participant contributed one right eye to the primary analysis.

Participants were recruited on a voluntary basis from undergraduate students and outpatient clinic attendees at UCSI University through campus announcements and clinic invitation posters. Recruitment followed a non-probability sampling approach.

Eligible participants were Malaysian Chinese adults aged 18–25 years who reported that both biological parents were of Chinese descent. Participants were required to have best-corrected distance visual acuity of 6/6 or better in each eye, a spherical equivalent refraction between −6.00 and +2.00 D, refractive astigmatism of ≤2.00 D, a normal anterior segment on slit-lamp biomicroscopy, and a clinically healthy optic nerve head on ophthalmoscopy. The optic disc eligibility criteria were a cup-to-disc ratio of ≤0.4, an intact neuroretinal rim, no disc haemorrhage, and an inter-eye cup-to-disc ratio difference of ≤0.2. Participants who wore contact lenses were required to discontinue soft lenses for at least 48 hours and rigid gas-permeable lenses for at least two weeks before examination. Exclusion criteria included corneal pathology; previous refractive or intraocular surgery; a history of ocular inflammation, infection, trauma or diagnosed glaucoma; systemic illnesses known to affect ocular fluid dynamics or connective tissues, including diabetes mellitus, Marfan syndrome and hypertension; use of systemic or topical medications known to influence IOP, including corticosteroids, beta-blockers and adrenergic agonists; and known hypersensitivity to topical proparacaine hydrochloride or natural rubber latex in the disposable probe cover used with the AccuPen. Individuals with ocular surface irregularities or signs of dry eye, or who had not discontinued contact lens wear for the required period, were also excluded.

Before tonometry and pachymetry, all participants underwent a preliminary examination by a trained optometrist, including history taking, distance visual acuity assessment, subjective refraction, keratometry and ocular health assessment. Distance visual acuity was assessed monocularly using a four-sided manual indirect Snellen chart (i4innovation Ltd, Thetford, Norfolk, UK). The right eye was tested first with the left eye occluded, followed by the left eye with the right eye occluded. Participants were asked to read the smallest line they could identify.

Subjective refraction was performed monocularly, beginning with the right eye while the left eye was occluded [13]. Spherical power was initially refined using the plus–minus technique, followed by refinement of cylinder axis and power using the Jackson cross-cylinder [13, 14]. Spherical power was then reassessed using the plus–minus technique to establish the monocular endpoint [13]. The procedure was repeated for the left eye. Binocular balancing was subsequently performed using alternate occlusion with both eyes initially fogged by adding +0.75 D to their monocular corrections [13, 15]. Additional plus power was introduced in 0.25 D steps until visual acuity in each eye was reduced by two to three lines relative to its best-corrected level. The fogging power was then reduced binocularly in 0.25 D steps to achieve the maximum plus power consistent with the best attainable visual acuity. Any remaining fogging power was incorporated into the final correction for each eye [13, 15, 16].

Horizontal and vertical keratometric readings, designated K1 and K2, respectively, and corneal astigmatism were measured using a manual keratometer (OM-4; Topcon Corporation, Tokyo, Japan). The anterior segment, tear film and corneal clarity were assessed using a CCD-equipped slit lamp (SLM-3ER; Chongqing Kanghua Ruiming S&T Co., Ltd., Chongqing, China), with diffuse illumination, parallelepiped illumination and optical sectioning. The posterior segment and optic nerve head were examined by stereoscopic slit-lamp biomicroscopy using a handheld 90-D diagnostic lens (Volk Optical Inc., Mentor, OH, USA) [17, 18]. Optic nerve head assessment included disc morphology, neuroretinal rim integrity, cup-to-disc ratio, inter-eye asymmetry and the presence of disc haemorrhage [17, 19, 20].

All tonometric and pachymetric measurements were scheduled between 12:00 and 17:00 to limit potential time-of-day effects, given the documented diurnal variation in IOP and central corneal thickness [21, 22]. Measurements were performed bilaterally by a single trained optometrist in a fixed sequence: non-contact tonometry, ultrasonic pachymetry and contact tonometry. Examinations were conducted under consistent ambient illumination, at a room temperature of 21–23°C and relative humidity of 50–60%.

