RESEARCH

Inter-optometrist variability of IOP measurement for modern tonometers and their agreement with Goldmann Applanation Tonometry.

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Running title: Variability of IOP measurement between tonometers

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Background: This study investigates: agreement in intraocular pressure measurements between three tonometers and Goldmann applanation tonometry (GAT); inter-optometrist agreement for each tonometer; intra-optometrist agreement for GAT; association between central corneal thickness (CCT) and IOP measurements with each tonometer.
Methods: IOP was measured using: CT-1P Non-Contact Tonometer (NCT) (Topcon Corporation, Tokyo, Japan), Pulsair IntelliPuff (Keeler Ltd., Windsor, UK) and Icare rebound tonometer (Icare, Helsinki, Finland) by two optometrists in a random order. Two GAT readings were obtained by each optometrist in a randomised masked manner. Mean differences, and 95% limits of agreement (LoA) for each measurement were calculated. CCT was measured by CT-1P pachymeter.
Results: Forty-one participants' IOPs were measured. Mean differences (95% LoA) between NCT, Pulsair, Icare compared to GAT for one optometrist were: 0.8 (−5.4 to 6.9) mmHg, −1.7 (−8.2 to 4.8) mmHg, −1.6 (−9.0 to 5.9) mmHg. Mean differences (95% LoA) in inter-optometrist agreement for GAT, NCT, Pulsair and Icare were: 0.3 (−6.7 to 7.3) mmHg, 0.4 (−2.1 to 2.9) mmHg, −0.9 (−3.6 to 1.9) mmHg and −0.2 (−4.9 to 4.5) mmHg, respectively. Mean differences (95% LoA) for intra-optometrist agreement for GAT were 0.2 (4.3 to −4.7) mmHg and 0.1 (3.6 to −3.9) mmHg for each optometrist, respectively. There was a weak positive association between CCT and both GAT (r^2 = 0.11) and NCT (r^2 = 0.12).
Conclusion: Pulsair and Icare may measure IOP lower than GAT. Mean differences for inter-optometrist agreement for all tonometers were < 1 mmHg; Pulsair showed a statistically significant difference. Intra-optometrist agreement for GAT was good. IOP measurements taken by two community optometrists are comparable using tonometers used in community practice.

INTRODUCTION

Primary open angle glaucoma (POAG) is normally slowly progressive and people with glaucoma usually have no symptoms until the late stages of the condition, with the result that approximately 50% of cases in the United Kingdom (UK) are undiagnosed.[1] Raised intraocular pressure (IOP) is an important risk factor for developing POAG and IOP is the only treatable risk factor.[2] If POAG is left untreated, this could lead to visual impairment and eventual blindness. IOP is routinely measured by eye care professionals including community optometrists and ophthalmologists, notably when people are assessed for suspected glaucoma. In the UK approximately 50% of patients referred for possible POAG based on high IOP alone are discharged at their first secondary care visit.[3,4] Obtaining an accurate baseline IOP measurement is essential in establishing a reliable estimate of the target pressure required for monitoring and management of the condition. The accuracy of tonometers is therefore of vital importance in the detection and treatment of people at risk of glaucoma.

A systematic review carried out in 2010 reported substantial intra- and inter-clinician variability for measurements taken on a range of tonometers, including Goldmann Applanation Tonometry (GAT), the current reference standard method.[5] Tonnu et al[6] stated that GAT is superior when compared to other available tonometers[6] and Cook et al.[5] agreed with this statement whilst also stating that the non-contact tonometer (NCT) gives measurements closest to GAT. There have been technological advances in tonometer design (excluding GAT) since this 2012 review, with many newer tonometers being less invasive than GAT and more automated than their predecessors e.g. CT-1P, (Topcon GB Ltd, Berkshire, UK) and the Icare® ic100 tonometer, (Icare, Helsinki, Finland). Non-contact tonometers have been used by UK community optometrists for nearly 40 years [7]. They are non-invasive, requiring no local anaesthetic with a minimal risk of infection. Rebound tonometers are quick and easy to use[8,9] and are increasingly used in ophthalmology and optometry settings.[10] Some research studies have demonstrated good agreement between IOP measurements taken using Icare and GAT.[11,12] The National Institute for Health and Care Excellence (NICE) published a review of the evidence comparing Icare to GAT[10] and found 52% (pooled value) of Icare IOP measurements were estimated to be in close agreement (within 2mmHg) with GAT measurements. This has generated particular interest among community optometrists regarding the use of Icare. There is, therefore, a need for studies comparing the Icare ic100 (available since 2016) to other tonometers frequently used in optometric practice. Additionally, it is unclear from the Cook review whether central corneal thickness (CCT), known to influence the accuracy of IOP measurement,[5,13] was always measured in previous studies due to limitations of the data reported in the literature. Whilst there is evidence comparing GAT measurements between ophthalmologists,[14] research into agreement between GAT measurements taken by two optometrists is lacking.

