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Effects of postural changes on measured intraocular pressure and repeatability of PT-100 tonometer and agreement with applanation and indentation tonometry

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Background: Repeatability and validity are important components of precision in any measurement system.

Aim: This study aimed to determine the effect of change in head and neck position and body posture on the repeatability of intraocular pressure (IOP) measurements with PT-100 non-contact tonometer and compare with Goldmann, PT-100 and Schiøtz tonometer readings.

Setting: Optometry clinic, Saudi Arabia.

Methods: The IOP was measured in one selected eye of 84 healthy participants (mean aged 21.9 ± 2.0 years) using PT-100 in three head and body positions, Goldmann tonometer and Schiøtz on two separate visits, in a randomised fashion. Central corneal thickness (CCT) was measured using an ultrasound pachymeter. The repeatability, agreement and correlations between CCT and IOP differentials were assessed.

Results: The IOP measured in three head and body positions with the PT-100 were similar and comparable to Goldmann IOPs in sessions one and two with 74% and 86% of PT-100 measurements within ±3 mmHg of the Goldmann tonometry, respectively, for sessions one and two. The Schiøtz tonometer-measured IOP was higher than the Goldmann IOPs ($p < 0.05$) with 60% and 44% of Schiøtz IOPs within ±3 mmHg of the Goldmann tonometer IOP in sessions one and two, respectively. The limits of repeatability and reproducibility were best with the PT-100 and worst with the Schiøtz tonometer. The mean CCT (552±36 µm) was negatively correlated with differences between Goldmann and both PT-100 and Schiøtz-measured IOP.

Conclusion: Postural changes did not affect the validity and repeatability of PT-100 readings. PT-100 measurements were interchangeable with Goldmann tonometer. Schiøtz overestimated Goldmann IOP in thicker corneas more than the PT-100.

Keywords: glaucoma; intraocular pressure; non-contact tonometer; Goldmann applanation tonometer; repeatability; posture.

Introduction

Intraocular pressure (IOP) remains the most significant and only modifiable, risk factor for the development and/or progression of glaucoma. [1,2,3,4] Glaucoma is a multifactorial disease but both the IOP level and its fluctuation play an important role in the development and progression of glaucomatous optic neuropathy,[4,5] and different local and systemic factors are believed to affect an individual's IOP.[6,7] Therefore, the accurate monitoring of IOP is crucial.

Intraocular pressure measurements are usually taken in the clinic at one time point and conventionally with the patient sitting upright and the head slightly leaning forward. Studies have shown that IOP varies with head, neck and body position, as well as with neck flexion or constriction.[6,7,8,9,10,11,12] Thus, the usual one-time in office IOP assessment may not give an accurate

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indication of IOP fluctuations during a typical 24-h day. These fluctuations would include spikes in IOP because of changes in head, neck and/or body position, which appear to be greater in people with glaucoma than in those without the disease.[13,14,15]

The effects of the autonomic nervous system on aqueous humour dynamics are crucial and many of the drugs used in the management of glaucoma and ocular hypertension primarily modulate these effects in order to control IOP.[15,16] The episcleral blood vessels are innervated by the autonomic nervous system and in humans, several vascular transmitters have been identified in the nerve endings around the episcleral vessels.[17] The autonomic system influences IOP through its action on episcleral venous pressure and this close relationship between the episcleral venous pressure and the autonomic system can be seen in medications such as topical clonidine, an alpha adrenergic agonist, which decreases IOP and episcleral venous pressure.[17] As the episcleral venous pressure increases, so does the IOP.[18] The changes in episcleral venous pressure and IOP (with changes of head and/or body position) occur rapidly as the body position changes (within 1–3 min), and these changes persist for between 30 min and 24 h, provided the new position is maintained.[18] As the episcleral venous pressure and IOP increase in the supine position, such as at night during sleep (when the blood pressure diminishes), this could place glaucoma patients at risk of progression of glaucomatous optic neuropathy and visual field loss, presumably because of a reduction in the perfusion pressure at the optic disc.[15,19,20]

Several studies[7,8,9,11,17] have demonstrated considerable IOP variations because of changes in head and body position between individuals. Part of this inter-individual variation depends on whether or not the individual is glaucomatous or non-glaucomatous. However, in non-glaucomatous patients, the posture-induced changes in IOP were shown to not exceed 2 mm of mercury (mmHg).[21] To date, no study has investigated the repeatability of such postural changes in IOP. If variations (from one day to the next) in the same individual are as high as the variations between individuals, it would be more difficult to make definitive statements about medium- and long-term effects of changing head and/or body position (in the course of normal daily activity) on IOP fluctuations.