IOP was measured by non-contact tonometry using the Canon Full Auto Tonometer TX-F (Canon Inc., Tokyo, Japan) before topical anaesthesia or corneal contact, to limit potential effects of preceding contact procedures on the readings [23]. Participants were seated comfortably and instructed to fixate on the internal target without squeezing their eyelids. The instrument was operated in full automatic mode with automated alignment. Three consecutive valid readings were obtained per eye and averaged. Measurements were repeated if misalignment or a blink artefact occurred, or if the readings differed by more than 1.0 mmHg. A five-minute rest period followed non-contact tonometry.

One drop of 0.5% proparacaine hydrochloride (Alcaine®; Alcon Laboratories, TX, USA) was then instilled into the lower conjunctival sac of each eye. Excess fluid was gently blotted at the lateral canthus without contacting the cornea. Central corneal thickness was measured using the AccuPach VI ultrasonic pachymeter (Accutome Inc., Malvern, PA, USA), with the probe positioned perpendicular to the central corneal surface. The device-generated mean thickness was accepted when the associated standard deviation was ≤5 μm; measurements exceeding this threshold were repeated. Three consecutive valid CCT measurements were obtained per eye, and their mean was used for analysis [24].

Following a two-minute interval after pachymetry, contact IOP was measured using the AccuPen® handheld applanation tonometer (Accutome Inc., Malvern, PA, USA). AccuPen calibration was checked before each day's measurements. A new disposable latex probe cover (AccuTip; Accutome Inc.) was used for each participant. With the cornea anaesthetised by the preceding proparacaine instillation, participants maintained fixation on a target at 5 m. The probe was applied gently and perpendicularly to the central cornea. Three readings were obtained per eye, and their arithmetic mean was used for analysis [25]. All IOP values were recorded in mmHg and analysed without correction for central corneal thickness.

Statistical analyses were performed using IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY, USA). Continuous variables were summarised as mean (standard deviation [SD]) and range, and categorical variables as frequencies and percentages. For central corneal thickness (CCT) and intraocular pressure (IOP), 95% confidence intervals (CIs) for the means were also reported. Distributional characteristics were assessed using the Shapiro–Wilk test and skewness and kurtosis statistics. Although measurements were obtained bilaterally, the primary analyses used only the right eye of each participant to avoid inter-eye dependence [26]. IOP readings from the non-contact tonometer (NCT) and AccuPen were compared using a paired t-test; the between-device difference was defined as NCT minus AccuPen and summarised as mean (SD) with a 95% CI. Associations between CCT and device-specific IOP readings were assessed using Pearson's correlation coefficients with 95% CIs. Separate simple linear regression models were fitted for each tonometer, with IOP as the outcome and CCT as the predictor: $IOP = \beta_0 + \beta_1(CCT)$. The intercept, slope, R^2, adjusted R^2 and standard error of the estimate were reported. R^2 was expressed as a percentage to indicate the proportion of variance in measured IOP explained by CCT within each model. Overall model significance was assessed using the F-test. Comparisons between the device-specific regression estimates were descriptive; no formal test of the difference between slopes was reported. All tests were two-sided, with statistical significance defined as $P < 0.05$.

RESULTS

Of the 98 individuals screened, 12 were ineligible because of non-Chinese ethnicity or mixed parentage (n = 4), refractive astigmatism exceeding 2.00 D (n = 3), insufficient discontinuation of contact lens wear (n = 3), or ocular surface irregularities

or signs of dry eye (n = 2). Two additional individuals declined participation. The remaining 84 participants underwent bilateral examination, and 84 right eyes were included in the primary analyses.

The sample comprised 30 men (35.7%) and 54 women (64.3%), with a mean (SD) age of 21.61 (1.88) years (range, 18–25 years). Mean (SD) spherical equivalent refraction was −3.11 (2.20) D (range, −6.00 to +0.75 D). Mean (SD) horizontal and vertical keratometric readings were 43.19 (1.48) D and 43.99 (1.50) D, respectively, and mean (SD) corneal astigmatism was 0.80 (0.45) D. All participants had best-corrected visual acuity of 6/6. Baseline characteristics are presented in Table 1.

The Shapiro–Wilk test identified a departure from normality for CCT ($P < 0.05$), although the reported skewness (0.26) and kurtosis (−0.14) were small. The test did not identify statistically significant departures from normality for NCT IOP ($P > 0.05$) or AccuPen IOP ($P > 0.05$). Distributional statistics are presented in Table 2.