GAT is not routinely used by UK community optometrists, who generally prefer one of the many less-invasive alternatives such as NCT.[9] This survey by Myint et al. into the diagnostic tests used to detect glaucoma by UK community optometrists found 43% used table-mounted NCTs. Since that survey, the use of advanced tonometers by community optometric practices has increased, with rebound tonometry (e.g. Icare) being used in 18% of UK practices that responded to a more recent survey.[8] This change in clinical practice was reflected in the choice of tonometers in this study.

The primary aim of this study is to investigate the agreement between three modern tonometers and GAT when all measurements are taken by community optometrists. A further aim is to investigate the reliability associated with the measurement of IOP for each tonometer, i.e. the inter-observer variation (reproducibility) for all tonometers and the intra-observer variation (repeatability) for GAT. All measurements were taken by two optometrists with considerable experience with GAT, who both currently hold academic positions while continuing to practise as community optometrists. A secondary aim is to investigate any association between central corneal thickness (CCT) and IOP measurements obtained from each tonometer.

In terms of outcomes, the study findings could help inform the choice of tonometer used in community optometric practice, and potentially reduce the number of false-positive referrals to secondary care. Community optometrists are responsible for approximately 95% of UK referrals for suspect glaucoma[15] and the outcomes of this research could improve the quality of glaucoma referrals to secondary care, leading to earlier detection and improved visual outcomes for people with glaucoma.

METHODS

This study was conducted at a University Optometry Clinic, approved by City, University of London Optometry Proportionate Review Ethics Committee and adhered to the tenets of the Declaration of Helsinki.[16] Study participants aged 18 years and over were recruited from University staff and students, and patients attending the university's eye clinic. Potential participants with a history of corneal disorders, a recent eye infection or eye inflammation (within the previous six months), or previous laser refractive surgery were excluded. All tonometry measurements for each participant were taken during the same session over a maximum period of one hour so any diurnal variation in IOP was unlikely to affect results. Participants wearing contact lenses removed their lenses at least 30 minutes prior to their examination. Participants with high corneal astigmatism (>3DC) were not excluded and their numbers were likely to be small in this cohort.[17] The research optometrists did not observe in any participant an elliptical rather than a circular shaped fluorescein pattern when carrying out GAT.

Two non-contact tonometers were included: the CT-1P, (Topcon GB Ltd, Berkshire, UK) and Pulsair IntelliPuff (Keeler Ltd., Windsor, UK), and the Icare rebound (ic-100) tonometer (Icare®, Helsinki, Finland). Agreement was assessed using the mean difference (bias) and 95% limits of agreement (LoA) between each tonometer and GAT, the reference standard.[18]

Prior to obtaining any measurements, the researchers discussed the procedure with participants and responded to participants' questions. Written consent was obtained from each participant. Following this, a brief ocular history was obtained from each participant detailing the date of last eye examination, previous ocular history, general health, medication and any allergies. The examination was conducted on both eyes of each participant, in line with standard clinical practice.