The Schiøtz Indentation Tonometer is no longer routinely used in the ophthalmologic examination of patients, but because of its low cost and ease of use, it is still sometimes employed for difficult patients and for paediatric cases.[22,23] Recently, the Schiotz tonometer (ST) has gained attention in literature for its use in measurement of IOP in patients fit with the Boston type 1 keratoprosthesis[24] and in determining IOP variation during scleral lens wear.[25] Also, in remote and rural areas especially in developing countries, the ST is sometimes used during vision screening and vision aid exercises. Although several studies have assessed the precision of IOP measurements made with the ST,[22,26] this study was partly designed to more comprehensively assess the validity of the IOP measurements made with the ST in the light of its resurgence in clinical practice.[22,23,27,28] The PT-100 is a hand-held or slit lamp mounted noncontact tonometer that is widely used in clinics and has been shown to provide IOP readings that compare favourably to the Goldmann applanation tonometer (GAT) within the normal range of IOP,[29,30,31] and in different positions.[29]

The repeatability of values measured by an instrument used to collect data for clinical purposes is an important reliability index, especially when it is used to determine and monitor changes in measured ocular parameters over time. This is also important when evaluating whether a treatment intervention has any influence on a disease or whether a disease process produces change in measurements. In addition, it is important to compare measuring devices so that we know whether the devices yield comparable values. The GAT is considered the clinical gold standard for IOP measurement, its measurements are affected by changes in corneal thickness, structure, and curvature,[32] and it requires a high level of user expertise for accurate measurements and the use of anaesthetic which affects its measurements. However, GAT can only be used when the patient is in a sitting position.[32] The finding of increased IOP in the standing position suggests that IOP measurements should be performed in this position too.[33] Therefore, the aims of this study were to determine if changes in head and neck and/or body posture significantly (and consistently) alter the resting IOP and to compare the magnitude, repeatability (within- and between-sessions) of IOP measured with the ST, the PT-100 and the GAT. We also sought to determine which of the ST weights (5.5 g or 7.5 g weight or the average of both weights) best approximates the IOP estimate returned by the GAT.

The findings of this study will provide information for clinicians regarding the effects of postural changes on measured IOP and the repeatability of the PT-100 tonometer and agreement with applanation and indentation tonometry. The information may be useful in the monitoring of IOP amongst in-patients who may be bedridden and/or are unable to sit upright.

Methods

Study design

This was a prospective clinical study that included adult participants of Saudi Arabian origin who were randomly selected from participants attending the Optometry Clinic of King Saud University for routine eye examination. One eye of each participant was assessed in this study.

The IOP was measured in two sessions (7–14 days apart) on every participant using the GAT (AT 900, Haag Streit AG, Gartenstadtstrasse, Koeniz Switzerland), the Schiøtz Tonometer (ST; Sklar, United States [US]) and the PT-100 (Reichert Inc., US) non-contact tonometer. The second set of measurements were taken to assess between-session

repeatability for each device. All measurements were compared against the gold standard for IOP measurement (GAT).

Sample size determination

The statistical software G*Power (version 3.0.5) was used to determine the minimum sample size required for the study. The number of participants required to avoid an error was based on a pilot sample of nine eyes of nine participants, with a repeated-measures correlation coefficient of 0.85. The participant sample size necessary to detect the computed difference of 0.64 mmHg, at a level of statistical significance (α) of 0.05 and with a statistical power of 95% was 67 participants. One randomly selected eye of a significantly larger number of participants (n = 86) was used for this study to account for the small attrition rate of 2% – 5% seen in our previous studies. This was also used to increase the precision of the limits of agreement (LoA) between the values obtained using the GAT and the other two devices.[34]

Procedures followed

All participants underwent a complete ophthalmological examination including visual acuity assessment, optic nerve head evaluation, tonometry, refraction, corneal thickness measurement and where warranted, automated visual field assessment was conducted to rule out diseases such as glaucoma.

Inclusion and exclusion criteria

Only participants who were oculovisually healthy during the study period were included. Participants were excluded if they had a positive history, or objective evidence of, anterior segment disease or surgery, a history of rigid contact lens wear, ocular hypertension or glaucoma and pregnancy. Soft contact lens wearers were required to discontinue wear at least 24 h prior to examination. A total of six participants were excluded because of a history of refractive surgery (three), rigid contact lens wear (two) and a diagnosis of keratoconus (one).

Measurement of outcome variables

Intraocular pressure measurement

At each session, IOP measurements with the PT-100 were first obtained in the three head and body positions (HBPs). In the first position (HBP-1), the participant was requested to sit upright with the head and neck in the habitual anatomical position and the tonometer was held by hand to measure IOP.[29] The second position replicated the neck flexion or constriction (with a tight necktie),[9] and the participant sat upright with the head and neck in forward head posture (i.e. cervical spine and chin pushed forward so that the ears were anterior to the shoulders) against the chinrest and forehead rest of the slit lamp, whilst the tonometer was mounted on the slit lamp attachment for the second position (HBP-2). In the third position, the participant was requested to lie in a supine position with the head and neck in the normal anatomical position and the tonometer was held by hand (HBP-3), similar to the position of measurement with the ST.

