Original Article – Clinical Science

Comparison of intraocular pressure measurement between rebound, non-contact and Goldmann applanation tonometry in treated glaucoma patients

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ABSTRACT

Background: To compare the intraocular pressure readings obtained with the iCare rebound tonometer and the 7CR non-contact tonometer with those measured by Goldmann applanation tonometry in treated glaucoma patients.

Design: A prospective, cross sectional study was conducted in a private tertiary glaucoma clinic.

Participants: 109 (54M:55F) patients including only eyes under medical treatment for glaucoma.

Methods: Measurement by Goldmann applanation tonometry, iCare rebound tonometry and 7CR non-contact tonometry.

Main Outcome Measures: Intraocular pressure

Results: There were strong correlations between the intraocular pressure measurements obtained with Goldmann and both the rebound and non-contact tonometers (Spearman r values ≥ 0.79, $p < 0.001$). However, there were small, statistically significant differences between the average readings for each tonometer. For the rebound tonometer, the mean intraocular pressure was slightly higher compared to the Goldmann applanation tonometer in the right eyes ($p = 0.02$), and similar in the left eyes ($p = 0.93$) however these differences did not reach statistical significance. The Goldmann correlated measurements from the non-contact tonometer were lower than the average Goldmann reading for both right ($p < 0.001$) and left ($p > 0.01$) eyes. The corneal compensated measurements from the non-contact tonometer were significantly higher compared to the other tonometers ($p \leq 0.001$).

Conclusions: The iCare rebound tonometer and the 7CR non-contact tonometer measure IOP in fundamentally different ways to the Goldmann applanation tonometer. The resulting IOP values vary between the instruments and will need to be considered when comparing clinical versus home acquired measurements.

Keywords: Intraocular pressure, Goldmann applanation tonometer, rebound tonometer, non-contact tonometer, glaucoma, self-tonometry

INTRODUCTION

Intraocular pressure (IOP) remains the only treatable risk factor in the management of glaucoma patients. There have been numerous methods since the late 1800's for IOP measurement, all having limitations in terms of accuracy. The Goldmann applanation tonometer (GAT) is used as the clinical standard for IOP measurement around the world; however, more recent devices have been developed in an attempt to overcome GAT intrinsic measurement error. The ideal tonometer in the clinical setting needs to be accurate in normal and disease states e.g. corneal irregularity and post-keratoplasty; minimally invasive to the patient and ocular surface; suitable to use in all patients including children and un-cooperative or wheel-chair bound patients; easy to use by all-levels of clinical staff; robust and portable from room to room. No current device fulfils all these criteria and in reality multiple measurements with a range of devices can be performed to derive an IOP value. The clinician must ultimately decide whether the IOP is consistent with the overall clinical condition.

There have been a number of studies measuring IOP in normal subjects with various devices usually compared to GAT[1-3] and more recently to dynamic contour tonometry (DCT).[4-6] The aim of this study is to compare the relative IOP measurements of 3 devices in a clinical setting; the iCare rebound tonometer (RT) (iCare, Helsinki, Finland), the 7CR non-contact tonometer (NCT) (Reichert, Buffalo, USA), and GAT in clinically diagnosed, treated glaucoma patients.

The iCare RT uses an induction-based rebound method where a magnetic probe is bounced off the cornea, and the deceleration of the probe caused by the eye is used to calculate the IOP.[7, 8] The 7CR is a recent non-contact tonometer based on ocular response analyser (ORA) technology that provides two applanation pressures during a single measurement; one when the air puff pushes the cornea inward and one as the cornea returns to its original position. The instrument provides a corneal compensated IOP measurement (IOPcc) which is thought to be less influenced by corneal properties than other applanation techniques and a Goldmann-correlated IOP measurement (IOPg) which is the average of the two applanation pressures.[9] Neither the iCare RT or 7CR require the cornea to be anaesthetised. Given the automated nature of the iCare and the 7CR, these devices have the potential to be used by glaucoma patients outside of the clinical setting as self-tonometry devices. It is therefore of

interest to compare these tonometers with the current gold standard (GAT) over a range of IOP's in a population of glaucoma patients.

METHODS

Patients were recruited from a tertiary glaucoma clinic (City Eye Centre, Brisbane, Australia) between July and November 2010. All patients were diagnosed with glaucoma on the basis of disc appearance and visual field change by a glaucoma specialist (GL). Only eyes under current treatment with glaucoma medication were included. The selection criteria reflected the usual case mix of glaucoma patients seen in a glaucoma-oriented practice with the majority diagnosed with primary open angle glaucoma; but also included narrow-angle glaucoma, neovascular and normal tension glaucoma. The research project was approved by an institutional ethics committee within which the work was undertaken and conforms to the provisions of the Declaration of Helsinki in 1995. All patients gave informed consent for participation in the study and patient anonymity was preserved.

IOP was measured on each patient in a sitting position. The RT and NCT were performed by an experienced optometrist (RV) and the GAT was performed in another room by an ophthalmologist (GL) in a masked fashion (GAT calibration was confirmed prior to and performed weekly during the study period). RT required 6 measurements from each eye on the central cornea, with the highest and lowest values excluded and the average calculated internally by the instrument. Only good quality measurements (as indicated by the device by one or no bar) were accepted. NCT required 3 measurements on each eye and a reported value was calculated internally by the instrument using a proprietary algorithm. The waveform score which indicates the quality of the measurement was noted and only measurements with a score of 7.0 or more were accepted. GAT was performed with the Goldmann applanation device mounted on a slit-lamp biomicroscope. The observer (GL) was masked to the IOP measurements obtained by RT and NCT. GAT was performed after the other 2 measurements (within 30 minutes of the first 2 readings). The tonometer was dialed to the "1" position and the knob adjusted until the usual end point whilst applanating the cornea. One "best" reading was taken to reduce the effect of multiple applanations causing disruption of the ocular surface and the potential for GAT to displace aqueous from the anterior chamber, falsely lowering IOP values. Central corneal thickness was also measured by ultrasonic pachymetry in the chronic glaucoma patients (54 right eyes and 63 left eyes).