The first research optometrist (RO1) performed the initial assessment comprising LogMAR visual acuity, assessment of corneal integrity, and measurement of CCT obtained optically with a CT-1P Noncontact Tonometer and Pachymeter (Topcon GB Ltd, Berkshire, UK). CCT measurements were obtained prior to taking any IOP measurements. The IOP measurements were then measured using the non-contact air-puff tonometers (CT-1P, Pulsair IntelliPuff), and the Icare rebound tonometer, first by one research optometrist and ten minutes later by the second research optometrist. The number of measurements taken with each tonometer was determined based on previous research on each model and the manufacturers' instructions. To overcome the effect of fluctuations in IOP caused by the cardiac pulse, three IOP measurements were obtained for each eye using the CT-1P[19] and Pulsair IntelliPuff,[20] and six measurements using the Icare,[21] with results averaged to give a final IOP measurement for each optometrist for each tonometer. The order in which the tonometers were used was randomised, with a recovery period of not less than two minutes between methods. The Icare tonometer uses a disposable probe for each participant, hence, there is no risk of cross-infection. All tonometers were calibrated at the start of the study and at regular intervals thereafter.

The participant's eyes were then anaesthetised with oxybuprocaine hydrochloride 0.4% and Fluorescein instilled using 1mg NaFl strips (Fluo Strips, Care Group, India). Two readings were taken on each eye using GAT by RO1. To reduce subjectivity in GAT recording, readings were obtained in a masked fashion, i.e. RO1 adjusted the GAT probe on the participant's cornea and informed RO2 when the end-point was reached. At this point RO2 recorded the final reading and re-set the force on the GAT probe to a randomly selected value (between 1g and 2g) in preparation for the second measurement. Following a ten-minute rest period, the procedure was repeated with RO1 and RO2 reversing their roles. Upon completion of all measurements, participants were given verbal and written advice relating to the effects of the anaesthetic drops. Each participant's visual acuity and corneal integrity were re-assessed at the end of the session.

A statistical function that produces left or right eyes in a random sequence was used to generate a spreadsheet informing researchers of the study eye (SE). The analysis was carried out on the study eye for each participant.

Data Analysis

A sample size calculation was carried out using the method for agreement studies described by McAlinden et al[22]. Based on a confidence interval for Limits of Agreement of 1mmHg, this calculation gave a sample size of 48. However, as a result of COVID-19, data collection was halted when data had been collected for 42 participants. Descriptive statistics for IOP results were calculated for each tonometer: mean, standard deviation, 95% limits of agreement. Bland/Altman difference plots were used to measure agreement between the different tonometers and GAT.[23] Correlation (Pearson's r) analysis was used to explore any association between measured IOP and CCT. Differences between means were analysed using the paired t-test with $p<0.05$ considered statistically significant.

RESULTS

Forty-two participants were recruited, further recruitment was stopped as a result of COVID-19 One participant was unable to tolerate GAT and their results were excluded. Demographic data for the study cohort along with IOP and CCT results for the study eye are presented in Table 1.

Agreement between tonometers and GAT

Table 2 outlines how each tonometer compares to GAT for RO1. Results for RO2 were similar and are included as supplementary material to this paper.

NCT showed the closest agreement to GAT in terms of mean bias, with NCT readings on average 0.8mmHg higher than GAT, whereas both Pulsair and Icare measurements were lower than GAT by approximately 1.5mmHg on average. **Error! Reference source not found.** Figure 1 shows the Bland-Altman difference plots for NCT, Pulsair and Icare, respectively, compared to GAT, illustrating the agreement between devices for RO1. There was little difference between the tonometers as regards the percentage of measurements within ±2mmHg of GAT.

Inter-observer variability for each tonometer

The mean differences (bias) and 95% Limits of Agreement (LoA) in IOP measurements for inter-optometrist agreement for GAT, NCT, Pulsair, and Icare are shown in Table 3. The Bland–Altman difference plot for inter-optometrist agreement in GAT IOP measurements is shown in Figure 2. All tonometers show good reproducibility, with Icare having the smallest mean bias (0.2mmHg) and Pulsair the greatest (0.9mmHg). The Pulsair was the only tonometer with a significant difference

between mean IOP measurements (p = 0.00). GAT had the widest 95% limits of agreement (-6.7 to 7.3mmHg) and NCT the narrowest (-2.1 to 2.9mmHg). Both NCT and Pulsair had 93% of readings within ±2mmHg of GAT, while the equivalent figure for Icare was 71%.