The order of measurement was randomised between HBP-1, HBP-2 and HBP-3 in each session. Randomisation was again applied when determining which IOP measuring device (GAT or ST) was used following the PT-100 measurements and which ST weight (5.5 g or 7.5 g) was first used for IOP measurement. For GAT, measurements can only be obtained in the sitting position. A graduate student, using a series of randomly generated numbers from a Microsoft Excel spreadsheet, performed all randomisation.

With the ST, a calibration check was performed at the beginning of measurement each day as described in the literature.[35] The footplate rested on the dummy cornea (provided with the tonometer's storage case) and it was ascertained that the scale reading of the tonometer was zero before that tonometer was used to collect data for the day. K.C.O made GAT measurements and another clinician (A.I.T.) was responsible for all PT-100 measurements. A third clinician (U.L.O.) took measurements with the ST. To assess within-session repeatability, three measurements were taken with each tonometer on each session (including in each of the three positions with the PT-100 and with each weight of the ST). For both sessions, IOP measurements were obtained between 14:00 and 16:00, when the IOP is at its lowest and most stable.[36] In each session, all clinicians were blinded to each other's measurements. A 15-min washout period was allowed between the ST and GAT measurements to minimise the influence of the ocular massage effect on subsequent IOP measurements, which has been shown to exist with applanation tonometry but not with noncontact tonometry.[37] At the second session, IOP measurements were taken using the same protocol that was used during the first session.

Central corneal thickness measurement

Central corneal thickness (CCT) was measured using the ultrasound pachymetry Pachette 2 DGH-550 (http://www.dghkoi.com/product.cfm) only in the first session. The probe of the pachymeter was placed perpendicular to the cornea, 1.5 mm temporal to the corneal reflex of a fixation light placed at a distance of 3 m. The measurements were made an hour after IOP measurements and an average of three readings was taken for analysis. With the exception of PT-100 measurements, other techniques including ST, GAT-IOP and CCT measurements were obtained after instillation of one drop of oxybuprocaine hydrochloride 0.4% (http://www.medicines.org.uk).

Data analyses

Statistical analyses were conducted with the Graphpad Instat for Windows programme, version 3.00 (Graphpad Software Inc., US). Within-session reproducibility of the three devices were determined following McAlinden's recommendation.[38] All

average IOPs (for each HBP, and then for each tonometer) for the first session (and again for the second session) were compared using repeated-measures analysis of variance (ANOVA). The differences between triplicate IOP measurements (with the same device) were used to generate a 'difference' column that was used to assess within-session repeatabilities for each of the HBPs (with the PT-100) and later for each of the tonometers. The repeatability was compared (between the 3 HBPs, and then separately between the three tonometers) separately for both sessions, each time, using repeated-measures ANOVA. Results extracted from the ANOVA comparisons in each session were comparisons of average IOPs (and repeatability) between the three HBPs; comparisons of average IOPs (and repeatability) between the Goldmann tonometer on the one hand and the PT-100 (HBP-1), the 5.5 g weight of the ST, the 7.5 g weight of the ST and average of both weights, on the other.

For each HBP and each tonometer, the test-retest (between-session) repeatability was assessed using a paired comparison of the average IOPs, measured at the first and second sessions, using the same HBP or device. Reproducibility was also compared for the same HBP or tonometer. All comparisons were made using parametric or non-parametric statistical methods as appropriate.

Assessment of differences between devices

For assessment of the limits of agreement between devices, the differences between the mean GAT IOP and the IOP values obtained with either the PT-100 or the ST were computed for each session and mean difference was plotted against the average IOPs.

To investigate the effect of CCT on the agreement between GAT and ST, we examined the relationship between CCT and IOP differentials between devices, using linear regression.

Ethical considerations

Ethical clearance to conduct this study was obtained from the College of Applied Medical Sciences (CAMS) – King Saud University Research Ethics Committee. The study adhered to the principles of the 1967 Helsinki declaration (as modified in Fortaleza 2013). Written informed consent was obtained from each participant after the study protocol had been explained to them.