Statistical analyses

The fellow eyes of each patient were regarded as dependent variables. Subsequently, the analysis of this data was performed separately for right and left eyes to avoid potential bias. The Kolmogorov-Smirnov test was used to assess normality. Data not normally distributed were analysed using non-parametric statistical techniques including the, Friedman test with Bonferroni post hoc corrections (Wilcoxon signed rank test) and Spearman's rank correlation. The Bland-Altman method[10] was used to analyze the level of agreement between each tonometer and GAT. Linear regression was used to examine the influence of IOP upon tonometer bias (difference from GAT) and the relationship between CCT and IOP for each tonometer. All statistical tests were two-tailed and p-values less than 0.05 were considered statistically significant. Statistical analyses were performed using SPSS statistical package version 17.0 (SPSS Inc., Chicago, IL).

RESULTS

109 glaucoma patients (54 male, 55 female) with a mean age of 65 ± 14 years (range 17 - 88) were recruited. Eyes not currently receiving glaucoma medication and scores of less than 7.0 on the NCT were excluded, leaving 78 right eyes and 88 left eyes for analysis.

Comparison of all tonometers

The average IOP values measured by each tonometer showed small, but statistically significant differences. Table 1 provides a summary of the mean, median and range of IOP measured with each tonometer and Table 2 displays the p-values of Wilcoxon signed rank post-hoc tests for between tonometer comparisons (adjusted p-value for statistical significance = 0.008). IOPcc measurements were significantly higher than compared with all other tonometers ($p \leq 0.001$). RT measurements were significantly higher than readings obtained from IOPg (mean difference 1.50 and 0.87 mmHg for the right and left eyes respectively, $p \leq 0.001$). The mean IOPg reading was significantly lower compared to GAT for the left eye analysis ($p < 0.001$), however this trend did not quite reach statistical significance for the right eye data ($p = 0.02$). Figure 1 displays the box plots of the data for the right and left eyes and highlights the significant differences between tonometers.

Comparison with GAT

All tonometers compared reasonably to GAT values (Spearman rank correlation r-values range 0.78 to 0.90, all p values < 0.0001) (Table 3 and Figure 2). The mean difference or bias from GAT for each tonometer is shown in Table 4. For the RT, the mean IOP was slightly higher compared to GAT in the right eyes (p = 0.02), and similar in the left eyes (p = 0.93) but did not reach statistical significance (Table 2). Mean IOPcc readings were higher than GAT readings in both right (2.17 ± 3.01 mmHg) and left (1.63 ± 2.38 mmHg) eyes. IOPg readings were on average, lower compared to GAT in right (-0.35 ± 2.93 mmHg) and left eyes (-0.92 ± 2.38 mmHg). The agreement between each tonometer and GAT was examined using Bland-Altman plots, displayed in Figure 3.

Influence of IOP

Simple linear regression was used to examine the relationship between the variation from GAT (bias) and the reported IOP value for each tonometer. Mean IOP was significantly associated with the measured bias from GAT for all tonometers (Table 5). The positive values of the regression slopes indicate that as IOP increased, all tonometers tended to overestimate IOP compared with GAT, however this did not reach statistical significance in 2 groups (Left IOPcc p = 0.52 and Right RT p = 0.09).

Influence of CCT

Simple linear regression was used to examine the relationship between CCT and IOP for each of the tonometers in the chronic glaucoma patient subgroup. No statistically significant relationship was observed between CCT and IOP for any of the tonometers for right or left eye analysis (all p values > 0.05, Table 6). Additionally, the slopes of the regression lines were not significantly different between the tonometers suggesting that the influence of CCT upon IOP measurement was similar for each tonometer.

DISCUSSION

GAT is utilised by clinicians around the world on a daily clinical basis. The measurements despite known limitations are used to formulate glaucoma management decisions. Although true IOP values as would be found by manometry are not being measured, relative IOP changes in an individual patient over time are clinically meaningful. The tonometry devices in this study have been compared to each other and found to over or underestimate GAT values.

Numerous recent studies have compared RT with GAT.[11, 12] Most have utilised the rebound tonometer manufactured by iCare (iCare, Helsinki, Finland). These studies have addressed measurements in normals as well as patients with glaucoma, ocular hypertension, normal tension and suspects. The general findings are that RT tends to overestimate the GAT measured IOP ranging from 0.1 to 3.36mmHg,[1, 12] similar to the findings in the current study. Variation from this trend may be influenced by technique, such as if performed by the patient[13] or the experience of the technician.[14] The level of IOP may also be a factor, with several studies showing overestimation compared with GAT as IOP increased[3, 15, 16] whilst another study showed a measurement underestimation.[17] These IOP measurement differences between the various tonometers need to be considered when comparing with GAT readings performed in the clinical setting, as average IOP values will differ especially if readings are multiply performed over time as may occur with home tonometry.