Intra-observer variability for GAT

The mean differences (95% LoA) in IOP measurements for intra-optometrist agreement were: RO1 = -0.2mmHg (4.3mmHg to -4.7mmHg); RO2 = -0.1mmHg (3.6mmHg to -3.9mmHg), with 83% and 85% of readings within ±2mmHg of each other for RO1 and RO2, respectively. Figure **Error! Reference source not found.**3 shows the Bland-Altman plots of the intra-optometrist agreement for RO1 and RO2, respectively.

Relationship between CCT and IOP

Correlation analysis (Pearson's r) found a weak positive association between CCT and mean GAT IOP (r = 0.33, r^2 = 0.11), and this was statistically significant (p = 0.03), Figure **Error! Reference source not found.**4 (a). Similar weak positive correlations were found when the data for RO1 (r = 0.25, r^2 = 0.06) and RO2 (r = 0.35, r^2 = 0.12) are considered separately, Figure 4 (b & c). There was also a weak positive association between CCT and NCT IOP (r = 0.35, r^2 = 0.12, p = 0.02). The associations between CCT and Pulsair, and CCT and Icare were negligible and not statistically significant (r = 0.24, r^2 = 0.06, p = 0.12; r = 0.18, r^2 = 0.03, p = 0.25, respectively). In all cases, the IOP value used in the correlation analysis was the mean of the measurements recorded by RO1 and RO2.

DISCUSSION

This study investigated how three tonometers commonly used by UK community optometrists compared to the reference standard GAT. Agreement between two practising community optometrists using four different tonometers commonly used in practice on forty-one eyes is reported.

Comparing the three tonometers to GAT, over fifty percent of measurements were within ±2mmHg of GAT, with NCT having the greatest agreement (56%), closely followed by Pulsair and Icare (54%). The systematic review by Cook et al[5] reported similar findings, with the overall percentages of readings within ±2mmHg of GAT to be 66% and 52% for NCT and Icare, respectively, compared to our values of 56% and 54%, respectively. Their review was based on averaging the results from twenty-six studies for NCT and fourteen for Icare (using the original Icare model, the TA01i), and included a range of different examiners including optometrists, ophthalmologists, students and other clinicians. The 95% LoAs for all three tonometers are outside the ±5mmHg tolerance specified by the ISO standard 8612 for comparison of a manufacturer's test tonometer with the reference standard[18].

However, our sample size, the distribution of IOPs in the sample and, in particular, the conditions under which the measurements were taken differed in many respects from those required in the standard.

The current study suggests that Pulsair and Icare record mean IOP lower than GAT, by 1.7 and 1.6mmHg respectively for RO1 and lower by 2.9 and 2.1mmHg respectively for RO2. Whilst these mean differences were statistically significant, some degree of caution is required in interpreting these findings due to the potential bias introduced by outliers in our relatively small sample. Based on these findings, one potential implication for community optometrists is the risk of recording an underestimate of the "true" IOPs when using the Pulsair or Icare devices. NICE guidance recommends referral when IOP is 24mmHg or greater, using GAT if available.[24] Optometrists who do not routinely perform GAT and rely on Icare or Pulsair may run the risk of under-referring patients with borderline IOP who are at risk of glaucoma. However, the recent EPIC-Norfolk observational study of more than 8600 participants found that 76% of undiagnosed cases of eye disease had IOP < 21mmHg, suggesting that IOP alone may be a less sensitive and specific indicator of glaucoma than previously thought.[25] Dahlmann-Noor et al.[26] also found Icare (the original Icare model, the TA01) underestimates IOP compared to GAT, with a mean difference of -3.34mmHg. Other researchers found Icare to underestimate GAT readings when GAT IOP was ≥ 23mmHg.[27,28] Our sample contained only four participants with GAT IOPs ≥ 23mmHg, so no firm conclusions can be drawn, but all three tonomfeters underestimated GAT IOPs for each of these four participants. The mean differences compared with GAT were -3.0mmHg, -6.3mmHg and -7.3 mmHg for NCT, Icare and Pulsair, respectively. There are conflicting findings in the literature, with reports of Icare measurements (using the Icare Pro, the 2011 updated version of the Icare TA01i) which were higher than GAT for IOP values of 22-30mmHg.[11] Nakakura[29] comparing the ic100 Icare to GAT in forty-five healthy subjects found lower values for Icare, with mean IOP -2.53mmHg (95% LoA -7.05 to 2.89mmHg). Cook et al,[5] averaging the results from fourteen studies using the original TA01i Icare device found a mean difference of +0.9mmHg for ICare compared to GAT. The evidence regarding Icare readings being higher or lower than GAT is therefore not conclusive and may vary between different models of the device.[12] Further work is required to investigate this relationship. Of the standard deviations of IOP measurements shown in Table 1 for each tonometer, the Icare has the greatest SD for both observers (4.2 and 4.4mmHg, respectively). Similar SDs have been found in other Icare studies[27,30] and also for NCT[31] but the explanation for these elevated SDs is unclear.