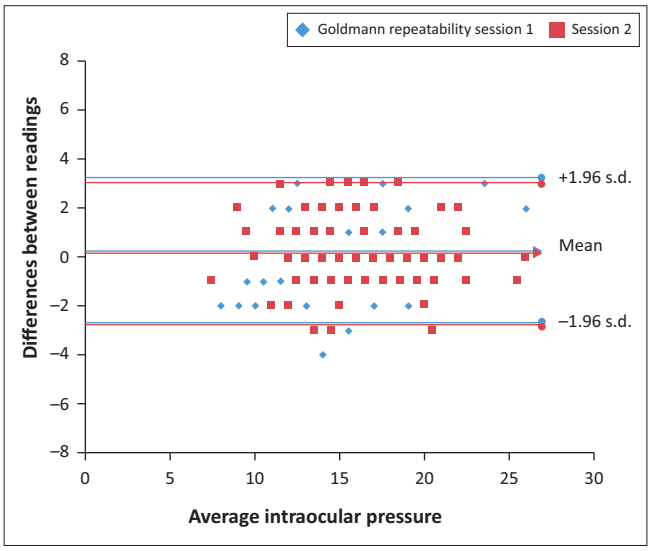
Results

A total of 86 participants were initially selected but 2 were lost to follow up. Data for the 84 eyes of 84 young Saudi Adults (46 men and 38 women) of mean age 21.9 ± 2.0 years (range: 19–29 years) were included in this study. The average (± standard deviation [s.d.]) IOP measured, with the PT-100 noncontact tonometer in HBP-1, HBP-2 and HBP-3, were similar in both sessions: 15 mmHg (±4), 15 mmHg (±4), and 15 mmHg (±4), respectively. There were no statistically significant differences between the PT-100 IOP values measured in the three HBPs, within session and between sessions. For the GAT and ST (5.5 g, 7.5 g and average of 5.5 g and 7.5 g) tonometers, the average IOPs measured, on the first session, were: 15 mmHg (±3), 17 mmHg (±5), 17 mmHg (±5) and 17 mmHg (±5), respectively. For the second session, the corresponding values were: 16 mmHg (±3), 19 mmHg (±4), 19 mmHg (±6) and 19 mmHg (±5), respectively.

The within-session repeatability plots showing differences between all three IOP readings in each session as a function of average IOPs for the same session are presented in Figure 1 for GAT. Similar plots of repeatability were shown for PT-100 in the three HBPs (Figure 2) and for ST (plots shown for 5.5 g, 7.5 g and average weight measurements) (see Figure 3). The repeatability data did not vary significantly from each other in the first and second sessions. The reproducibility coefficients for the average IOPs measured with the GAT, PT-100 (HBP-1), ST 5.5 g, ST 7.5 g and ST (averaged), respectively, were: ± 5.0 mmHg, ± 4.9 mmHg, ± 10.4 mmHg, ± 13.1 mmHg and ± 10.2 mmHg, respectively. Figure 4 shows the reproducibility plots for the three devices. No statistical significant difference was found between-sessions for each device and for the PT-100 reproducibility in the 3 HBPs ($p > 0.05$, for all comparisons).

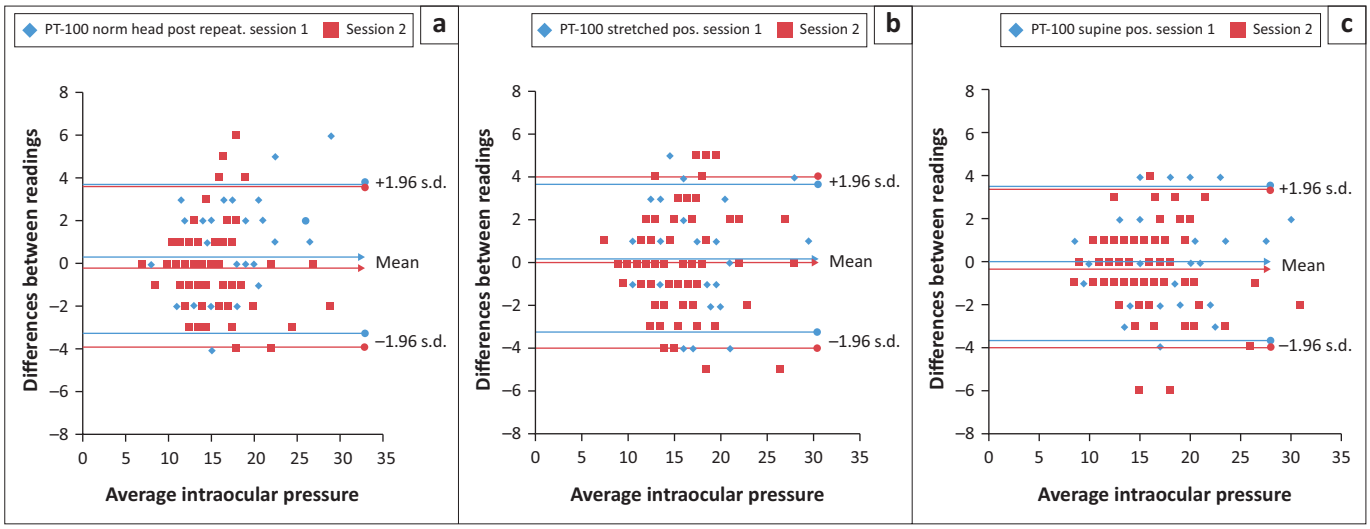
Limits of agreement between devices

Table 1 shows the limits of agreements between the devices. There were no significant differences between the mean GAT and the PT-100 IOP values measured in session one ($p = 0.32$). However, the ST returned significantly higher IOP measurements compared with the GAT, in both sessions ($p < 0.001$), except for the comparison between GAT and the IOP measured with the 7.5 g weight of the ST in session one (mean difference: –1.9 mmHg, 95%