Mean (SD) CCT was 570.11 (36.50) μm (95% CI, 562.19–578.03; range, 485–661 μm). Mean (SD) IOP was 15.50 (2.13) mmHg with the NCT (95% CI, 15.04–15.96; range, 10.40–20.20 mmHg) and 13.00 (2.35) mmHg with the AccuPen (95% CI, 12.49–13.51; range, 8.00–20.00 mmHg; Table 3). NCT readings were higher on average, with a mean paired difference of 2.50 ± 1.78 mmHg (95% CI, 2.11–2.89; t = 12.87, $P < 0.001$).

CCT was positively correlated with IOP measured by both devices. Pearson's correlation coefficient was 0.339 for the NCT (95% CI, 0.134–0.516; $P < 0.05$) and 0.310 for the AccuPen (95% CI, 0.103–0.491; $P < 0.05$; Table 4). Thus, greater CCT was associated with higher IOP readings from both instruments.

In the NCT regression model, the fitted equation was IOP (mmHg) = 4.226 + 0.0198 × CCT (μm). The model accounted for 11.5% of the variance in NCT readings ($R^2 = 0.115$; adjusted $R^2 = 0.104$), with a standard error of the estimate of 2.01 mmHg ($F = 10.63$, $P < 0.05$).

For the AccuPen, the fitted equation was IOP (mmHg) = 1.663 + 0.0199 × CCT (μm). CCT accounted for 9.6% of the variance in AccuPen readings ($R^2 = 0.096$; adjusted $R^2 = 0.085$), with a standard error of the estimate of 2.25 mmHg ($F = 8.74$, $P < 0.05$; Table 5). The two models yielded numerically similar slopes, corresponding to approximately 0.20 mmHg higher measured IOP per 10-μm greater CCT. CCT accounted for 11.5% of the variance in NCT readings and 9.6% of the variance in AccuPen readings, indicating that CCT explained a modest proportion of the variability in measurements from either device. Although the explained variance was slightly greater for NCT, no formal comparison of the device-specific slopes was performed; these findings therefore do not establish a difference in CCT sensitivity between the instruments.

Table 1. Baseline characteristics of the study participants (n = 84).

Parameter	Value
Age (y), Mean ± SD (Range)	21.61 ± 1.88 (18–25)
Sex (Men / Women), n (%)	30 (35.7) / 54 (64.3)
Spherical equivalent (D), Mean ± SD (Range)	−3.11 ± 2.20 (−6.00 to +0.75)
K1 (D), Mean ± SD (Range)	43.19 ± 1.48 (39.50–46.25)
K2 (D), Mean ± SD (Range)	43.99 ± 1.50 (40.00–47.00)
Corneal astigmatism (D), Mean ± SD (Range)	0.80 ± 0.45 (0.00–2.00)
Best-corrected visual acuity (Snellen)	6/6 in all participants

Abbreviations: N, number of participants; y, years; SD, standard deviation; D, diopters; K1, horizontal keratometry; K2, vertical keratometry. Note: Ranges are observed ranges within the sample.

Table 2. Distributional statistics for right-eye measurements (n = 84).

Parameter	Shapiro–Wilk *P*-value	Skewness
CCT	**0.044**	0.26
IOP, NCT	0.750	0.18
IOP, AccuPen	0.093	0.24

Abbreviations: n, number of eyes; CCT, central corneal thickness; IOP, intraocular pressure; NCT, non-contact tonometer. Note: *P*-value < 0.05 is shown in bold. The reported standard error of skewness was 0.26.

Table 3. Central corneal thickness and IOP in right eyes (n = 84).

Parameter	Mean ± SD	Observed range	95% CI of mean
CCT (μm)	570.11 ± 36.50	485–661	562.19–578.03
IOP, NCT (mmHg)	15.50 ± 2.13	10.40–20.20	15.04–15.96
IOP, AccuPen (mmHg)	13.00 ± 2.35	8.00–20.00	12.49–13.51

Abbreviations: n, number of eyes; SD, standard deviation; CI, confidence interval; CCT, central corneal thickness; μm, micrometer; IOP, intraocular pressure; NCT, non-contact tonometer; mmHg, millimeter of mercury. Note: The paired NCT-minus-AccuPen difference was 2.50 ± 1.78 mmHg (95% CI, 2.11–2.89; t = 12.87, *P*-values < 0.001).

Table 4. Pearson correlations between CCT and IOP in right eyes (n = 84).