Intra-optometrist agreement for GAT was good and comparable to that found by other researchers.[32] The mean differences for inter-optometrist agreement for all four tonometers were less than 1mmHg. Only Pulsair showed a statistically significant difference between optometrists, with a mean bias of

0.9mmHg. These results are comparable to findings from other researchers. Dhalmann-Noor et al[26] found inter-observer bias for Icare (using the original Icare model, the TA01i) in 45 children with glaucoma to be 0.11mmHg, with 95% LoAs of -5.75mmHg to 5.97mmHg. Inter-observer agreement for Icare in the current study was 0.2mmHg with similar 95% LoAs of -4.9mmHg to 4.5mmHg. Kotecha et al.[14] found inter-observer agreement for GAT between ophthalmologists to be 0.2mmHg, with 95% LoAs ±4.9mmHg; inter-observer agreement in the current study was found to be comparable: 0.3 mmHg although 95% LoAs were wider (-6.68 to 7.27mmHg). These wider LoAs may result from the combination of our smaller than intended sample size and the influence of outliers. Removal of the two outliers from our data set (differences between optometrists GAT readings of 10 and 11mmHg, respectively) lowers the LoAs to -5.6 to +5.1mmHg, similar to those from Kotecha et al. However, even with these outliers removed GAT remained the tonometer with the greatest inter-observer differences, closely followed by the Icare. In their systemic review of the agreement between tonometers and GAT, Cook et al[5] noted that “Consistent use of the same tonometer during clinical follow-up is arguably almost as important as the choice of tonometer.” The variation between tonometers shown in Table 2 supports that view. Furthermore, the inter-observer differences for all the tonometers tested (Table 3), suggests that, in the context of the measurement of IOP for the detection of suspected glaucoma in community optometric practice, the optimum procedure would be for the same clinician to measure the IOP using the same tonometer at every clinical visit.

IOP measurements obtained by most tonometers are affected by CCT, with IOP readings from some tonometers affected more than others. In this sample there was a significant, though weak, positive association between GAT IOP measurements and CCT, consistent with previous studies.[33–35] A weak positive association was found between CCT and mean NCT IOP. Interestingly, previous studies have also found NCT to be more susceptible to the effects of CCT than GAT[36–38] though this was not evident with the NCT model used in the current study. Previous studies have investigated correlations between rebound tonometry readings using the Icare and CCT. Nakamura et al.[39] reported $r^2 = 0.352$, $p<0.0001$ between CCT and IOP measurements using Icare and Pakrou et al.[40] noted an increase in Icare IOP measurements with increasing CCT ($r = 0.16$ ($p = 0.05$) right and $r = 0.21$ ($p = 0.01$) left). Interestingly, the present study found negligible associations between CCT and both Pulsair and Icare. This hints at the possibility that CCT has a lesser influence on IOP measured with these two tonometers than on GAT. However, the differences in r between GAT and these two tonometers are small, as is the sample size, so this is a tentative suggestion.

Whilst GAT is the current reference standard for IOP measurement, it has its limitations. When using GAT on eyes with identical IOPs but differing CCTs, a thicker than average cornea requires greater force to applanate and, conversely, a thinner than average cornea requires less force[6] hence

recording artificially low IOPs. Newer tonometers may be less affected by CCT than GAT, and can offer other significant advantages compared with GAT such as increased portability, digital recording and use without anaesthesia. It is noteworthy that, despite the marked increase in reported frequency of use of applanation tonometry (Goldmann/Perkins) in community practices from 47% in 1987/88 to 61% in 2007 and reaching 81% in 2013,[8] many UK community optometrists working in these community practices still do not routinely carry out GAT.