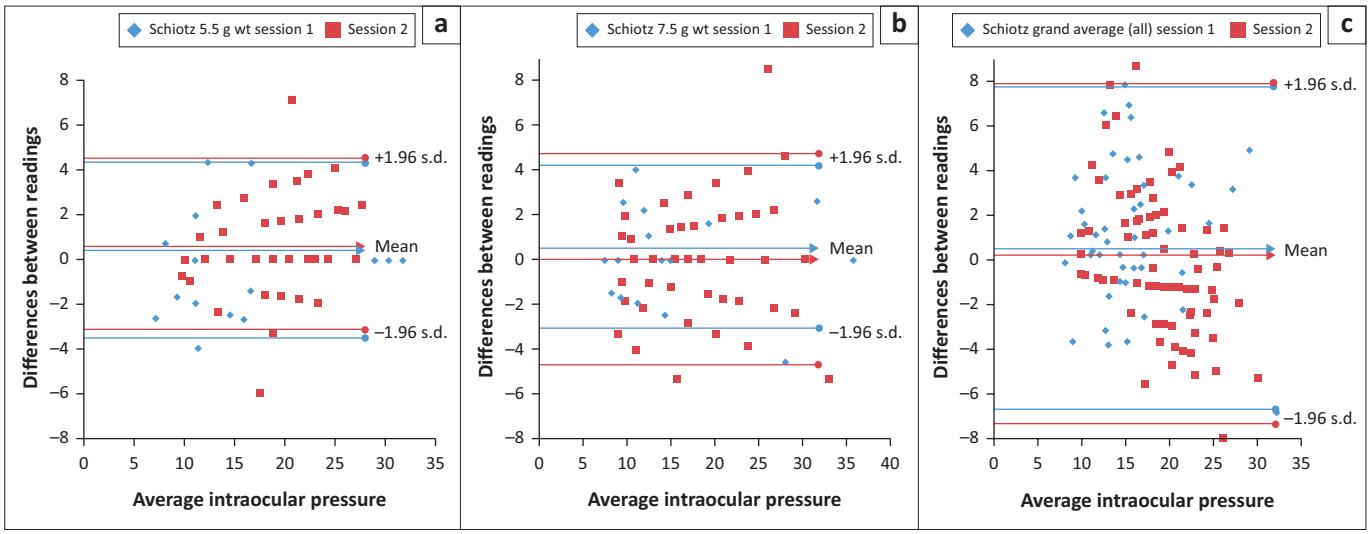
s.d., standard deviation.

FIGURE 1: Limits of within-session repeatability for Goldmann applanation tonometer intraocular pressure measurements in mmHg.



s.d., standard deviation; repeat., repeatability; post, posture; pos., position.

FIGURE 2: Limits of within-session repeatability for PT-100 non-contact tonometer, measurements in mmHg: (a) head-body posture 1, (b) head-body posture 2 and (c) head-body posture 3.



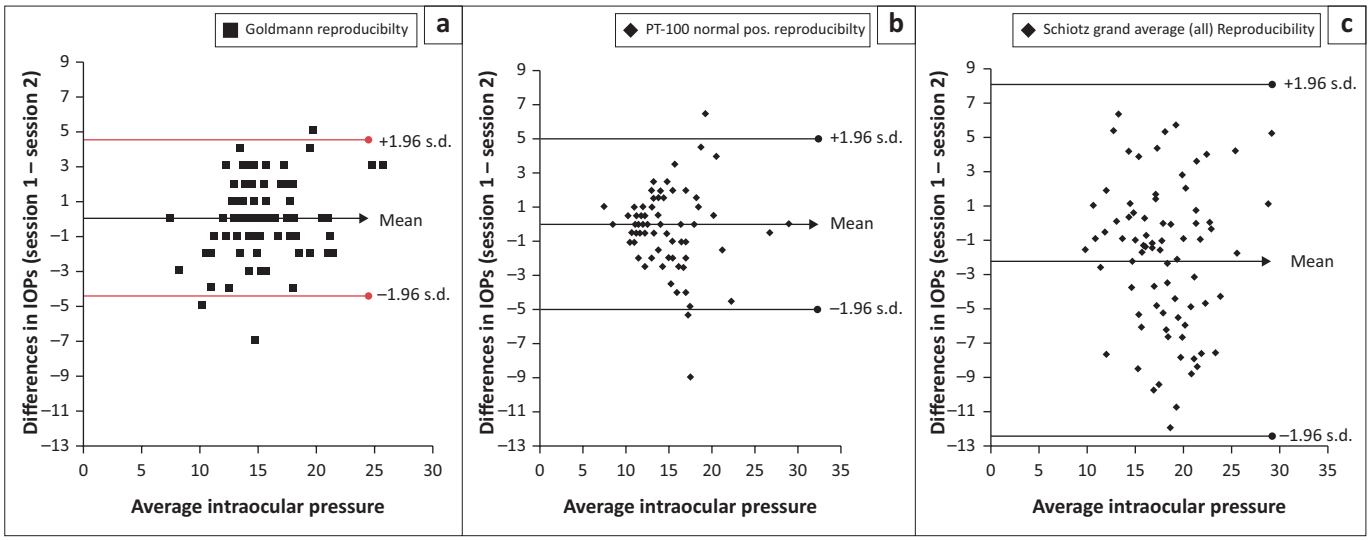
s.d., standard deviation; wt, weight.