In a study of 198 normal eyes, Moreno-Montanes et al[11] reported on another type of RT, the IOPen (Medicel, Wolfhalden, Switzerland). The IOPen readings were found to be significantly lower than GAT (mean 3.2 ± 3.6 mmHg). This is likely related to the internal processing algorithm of the device that differs from that of the iCare RT.
A number of studies have compared NCT using the ORA (Reichert, Buffalo, USA) versus GAT in normal and glaucoma patients.[11, 18, 19,20] Three studies found IOPcc tended to overestimate GAT[18-20] ranging from 1.56 - 2.67 mmHg. The IOPg values were more variable ranging from slight underestimation[18] at -0.1 ± 4.8 to overestimation 1.7 ± 3.7 mmHg.[20] The overestimation of IOPcc and the slight underestimation of IOPg compared with GAT findings are consistent with the current study. In contrast, a study by Moreno-Montanes et al[11] reported a good comparison with GAT readings (mean difference IOPg 0.2 ± 2.3 mmHg and IOPcc -0.4 ± 2.8 mmHg). In this study, the data collected from both eyes were analysed separately. It would be expected the results to be similar between the eyes, however there

was a small degree of variation. This difference between the eyes may disappear with a greater number of subjects in the study. Another possible explanation is a systematic bias identified in a study by Pekmezci et al.[21], that found IOP to be higher in the first measured eye. In our study, the right eye was measured first followed by the left for all three instruments, potentially resulting in the mean right IOP higher than the left IOP.
The importance of comparing RT and NCT to GAT is that these two devices are currently being utilised as home tonometry methods. The RT can be self-administered or performed by a family member. The device can be held free hand (Figure 4) or an alignment device fitted. The 7CR, although not as portable, can be installed in a domestic environment and easily self-administered (Figure 5) by the patient or a household member. Diurnal variation of IOP including levels in relation to drop administration could be obtained and used in the clinical management of glaucoma, particularly in cases where IOP fluctuation is considered a significant risk factor and/or medication compliance is questionable. The measurements recorded by a patient can be compared to GAT measurements performed in the clinic, however these values as shown by this study and others will not be not directly equivalent.

This prospective study addressed a group of treated glaucoma patients in a real clinical setting. IOP measurements were performed as part of the routine clinical workup and used accordingly to modify management. For future study, IOP measurements in more patients could be performed with investigation into various subgroups of glaucoma, for example in normal tension glaucoma and in anterior segment pathologies such as post-surgery corneal scarring. This would help to determine whether the measurement bias is consistent amongst these patient groups. It is inevitable that further tonometry devices will be developed and it is hoped that accurate IOP measurement will become available for both clinical and self-tonometry purposes.

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TABLES

Table 1: Mean, median and range of IOP (mmHg) for all tonometers.

	Right eyes			Left eyes		
Tonometer	**Mean ± SD**	**Median (IQR)**	**Range**	**Mean ± SD**	**Median (IQR)**	**Range**
IOPcc	18.02 ± 5.30	17.00 (14.80 - 20.25)	8.40 - 38.30	17.59 ± 4.90	17.10 (14.08 - 21.00)	7.90 - 30.70
IOPg	15.49 ± 5.32	14.35 (11.83 - 17.75)	6.90 - 30.30	15.05 ± 5.31	14.25 (11.30 - 19.40)	4.60 - 29.50
RT	16.54 ± 4.90	16.00 (13.00 - 19.00)	8.00 - 30.00	15.92 ± 5.35	15.00 (11.75 - 20.00)	7.00 - 31.00
GAT	15.85 ± 4.40	15.00 (13.00 - 18.75)	8.00 - 30.00	15.97 ± 4.75	15.00 (12.75 - 19.00)	9.00 - 30.00

IOPcc: corneal compensated intraocular pressure from 7CR NCT, IOPg: Goldmann correlated intraocular pressure from 7CR, RT: Rebound Tonometer from iCare, GAT: Goldmann Applanation Tonometer.

Table 2: Summary of post-hoc analysis p-values using Wilcoxon signed rank tests

Post hoc comparison	Right eyes	Left eyes
IOPcc v IOPg	< 0.0001*	< 0.0001*
IOPcc v iCare	< 0.0001*	< 0.0001*
IOPcc v GAT	< 0.0001*	< 0.0001*
IOPg v RT	< 0.0001*	0.001*
IOPg v GAT	0.16	< 0.0001*
RT v GAT	0.02	0.93

* Statistically significant difference (post-hoc adjusted p-value for significance 0.008).
IOPcc: corneal compensated intraocular pressure from 7CR NCT, IOPg: Goldmann correlated intraocular pressure from 7CR NCT, RT: Rebound Tonometer from iCare, GAT: Goldmann Applanation Tonometer.

Table 3: Spearman correlation coefficient r values (and p values) for each tonometer compared with GAT.

	Spearman rank correlation r-value	
Tonometer	**Right**	**Left**
IOPcc	0.81*	0.86*
IOPg	0.79*	0.90*
RT	0.84*	0.86*

* $p < 0.0001$

IOPcc: corneal compensated intraocular pressure from 7CR NCT, IOPg: Goldmann correlated intraocular pressure from 7CR NCT, RT: Rebound Tonometer from iCare, GAT: Goldmann Applanation Tonometer.

Table 4: Mean difference (bias) and 95% confidence intervals for each tonometer in comparison to GAT (mmHg).