Tonometer	Pearson r	95% CI	*P*-value
NCT	0.339	0.134–0.516	**0.002**
AccuPen	0.310	0.103–0.491	**0.004**

Abbreviations: CCT, central corneal thickness; IOP, intraocular pressure; n, number of eyes; NCT, non-contact tonometer; CI, confidence interval. Note: *P*-values < 0.05 are shown in bold.

Table 5. Simple linear regression of IOP on CCT in right eyes (n = 84).

Tonometer	Intercept (β_0)	Slope (β_1)	R^2	F	*P*-value
NCT	4.226	0.0198	0.115	10.63	**0.0016**
AccuPen	1.663	0.0199	0.096	8.74	**0.004**

Abbreviations: CCT, central corneal thickness; IOP, intraocular pressure; NCT, non-contact tonometer. Note: *P* < 0.05 are shown in bold. Intercepts are in mmHg and slopes in mmHg/μm. The adjusted R^2 values were 0.104 for NCT and 0.085 for AccuPen; the corresponding standard errors of the estimate were 2.01 and 2.25 mmHg. The device-specific slopes were not formally compared.

DISCUSSION

In healthy young Malaysian Chinese adults, greater CCT was associated with higher IOP readings obtained by both Canon TX-F NCT and AccuPen. These associations were modest, with CCT accounting for 11.5% and 9.6% of the variance in NCT and AccuPen readings, respectively. The regression slopes were numerically similar, corresponding to approximately 0.20 mmHg higher measured IOP per 10-μm greater CCT for each device. NCT yielded IOP readings that were, on average, 2.50 mmHg higher than those obtained with AccuPen. These findings highlight the importance of considering both CCT and the tonometer used when interpreting IOP measurements in this population.

The mean NCT reading of 15.50 mmHg was numerically close to the 15.52 mmHg reported in the Anyang University Students Eye Study [8]. That study used a different NCT model and optical biometry for CCT measurement. The similar group means provide a useful young-adult comparison, but do not demonstrate agreement between instruments or establish a normative pressure range for Malaysian Chinese adults.

The mean CCT of 570.11 μm was higher than several reported means in Chinese populations of broadly comparable age. Li et al. reported a mean of 548.58 μm using ultrasound pachymetry in a Chinese sample with a mean age of approximately 24 years [27]. In the Anyang University Students Eye Study, Sun et al. reported a mean CCT of 539.83 μm using optical biometry [28]. By comparison, the ethnically diverse cohort of myopic young adults in the Correction of Myopia Evaluation Trial (COMET) had a mean CCT of 562.4 μm measured by handheld ultrasound pachymetry [29]. The present value should therefore be considered a descriptive estimate for this selected sample. Differences in recruitment, refractive distribution and measurement technique preclude attributing the higher mean to Malaysian Chinese ethnicity.

Regional and ethnic evidence further cautions against treating Chinese populations as having a single normative CCT. The Singapore Epidemiology of Eye Diseases study reported a mean CCT of 552.3 μm in Chinese adults older than 40 years and significant differences from Malay and Indian participants [7]. A large multicentre Chinese study also documented geographical variation in corneal thickness [30]. Multiethnic clinic studies have reported differences between Asian subgroups, but their older populations, glaucoma case mix and measurement methods differ from those of the present study [31, 32]. Without an ethnic comparison group and probability sampling, the current data characterise the enrolled cohort rather than ethnic differences.

Measurement method is particularly relevant when comparing CCT values. Kan et al., using the same AccuPach VI pachymeter, reported a mean ultrasound CCT of 549 μm in healthy eyes and differences between ultrasound and optical biometry [33]. Thus, using the same pachymeter does not necessarily produce the same population mean. Within-eye comparisons in Hong Kong Chinese subjects and in healthy myopic eyes have demonstrated differences between ultrasound and optical CCT estimates [24, 34]. Another comparison found that strong correlations between methods did not make all measurements directly interchangeable [35]. These findings support accounting for both participant characteristics and the specific measurement method when interpreting the present CCT distribution.

The positive CCT–IOP associations are consistent with much of the tonometry literature. Doughty and Zaman's meta-analysis found that the association was smaller in healthy eyes than in samples containing ocular disease [36]. Tonnu et al. reported increases of 0.46 and 0.31 mmHg per 10-μm greater CCT for Canon TX-10 NCT and Tono-Pen XL, respectively, in untreated patients with ocular hypertension or glaucoma [4]. The numerically lower slopes in the present sample are compatible with differences in clinical selection and instrument model, although cross-study comparisons cannot identify the cause of the difference. A healthy-eye Canon TX-10 study also found a positive CCT association [37], whereas Garcia-Resua et al. did not detect a significant association in their young healthy sample [5]. Statistical significance and effect estimates therefore require interpretation within each study's CCT range, population and protocol.