FIGURE 3: Limits of within-session repeatability for Schiøtz Indentation Tonometer, measurements are in mmHg: (a) 5.5 g weight, (b) 7.5 g weight and (c) average of 5.5 g and 7.5 g weights.

limits of agreement: –11.1 mmHg – 7.4 mmHg; $p < 0.0001$). In sessions 1 and 2, respectively, the ST readings were significantly higher than the GAT readings by up to 5 mmHg (Table 1).

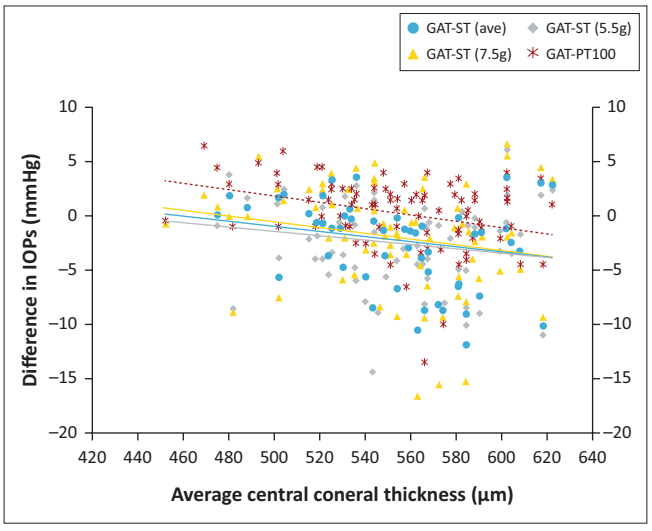
The mean differences (95%, LoA), for both sessions, between the GAT on the one hand, and the PT-100 (HBP-1) and ST (averaged) on the other, are presented in Table 1. The differences between the GAT on the one hand, and the ST 5.5 g and ST 7.5 g weights on the other were statistically significant in both sessions suggesting poor agreement. Although the PT-100 returned significantly higher IOP compared with GAT, the difference (–1.1 mmHg, 95%LoA: –3.9 mmHg – 6.2 mmHg) was within tolerance limits of ±3 mmHg[39] and thus, not clinically significant. Overall, 74% of the PT-100 IOP measurements, 60% each for both the ST 5.5 g and 7.5 g weights, and 61% of the ST average IOP measurements were within ±3 mmHg of the GAT measured IOP in session 1. For session two, the percentages were: 86% for the PT-100, 44% for the ST 5.5 g weight, 42% for the ST 7.5 g weight and 44% of the ST averaged IOP.

The mean CCT was 551.9 ± 36.4 µm (range: 452 µm – 622 µm). There was an inverse correlation between the CCT and IOP differentials between the Schiøtz ($r = –0.2$, $p < 0.04$ for all three weights) and PT-100 ($r = –0.3$, $p = 0.001$) on the one hand and the GAT on the other. At the lower end of the CCT scale, the PT-100 underestimated the GAT-IOP by about 3 mmHg (Figure 5), reducing to zero at about 560 µm and at the top of the CCT scale, the PT-100 was overestimating the GAT-IOP by about 2 mmHg on average. The Schiøtz tonometer weights showed the same inverse correlation as the PT-100 but the difference in measured IOP started at about 0 mmHg at the lower end of the CCT scale (Figure 5) and by 620 µm, the Schiøtz tonometer weights overestimated the GAT-IOP by about 4 mmHg.



s.d., standard deviation; IOP, intraocular pressure.

FIGURE 4: Limits of reproducibility for: (a) Goldmann applanation tonometer, (b) PT-100 noncontact tonometer, and (c), Schiøtz indentation tonometer intraocular pressure measurements in mmHg.



GAT, Goldmann applanation tonometer; ST, Schiotz tonometer; IOP, intraocular pressure.

FIGURE 5: Relationship between Goldmann applanation tonometer and PT-100 non-contact tonometer-measured intraocular pressure differences and central corneal thickness. The scatterplot shows a negative correlation between intraocular pressure measurements (Goldmann applanation tonometer-other devices) and central corneal thickness, which reached a level of significance ($p < 0.05$).

TABLE 1: Limit of agreement among the intraocular pressure values measured by the three tonometers in normal subjects. Goldmann applanation tonometer, PT-100 noncontact tonometer in the head upright position and all weights of Schiøtz tonometer.

Tonometers	Mean difference† (mmHg) GAT – Others	95% LoA‡	*p*
PT-100 NCT			
Session 1	+0.4	−6.1 to +6.8	0.3200
Session 2	+1.1	−3.9 to +6.2	< 0.0001
Schöitz (ST)			
Average – Session 1	−2.1	−9.7 to +5.4	< 0.0001
Session 2	−3.5	−12.1 to 5.1	< 0.0001
5.5 g weight – Session 1	−2.4	−9.8 to +5.0	< 0.0001
Session 2	−3.6	−11.8 to 4.6	< 0.0001
7.5 g weight – Session 1	−1.9	−11.1 to +7.4	< 0.0001
Session 2	−3.4	−13.9 to 7.1	< 0.0001

GAT, Goldmann applanation tonometer; LoA, limits of agreement; NCT, non contact tonometer; ST, Schiotz tonometer.