	Right eyes			Left eyes		
Tonometer	**Bias ± SD**	**95% CI**	**Range of CI**	**Bias ± SD**	**95% CI**	**Range of CI**
IOPcc	2.17 ± 3.01	-3.72, 8.07	11.79	1.63 ± 2.38	-3.03, 6.29	9.32
IOPg	-0.35 ± 2.93	-6.10, 5.38	11.48	-0.92 ± 2.38	-5.59, 3.75	9.34
RT	0.69 ± 2.65	-4.50, 5.89	10.39	-0.05 ± 2.56	-5.06, 4.97	10.03

Bias = Tonometer IOP - GAT IOP

IOPcc: corneal compensated intraocular pressure from 7CR NCT, IOPg: Goldmann correlated intraocular pressure from 7CR NCT, RT: Rebound Tonometer from iCare, GAT: Goldmann Applanation Tonometer..

Table 5: Slopes (β) and r and p-values of linear regressions for tonometer bias as a function of IOP.

	Right eyes		Left eyes	
Tonometer	**β**	**r (p- value)**	**β**	**r (p- value)**
IOPcc	0.20	0.31 (0.005)**	0.04	0.07 (0.52)*
IOPg	0.21	0.33 (0.003)**	0.12	0.24 (0.02)*
RT	0.12	0.20 (0.09)*	0.13	0.24 (0.02)*

* $p < 0.05$, ** $p < 0.01$

IOPcc: corneal compensated intraocular pressure from 7CR NCT, IOPg: Goldmann correlated intraocular pressure from 7CR NCT, RT: Rebound Tonometer from iCare, GAT: Goldmann Applanation Tonometer.

Table 6: Slopes (β) and r and p-values of linear regressions for IOP as a function of CCT.

	Right eyes		Left eyes	
Tonometer	**β**	**r (p- value)**	**β**	**r (p- value)**
GAT	0.01	0.10 (0.47)	0.00	0.02 (0.88)
IOPcc	0.02	0.17 (0.21)	0.00	0.03 (0.84)*
IOPg	0.03	0.24 (0.08)	0.01	0.07 (0.57)
RT	0.03	0.22 (0.12)*	0.01	0.03 (0.81)

IOPcc: corneal compensated intraocular pressure from 7CR NCT, IOPg: Goldmann correlated intraocular pressure from 7CR NCT, RT: Rebound Tonometer from iCare, GAT: Goldmann Applanation Tonometer.

FIGURES

Figure 1: Box plots of IOP in glaucoma patients with all tonometers for right and left eyes. IOPcc: corneal compensated intraocular pressure from 7CR NCT, IOPg: Goldmann correlated intraocular pressure from 7CR NCT, iCare: iCare rebound tonometer, GAT: Goldmann applanation tonometer. * $p < 0.008$ (post-hoc adjusted p-value), • statistical outlier.

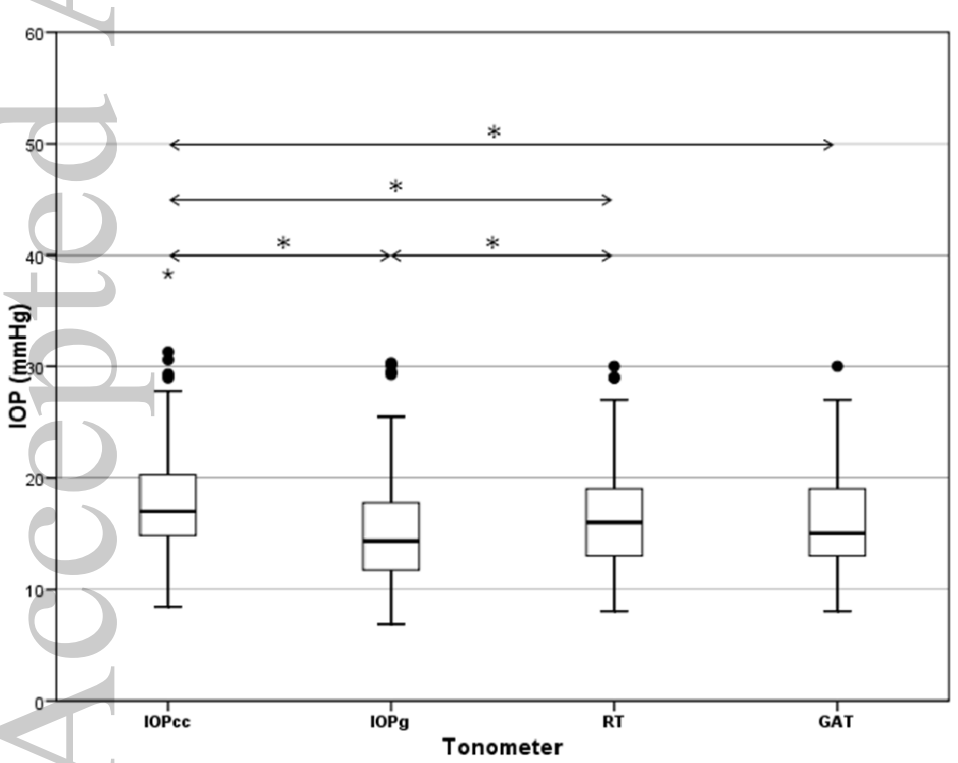
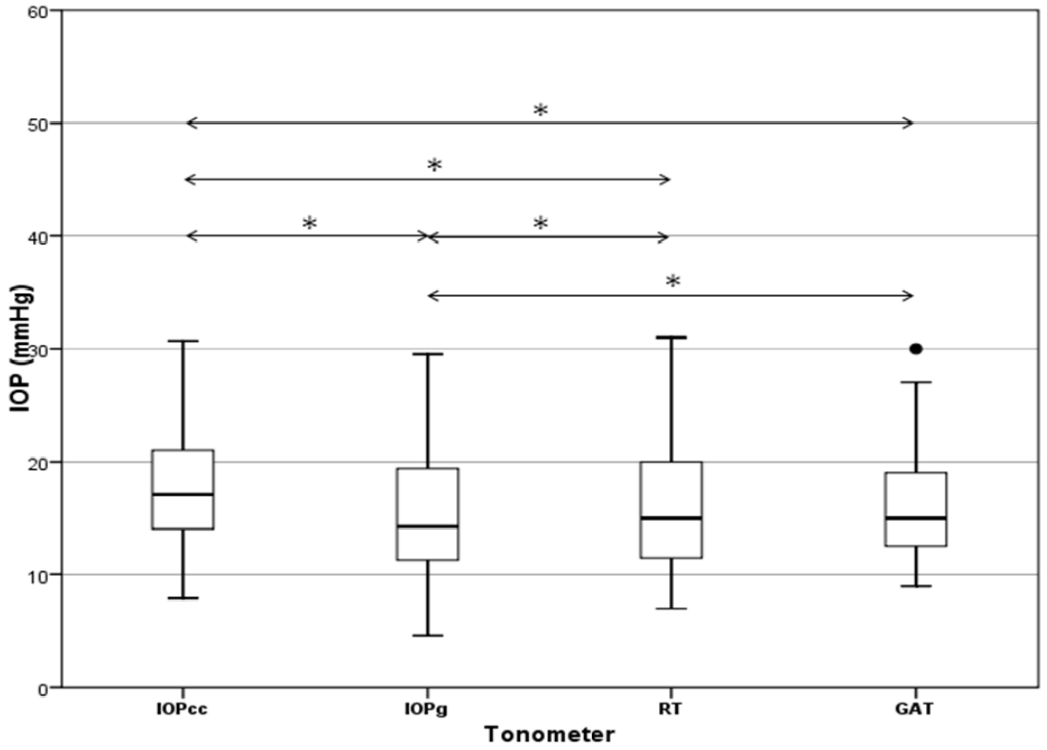
Right eyes	Left eyes
	