In view of the projected rise of glaucoma cases (44% increase by 2035),[41] and the effects of diurnal variation on IOP and monitoring, there is a need to plan for a future in which the current volume of eye care services does not match their growing requirement. Non-invasive, self-measurement devices such as the Icare HOME tonometer could be linked to the patient's smart phone and IOP measurements uploaded to the cloud, allowing clinicians remote access to data thus increasing patients' engagement and adherence to their glaucoma treatment.[42]. Dabasia et al.[43] found that Icare Home tonometry, using a modified version of the Icare device that integrates eye recognition and eye alignment, can be used for self-measurement by a majority of trained subjects, IOP measuring using Icare Home was underestimated compared to GAT (mean bias -0.3mmHg 95% limits of agreement between −5.2 and 4.6mmHg Huang et al[44] also found that Icare Home tends to underestimate IOP (mean bias, −1.7 mmHg; 95% limits of agreement, −7.0 to +3.6mmHg). Additionally, targeting community settings has been recommended to increase the detection rate of glaucoma suspects.[45] Measuring IOP in large numbers of the public via a shopping centre Pop-Up is one feasible option though it is noteworthy that public engagement was greater when a BP check was offered alongside an IOP check, suggesting unfamiliar health checks can be promoted by aligning them with a more familiar check.[46]

This study should be considered with reference to its strengths and limitations. A key strength is the use of masking when obtaining the GAT readings to assess intra-observer variability. Additionally, IOP measurements using all four instruments were taken by two experienced optometrists currently working in primary care. Previous studies in this area have used a range and mixture of examiners including a combination of optometrists, ophthalmologists, students and other clinicians. This study is the first that the authors are aware of comparing results between optometrists. One study limitation was the small sample size. The study was conducted on a relatively young, normotensive population, limiting the generalisability of the results. It is likely that the majority of study participants were more motivated to respond and engage in a study measuring IOPs because they were interested in knowing more about their eye health. It would be useful to extend the current study sample to include

a wider age range of participants, a greater range of CCTs, people with glaucoma, and ocular hypertension patients being treated with glaucoma medication. The present study used the CT-1P Noncontact Tonometer which utilises a non-contact optical pachymeter to measure CCT. The ultrasound contact pachymetry is regarded as the reference standard,[47] but differences between these devices have not been found to be significant in healthy eyes.[48] Another limitation in this study is not having access to the Ocular Response Analyser (ORA) to measure corneal hysteresis, a more inclusive measurement of the effects of corneal biomechanics and a superior predictor of glaucoma progression. The ORA corneal compensated (cc) IOP (IOPcc) values may give an IOP measurement that is closer to the true IOP value, as it directly measures and compensates for the individual corneal response.[49,50] However, this device is still not commonly used by UK community optometrists.

CONCLUSION

The CT-1P Non-Contact tonometer showed close agreement with GAT and these results are similar to findings for other non-contact tonometers. The Icare ic100 rebound tonometer and Pulsair IntelliPuff tonometer measured IOP lower than GAT, and this may be clinically significant. Inter-optometrist agreement for four tonometers commonly used in community optometry practice was comparable with an agreement for similar tonometers obtained by non-optometrist clinicians. Intra-optometrist agreement for GAT was good. There was a weak but statistically significant positive association between CCT and both GAT and the CT-1P NCT, but negligible associations for Pulsair and iCare. Further work is needed to investigate the clinical impact of the choice of tonometer used in the detection of patients at risk of glaucoma.

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Table 1 Demographic Data of Study Cohort (N = 41) and mean tonometry results from four study tonometers. GAT = Goldmann applanation tonometry, NCT = Non-contact tonometry, CCT= central corneal thickness, RO1 = Research Optometrist 1, RO2 = Research Optometrist 2.