Evidence from handheld contact tonometers provides useful context but requires a clear distinction between devices. Positive CCT associations have been reported for Tono-Pen in normal corneas [38]. In a large clinical database, Bao et al. estimated a Tono-Pen slope of 0.15 mmHg per 10 μm [39]; a schoolchildren study reported an equivalent slope of 0.21 mmHg per 10 μm, alongside a larger NCT slope [40]. These estimates illustrate variation across populations and instruments. Tono-Pen and AccuPen are distinct instruments, so similarity to a Tono-Pen estimate does not validate the AccuPen measurement or establish equivalent biomechanical behaviour. The present analysis contributes direct observations for AccuPen in the population studied.

The human AccuPen literature also includes investigations with different physiological objectives. Hao et al. used AccuPen to investigate nocturnal posture-related IOP patterns and included a preliminary comparison with Goldmann tonometry [10]. Xie et al. measured IOP with AccuPen during simulated high-altitude exposure; IOP declined while CCT did not change significantly [25]. Such studies demonstrate applications of the instrument and the influence of physiological context on measured pressure. Their designs do not directly answer the present question about between-participant CCT associations during routine daytime testing. Conversely, the current findings should not be extrapolated to nocturnal, recumbent or hypoxic conditions.

The numerically similar slopes and different R^2 values warrant separate interpretation. A regression slope expresses the estimated difference in measured IOP associated with a specified difference in CCT. R^2 describes the proportion of variation in the observed outcome accounted for by that model and is influenced by the distributions of CCT and IOP within the sample [41]. Consequently, the slightly lower AccuPen R^2 does not establish lower CCT sensitivity, greater accuracy or better clinical performance. No formal comparison of the paired device-specific slopes was performed, and the sample-size calculation addressed a correlation rather than an equivalence question. The results support positive associations for both devices but establish neither a difference nor equivalence between their CCT slopes [42].

The limited explained variance is biologically plausible because thickness is only one aspect of corneal behaviour. Studies incorporating corneal responsiveness and curvature have identified influences beyond CCT [43]. Tranchina et al. found that corneal resistance factor explained more of the air-puff–Goldmann difference than CCT alone [44], while Dey et al. showed that biomechanical associations varied between tonometer comparisons [45]. A recent myopic-population analysis also identified corneal hysteresis and resistance factor as correlates of measured IOP [46]. These observations support a multifactorial interpretation of tonometry. Because the present models did not include biomechanical parameters or axial length, the CCT coefficient cannot be interpreted as an isolated effect of thickness on instrument mechanics.

The mean between-device difference should likewise be interpreted as specific to the instruments and protocol used. Previous NCT–Tono-Pen comparisons have not shown a consistent direction or magnitude of difference. Yilmaz et al. reported nearly identical mean NCT and Tono-Pen XL readings in normal subjects [47]. Osman et al. reported slightly higher NCT than Tono-Pen XL readings in controls [48], whereas Yildiz and Yasar found lower mean NCT than Tono-Pen readings in healthy eyes [49]. Different contact devices were used in those studies. Moreover, Bang et al. demonstrated different measurement tendencies among three NCT models [50], and Tzamalis et al. included the Canon TX-F in a comparison showing model-dependent agreement with Goldmann tonometry [9]. The 2.50-mmHg difference observed here should not be adopted as a general conversion factor between contact and non-contact measurements.

A significant paired mean difference does not describe agreement for an individual patient. The systematic review by Cook et al. found substantial variability within and between tonometer comparisons [6]. More recent Tono-Pen–Goldmann data similarly demonstrate that a small average difference can coexist with appreciable discrepancies in individual eyes [51]. The present study did not report limits of agreement, pressure-dependent disagreement or formal repeatability estimates. It therefore cannot establish interchangeability. In optometric practice, our findings support documenting the instrument used and interpreting a change in reading after switching devices in its measurement context. They do not justify deciding that a higher NCT reading is an overestimate of the patient's true IOP or that a lower AccuPen reading is more accurate.