Figure 2: Scatter plots for corneal compensated IOP (IOPcc) (left panel), Goldmann correlated IOP (IOPg) (middle panel) and iCare rebound tonometry (RT) (right panel) with respect to Goldmann applanation tonometry (GAT) measured in mmHg.

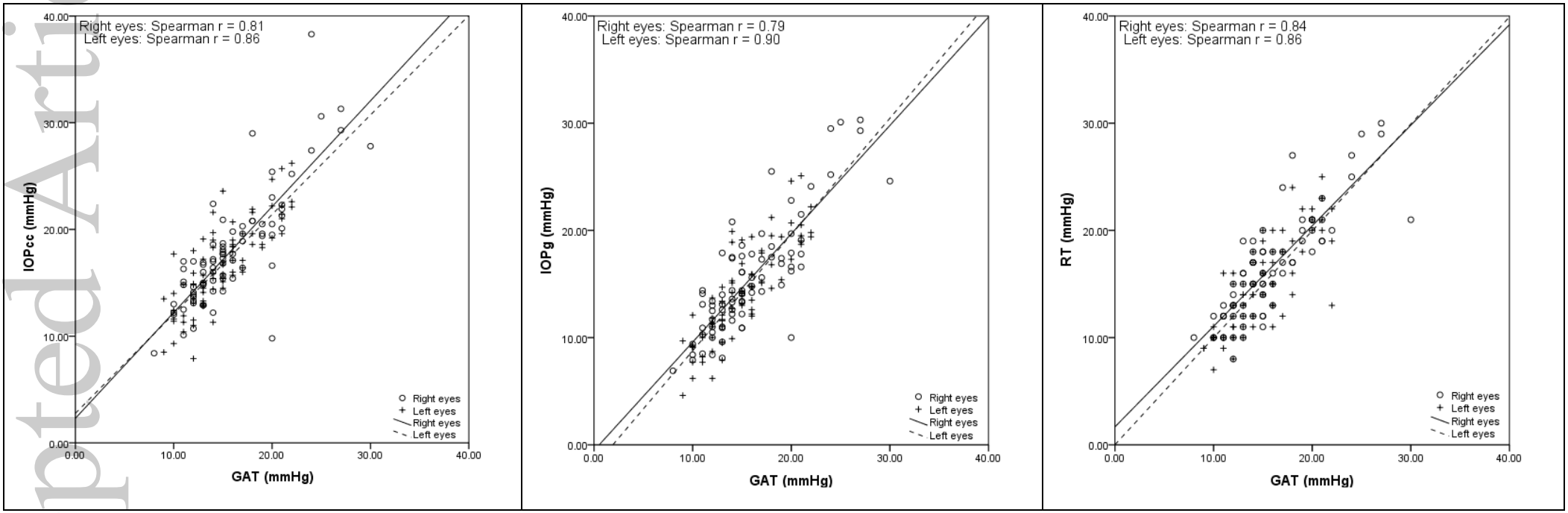


Figure 3: Bland-Altman plots for corneal compensated IOP (IOPcc) (left panel), Goldmann correlated IOP (IOPg) (middle panel) and iCare rebound tonometry (RT) (right panel) with respect to Goldmann applanation tonometry (GAT) measured in mmHg. SD; standard deviation.