Total Cohort (n=41) *Number of left eyes=22*	**Mean**	**Standard Deviation**	**Range**
Female Gender (no.)	29		
Age (yrs)	37.2	17.0	18 – 72
CCT (µm)	533.6	29.8	476 - 604
	Mean (mmHg)	**Standard Deviation (mmHg)**	**Range (mmHg)**
GAT			
RO1	17.1	3.7	10 - 28
RO2	17.4	3.6	12 - 24
NCT (CT-1P)			
RO1	17.9	3.2	12 - 24
RO2	18.3	2.9	12 - 25
Pulsair			
RO1	15.4	2.6	11 - 21
RO2	14.6	2.8	10 - 21
Icare			
RO1	15.6	4.2	8 - 26
RO2	15.3	4.4	7 - 26

Table 2 Comparison of each tonometer to GAT (Goldmann Applanation Tonometry) for RO1 (95% LoA: Limits of Agreement) for 41 study eyes. NCT = Non-Contact Tonometer.

Tonometer	Mean (SD) IOP (mmHg)	Mean Bias: Tonometer - GAT IOP (mmHg)	95% LoA (mmHg)	P Value (t-test)	% Agreement within ±2mmHg of GAT
GAT	17.1 (3.7)	-	-	-	-
NCT	17.9 (3.2)	0.8	-5.4 to 6.9	0.13	56
Pulsair	15.4 (2.6)	-1.7	-8.2 to 4.8	0.02	54
Icare	15.6 (4.2)	-1.6	-9.0 to 5.9	0.01	54

Table 3 Inter-observer agreement (RO1-RO2) for each tonometer (95% LoA: Limits of Agreement) for 41 study eyes. GAT = Goldmann Applanation Tonometry, NCT = Non Contact Tonometer.

Tonometer	Mean Bias: RO2-RO1 IOP (mmHg)	95% LoA (mmHg)	P Value (t-test)	% Agreement within ±2mmHg
GAT	0.3	-6.7 to 7.3	0.60	61
NCT	0.4	-2.1 to 2.9	0.06	93
Pulsair	-0.9	-3.6 to 1.9	0.00	93
Icare	-0.2	-4.9 to 4.5	0.56	71

Figure Captions

Figure 1 Bland-Altman difference plots for NCT (Non-contact tonometer), Pulsair and ICare compared to GAT (Goldmann applanation tonometry) for 41 study eyes. Dotted line = bas, dashed lines = 95% Limits of agreement. RO1 = Research Optometrist 1, SE1 = study eye. The number of identical values for NCT, Pulsair and Icare compared to GAT were: five, seven and three respectively

Figure 2 Bland–Altman difference plot showing the inter-optometrist agreement for GAT (Goldmann Applanation Tonometry) IOP (Intraocular pressure) measurements between RO1 and RO2 for 41 study eyes Dotted line = bias, dashed lines = 95% Limits of agreement.. Six results were identical in value giving overlapping data points on the plot.

Figure 3 Bland–Altman difference plots showing the intra-optometrist agreement in GAT IOP measurements for RO1 and RO2 for 41 study eyes Dotted line = bias, dashed lines = 95% Limits of agreement. SE1 = study eye. Nine values were identical for RO1 and ten values for RO2 giving overlapping data points on the plot.

Figure 4 Scatter plot of (A) mean GAT (Goldmann Applanation Tonometry) IOP reading in mmHg (B) RO1 GAT IOP reading (C) RO2 GAT IOP reading versus central corneal thickness (CCT) in µm for 41 study eyes. RO1 = Research Optometrist 1, RO2 = Research Optometrist 2. SE1 = study eye.

SUPPLEMENTARY MATERIAL

Results for Research Optometrist 2 comparing each tonometer to GAT.

Table S4 Comparison of each tonometer to GAT (Goldmann Applanation Tonometry) for RO2 (95% LoA: Limits of Agreement) for 41 study eyes. NCT = Non-Contact Tonometer.