†, Average difference (GAT minus PT1-00; GAT minus Schöitz tonometer, ST).

‡, 95% limits of confidence intervals of the difference between tonometers (lower to upper limits).

Discussion

This study determined whether changes in head and neck and/or body posture significantly affect the resting IOP and compared the IOP values obtained with three popularly used devices. To the best of the authors' knowledge, this is the first time any study has attempted to examine and replicate the effects of head and body position on the repeatability of measured IOP with the PT-100 tonometer, except for a prior abstract publication in 2019. There was no significant effect of change in head and body position on PT-100 measured-IOPs and the repeatability of its measurements obtained in the three head body postures. The within-session repeatability was similar between devices, but GAT had a similar between-session repeatability (±5 mmHg) to the PT-100, but was twice as good as those for the different weights of the ST.

The present findings are in contrast to a number of studies conducted in participants with and without glaucoma, which showed that changing body posture from sitting to supine (or rotating the body through 360° using a mechanically rotating bed) caused IOP variations by as much as threefold. The magnitude of IOP change seemed to vary with the magnitude of tilt, being greatest when the participants were completely upside down.[7,9,11,12,21,40,41,42] Although many of the aforementioned studies reported an increase in IOP with change in posture (from sitting to supine), there was not always an increase in IOP on lying down, and when there was a change, it was as small as ±1 mmHg[12] or ±2 mmHg.[21] One possible reason for such differences between our study and others is the different tonometry devices and the methodology used. The aforementioned studies explored the effect of head and body posture on IOP obtained using tonometers other than the PT-100 tonometer. However, the PT-100 has slightly better repeatability compared with GAT, hence changes in head and body positions may not affect its repeatability.[31]

The mechanism behind the change in IOP with posture involves a change in the aqueous production, outflow or change in episcleral venous pressure.[11] Although these parameters were not directly evaluated in this study, a study by Carlson et al.[43] Reported an IOP increase of as much as 11 mmHg in an inverted body posture despite aqueous production remaining same, whilst another study showed that aqueous outflow did not change significantly when compared between upright and supine positions.[44] However, a study evaluating the effect of postural change on IOP and episcleral venous pressure (EVP) found significant IOP increase between the upright and supine position and a corresponding significant increase in EVP between both positions. However, the increase in IOP was not significantly different from the increase in EVP indicating that the rise in IOP with posture may be attributed to change in EVP.[11]

In the present study, the within- and between-sessions repeatabilities were worse with the ST, a fact that served to limit the agreement between the ST and the GAT. The reason for variation in the measurements obtained with the ST may be because of several factors that affect its repeatability and reliability. These factors include the physiological menace reflex, which results in involuntary blinking, the eye movements during the measurement, which can affect the IOP values obtained using the ST and anatomical factors such as curvature variation or variation time at the point of measurement.[45] Also, the handling of the tonometer itself may be a possible source of variation in the measurements obtained with the ST. Although a previous study has reported good agreement between the ST and GAT,[46] it is important to note that the IOP values obtained with the ST are affected by the rigidity of the eye being measured.[47] Hence, variation in ocular rigidity and the factors that may affect ocular rigidity may lead to variation in the IOP values obtained with the ST.

Similar to our findings, earlier reports have shown agreement between PT-100 and GAT IOP readings within the normal range of IOP.[22,29,30] In another study that evaluated the performance of the PT-100 tonometer in healthy eyes, the instrument had better repeatability than the GAT. As the LoA between the PT-100 and GAT-measured IOP was within the maximum tolerance range of ±3 mmHg, which was suggested for the validity of a tonometer used to appropriately manage diseases that threaten vision,[39] both tonometers can be used interchangeably in disease management. In contrast, the LoA between the ST and GAT-measured IOPs were consistently above this maximum tolerance range (±4 mmHg for 5.5 g weights and within ±5 mmHg for 7.5 g weights) suggesting that both instruments cannot be interchangeably used in disease management, particularly in this population.

Previous studies[29,31,48] that compared IOP measurements with the PT-100 and GAT tonometers found no significant differences between the mean IOPs, but only one study[29] had compared measurements with both devices on two separate sessions. The authors found comparable IOP measurements with both instruments. Smaller differences between the ST and the GAT have been reported by a study exploring these tonometers in normal and irregular corneas,[26] with the GAT returning higher IOP readings than the ST. In that study, about 69% of ST readings were within ±3 mmHg of the GAT pressure, which was similar to the 60% (for all three weights) of IOP readings, within the same range, in session one, but reduced to 43% (for all three weights) in session two in our study.