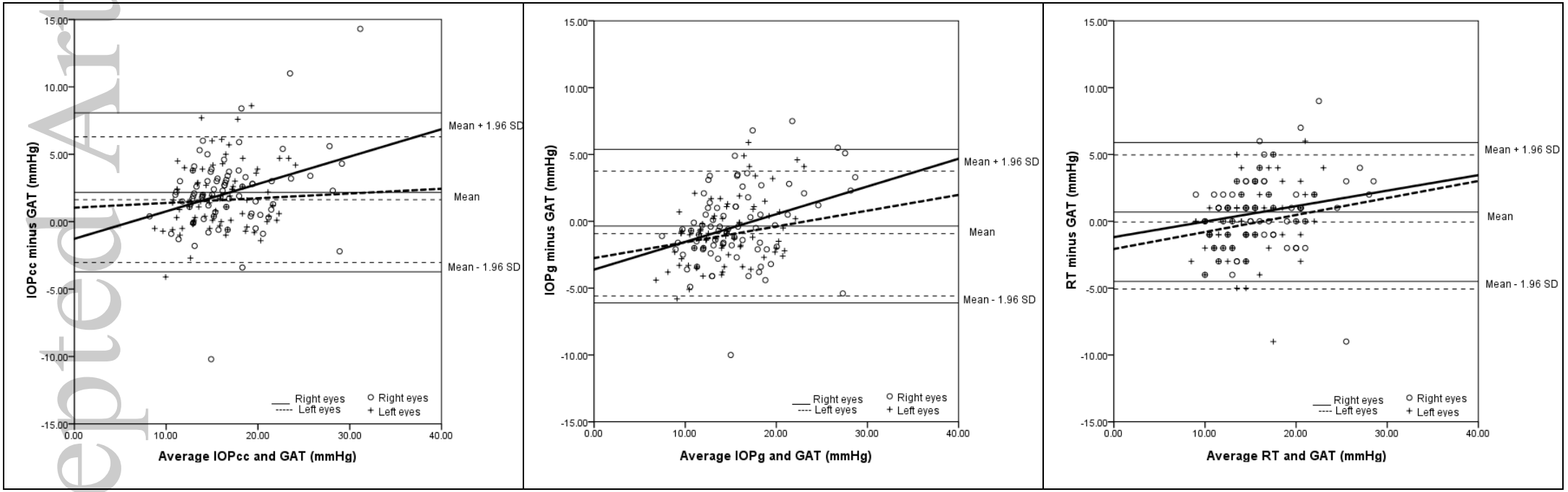


Figure 4: Photograph demonstrating the use of the iCare Rebound Tonometer as a self-tonometer.

Figure 5: Photograph of the 7CR Non-contact Tonometer being used as a self-tonometer

Figure 1

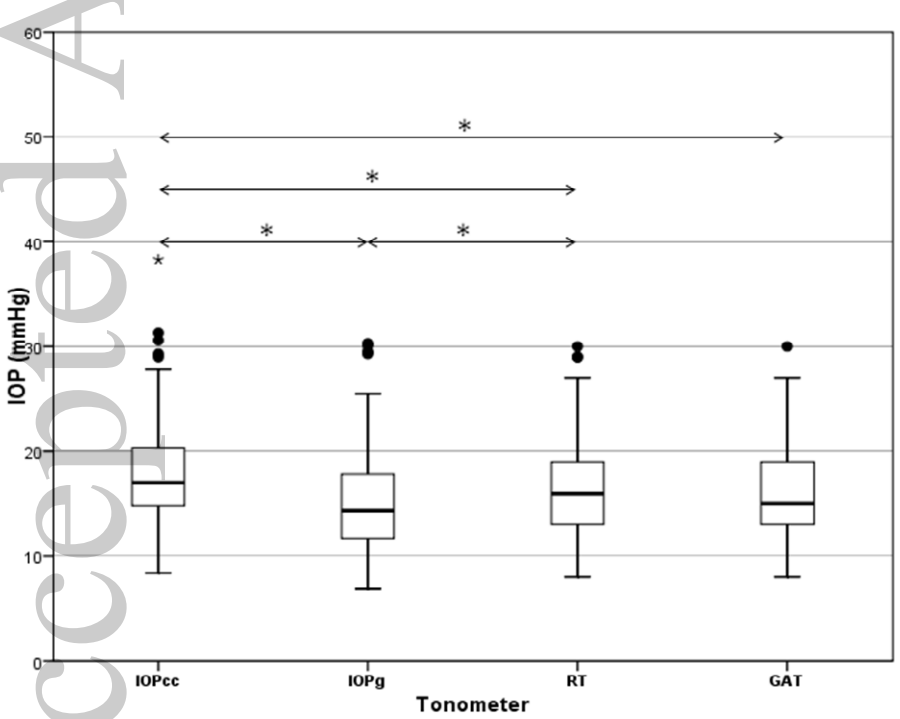
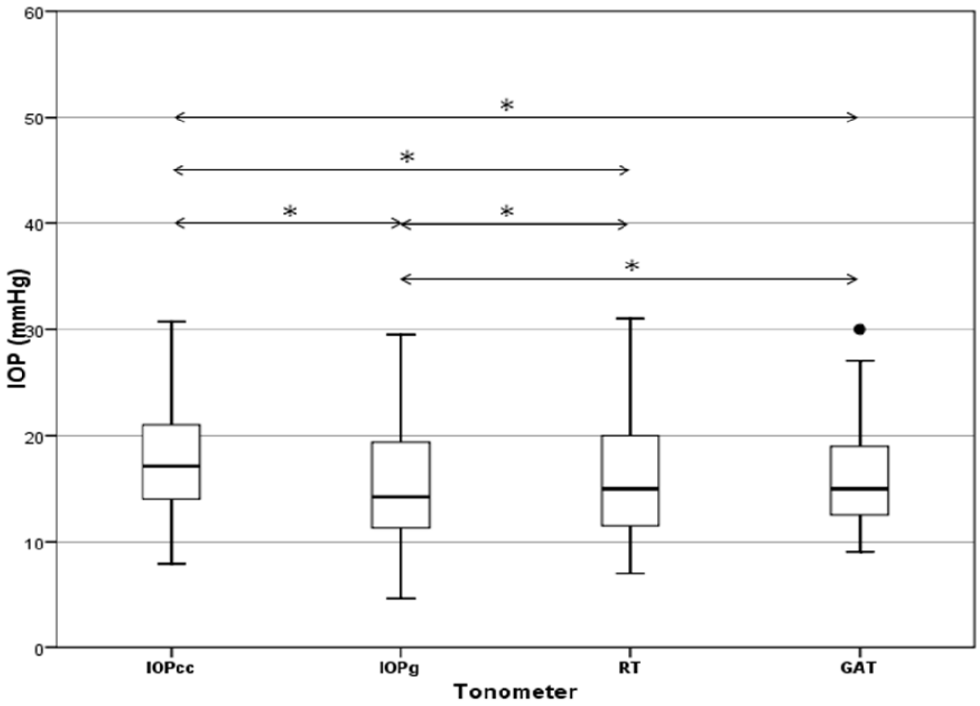
Right eyes	Left eyes
	