Refractive selection may also influence comparability with other studies. The current cohort had a myopic mean spherical equivalent, but refraction was not included in the CCT–IOP regression models. Studies in Chinese myopic populations have not consistently identified a relationship between refractive error and CCT [52, 53]. Nevertheless, university-based and clinic-based studies have reported associations of NCT readings with refraction or other ocular biometric parameters after adjustment for CCT [8, 54]. A Chinese high-myopia study found higher NCT than Goldmann readings and an association between their difference and CCT [55]. Its refractive selection and reference comparator differ from those used here. Restricting eligibility reduces some heterogeneity but does not demonstrate that refraction, curvature or other ocular characteristics had no influence on the present associations.

The examination schedule and repeated measurements improved procedural consistency. Young-adult studies document diurnal variation in IOP and ocular biometry, including CCT [21, 22]. Kida et al. demonstrated higher nocturnal CCT and IOP in healthy participants aged 20–25 years [56], and more recent evidence confirms that time of day remains relevant to interpretation [57, 58]. Scheduling examinations between 12:00 and 17:00 avoided early-morning testing, but a five-hour window did not eliminate diurnal variation or measure each participant at the same physiological time. Averaging three

readings also reduced dependence on a single acquisition, although this protocol alone does not establish between-visit reproducibility.

The fixed examination sequence introduces another qualification. Performing NCT before drops and corneal contact standardised its position in the protocol. Contact IOP, however, was obtained after topical anaesthesia and pachymetry, so device and procedural order were not separated experimentally. Nam et al. observed transient CCT changes after proparacaine [59], whereas Lam and Chen found no significant change after a single drop of the same concentration [60]. Montero et al. reported lower NCT readings after topical anaesthesia without a corresponding mean CCT change [61]. A recent study also found increased variability of ultrasound pachymetry after Goldmann tonometry, although that procedure and sequence differ from the present protocol [62]. These observations do not establish that the current readings were biased, but they limit attribution of the between-device difference solely to instrument design.

In the present study, IOP readings were analysed without correction for CCT to examine the association between measured CCT and the IOP reported by each tonometer. The regression equations derived from our data describe these associations within the study sample. They were not calibrated against manometrically measured IOP and should not be used as clinical CCT correction formulas. In the OHTS reanalysis, applying CCT correction formulas did not improve glaucoma prediction over using IOP and CCT as measured [63]. That finding concerns ocular-hypertension risk prediction and does not validate either instrument in healthy young adults. Clinical interpretation should incorporate CCT alongside the optic nerve and other relevant findings, consistent with the established role of pachymetry in ocular-hypertension assessment [64]. The present cross-sectional results provide no evidence about future glaucoma development or protection associated with a thicker cornea.

Strengths of the present study include a clearly defined young-adult population, clinical eligibility assessment, repeated readings, a single examiner and a consistent examination sequence. Using one right eye per participant also avoided treating correlated fellow eyes as independent observations [26]. These features support interpretation of the observed within-sample associations. Generalisability remains limited by voluntary non-probability recruitment, the single-centre setting, the sample of 84 participants and the greater proportion of women. Selection of healthy corneas and a restricted refractive range also limits application to ocular hypertension, glaucoma, corneal disease, postoperative eyes and more extreme refractive errors. Further work should evaluate the same device pair in larger, more representative populations, with prespecified assessment of agreement and repeatability as well as CCT associations. Randomised measurement order, masking where feasible, narrower or repeated examination times, and assessment of corneal biomechanics and ocular biometry would help separate procedural and participant-related influences. Inclusion of a reference tonometer would permit direct comparison with established clinical measurement, while recognising that reference tonometry itself is influenced by corneal properties. A prespecified paired analysis of device-by-CCT effects would be needed to test whether the slopes differ.

CONCLUSIONS

Greater CCT was associated with higher uncorrected IOP readings from both Canon TX-F NCT and AccuPen in healthy young Malaysian Chinese adults. The devices showed numerically similar CCT slopes, while NCT yielded higher mean readings. These findings support interpreting pressure measurements with attention to both CCT and the specific instrument, within the limits of the population and protocol studied.

ETHICAL DECLARATIONS

Ethical approval: The study was approved by the UCSI University Institutional Ethics Committee before participant recruitment and was conducted in accordance with the Declaration of Helsinki. Before enrolment, all participants received a written information sheet explaining the study purpose, examination procedures, potential risks and discomforts, and measures to protect data confidentiality. Written informed consent was obtained from all participants before examination.
Conflict of interests: None.

FUNDING

None.

ACKNOWLEDGMENTS

None.

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