In contrast to our study, the authors of one of the earlier studies used three tonometers in a non-randomised order, with the GAT first and the ST last. With the GAT, consecutive readings were taken until three readings were within ±1 mmHg[26] meaning that the authors made several applanations with the GAT, which could make the ocular massage effect more pronounced for the later readings taken with the other devices. Assuming the ST normally reads higher than the GAT (as was found in this study), this would lead to a reduction of the ST readings compared with the GAT readings. In another study,[49] the authors took three GAT readings in each of two positions – one sitting, one supine – before a single measurement was made with the 7.5 g weight of the ST. Here again, the ocular massage effect would be expected to reduce the subsequent IOPs measured with the ST. This could go some way to explaining why the authors also reported GAT readings that were higher than the IOP measured with the ST by 1 mmHg.

Another finding of this study was the significant negative correlation of IOP differentials with the CCT. The ST tended to overestimate GAT-measured IOPs in the thickest corneas but slightly underestimated the GAT-IOP in the thinnest corneas. For the PT-100, a significant underestimation of the GAT-IOP for the thinnest corneas reduced to zero at about 560 µm and then became a small overestimation for the thickest corneas. The PT-100 like all NCTs is calibrated using the GAT, which also tends to underestimate the pressure in thinner corneas but overestimate IOPs in thicker corneas. It appears that this tendency is magnified in the PT-100 and ST, which is why the tonometers read higher IOPs in thicker corneas whilst normo-estimating or underestimating thinner corneas. In an earlier study,[50] the difference between the GAT-measured IOP and two NCTs (Topcon CT80 and Nidek RKT-7700) in non-glaucomatous eyes, were more strongly correlated (r = –0.5) with CCT and both NCTs tended to overestimate IOPs in relation to GAT in thicker corneas than the PT-100 used in this study. The LoAs between NCT and GAT were significant (–6.5 to +1.3 mmHg for GAT vs. RKT-7700 and –6.7 mmHg to +1.1 mmHg for GAT vs. CT-80, $p <$ 0.05 for both) suggesting that the PT-100 better approximates GAT-measured IOPs in normal patients and is less affected by corneal thickness.[50] Other corneal biomechanical properties such as corneal hysteresis[51] and corneal resistance factor (CRF)[52] have also been shown to influence tonometer readings. Mangouritsas et al.[51] found that the Pascal Dynamic Contour Tonometer (DCT) was less dependent on corneal parameters than the GAT, whilst Kotecha et al.[52] showed that the CRF (but not CCT) was correlated significantly with DCT and GAT measurements.

The present study is strengthened by the randomisation, double blind design and the use of head body positions traditionally utilised in physiotherapy management of patients. Despite these strengths, this investigation has certain limitations that must be acknowledged. First, the study was conducted on a young adult population with normal IOPs, which may not represent the population attending optometry clinics. Also, the level of agreement of these three devices in older subjects and children and in those with high IOP remains for future investigations. Second, the IOP was measured during the time of the day when it is known to be most stable and blood pressure measurements known to affect postural IOP were not measured, therefore the effects of diurnal variations on the measured parameters are unknown. Third, the study used IOP measuring devices that are known to be affected by corneal thickness and did not consider the biomechanical properties of the cornea, which have an influence on IOP readings.

Conclusion

In conclusion, the study showed that changes in head, neck or body posture (up to 5 min after a postural change), did not affect the IOP measured with the PT-100 NCT in healthy young adults. In non-glaucomatous participants, PT-100 reading was valid, repeatable and can be used interchangeably with the GAT. In contrast to these, ST measured IOPs were invalid, unreliable and not comparable with the GAT-measured IOP. There is a greater tendency for ST to return higher IOPs compared with GAT in thicker corneas. These findings are relevant for clinicians. It appears that the use of the PT-100 tonometer in different postures does not affect the repeatability of the instrument. The resurgence in the use of Schiøtz tonometer in developing countries and its use in keratoprosthetic corneas or during scleral lens wear necessitates a proper assessment of its validity in IOP measurements to guide clinicians who rely on it for monitoring IOP and managing diseases.

Article context

What is known

The PT-100 noncontact tonometer is widely used in clinics and provides IOP readings that are comparable to the Goldmann tonometer. However, there is paucity of data on the validity and repeatability of its measures in different head and body positions.

What the article adds to the topic

This study provides evidence that PT-100 measured IOP are unaffected by postural changes and comparable with Goldmann tonometer in healthy patients. In contrast, Schiøtz tonometer IOPs are unreliable and not comparable with the clinical gold standard Goldmann tonometer.

What are the implications of the article

Findings are relevant to optometrists serving those with disability and in developing countries where there is a resurgence in the use of Schiøtz.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

A.I.T., K.C.O., H.Z., M.D.K., C.J.O., K.P.M. and U.L.O. contributed equally to the design and implementation of the research, analysis of the results and to the writing of the manuscript.

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Data availability

The data that support the findings of this study are available on request from the corresponding author, U.L.O.

Disclaimer

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