Figure 2

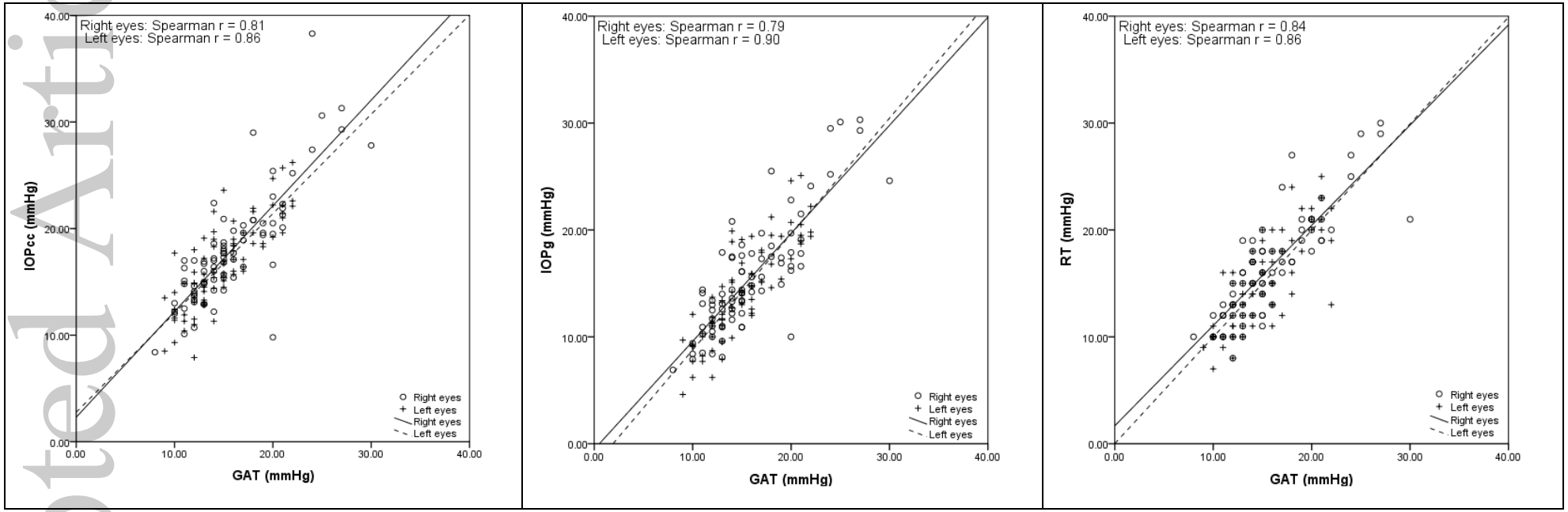
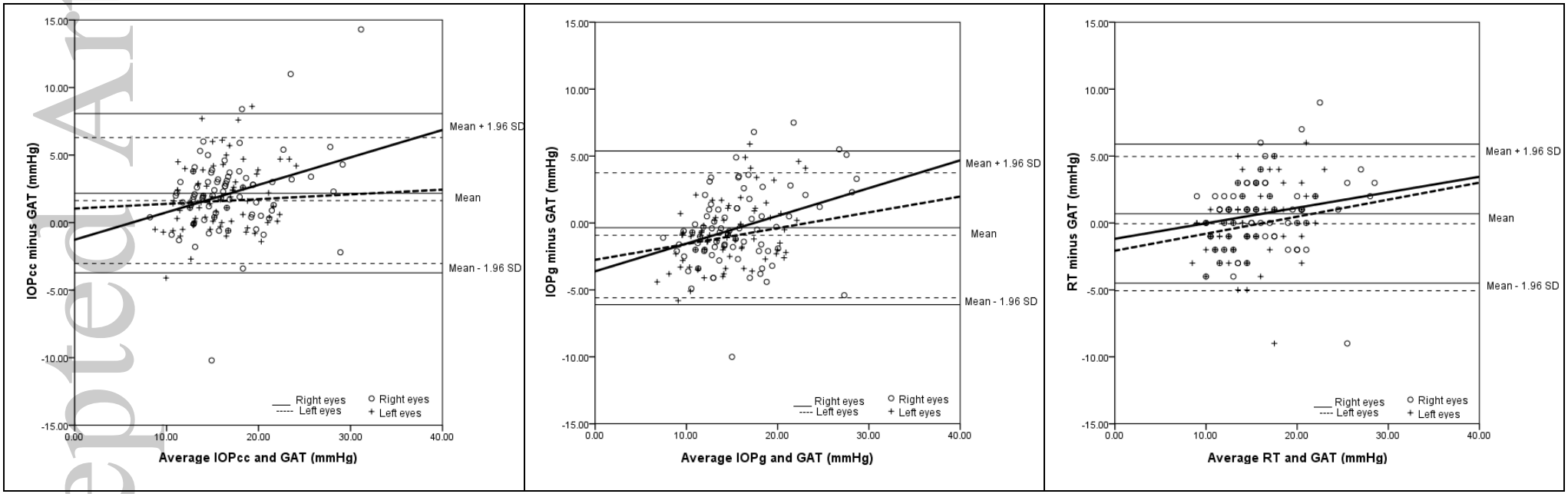