Tonometer	Mean (SD) IOP (mmHg)	Mean Bias: Tonometer -GAT IOP (mmHg)	95% LoA (mmHg)	P Value (t-test)	% Agreement within ±2mmHg of IGAT
GAT	17.4 (3.6)	-	-	-	-
NCT	18.3. (2.9)	0.9	-6.3 to 8.0	0.14	51
Pulsair	14.6 (2.8)	-2.9	-9.2. to 3.4	0.00	44
Icare	15.3 (4.4)	-2.1	-6.9 to 11.1	0.01	46

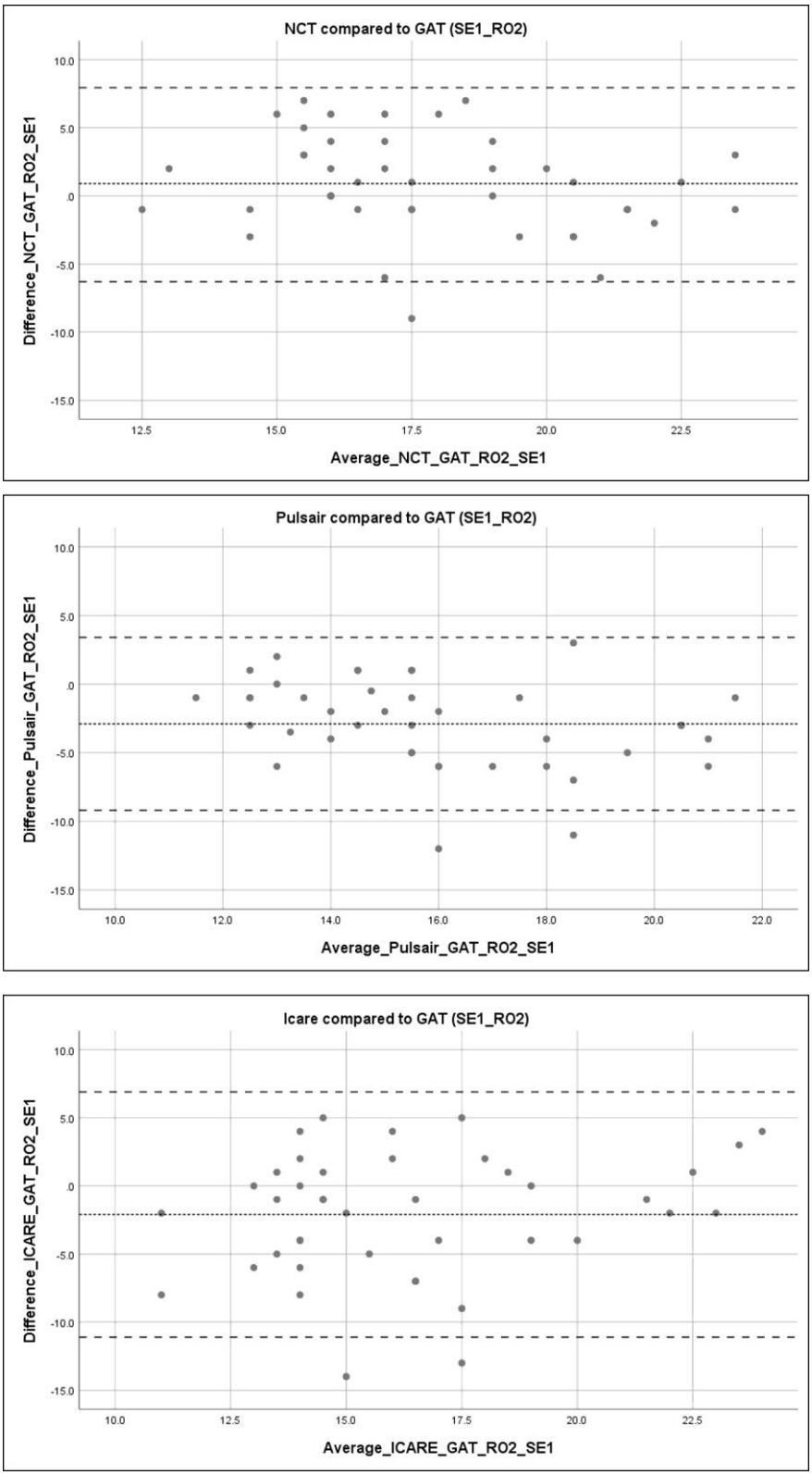

Figure S1 Bland-Altman difference plots for NCT (Non-contact tonometer), Pulsair and ICare compared to GAT (Goldmann applanation tonometry) for 41 study eyes. ***Dotted line = bas, dashed lines = 95% Limits of agreement. RO2 = Research Optometrist 2, SE1 = study eye.***