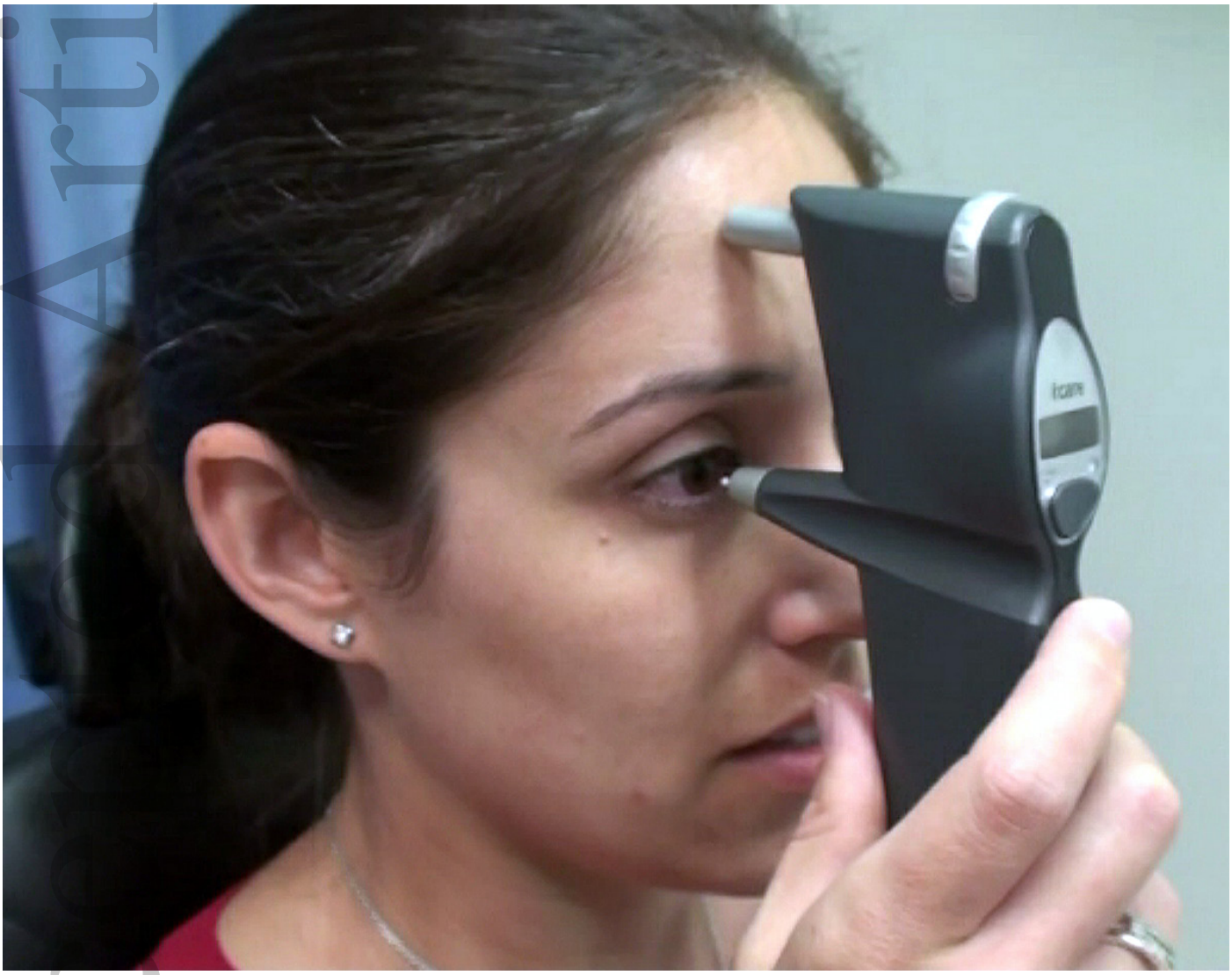


Figure 3





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