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**Impact of corneal parameters on intraocular pressure measurements in different tonometry methods**

**Running title: Tonometry methods and corneal parameters**

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**Abstract**

**AIM:** To evaluate the impact of central corneal thickness (CCT) and corneal curvature on intraocular pressure (IOP) measurements performed by three different tonometers

**METHODS:** IOP in 132 healthy eyes of 66 participants was measured using three different tonometry techniques: Goldmann applanation tonometer (GAT), Pascal dynamic contour tonometer (DCT), and ICare rebound tonometer (RT). CCT and corneal curvature were assessed.

**RESULTS:** In healthy eyes, DCT presents significantly higher values of IOP than GAT ( $17.34 \pm 3.69$  and  $15.27 \pm 4.06$  mm Hg;  $P < 0.0001$ ). RT measurements are significantly lower than GAT ( $13.56 \pm 4.33$  mm Hg;  $P < 0.0001$ ). Compared with GAT, DCT presented on average 2.51 mm Hg higher values in eyes with  $CCT < 600 \mu m$  and 0.99 mm Hg higher results in eyes with  $CCT > 600 \mu m$ . The RT results were lower on average by 1.61 mm Hg and 1.95 mm Hg than those obtained by GAT, respectively. Positive correlations between CCT in eyes with  $CCT < 600 \mu m$  were detected for all IOP measurement techniques, whereas a similar relationship was not observed in eyes with thicker corneas. A correlation between IOP values and keratometry in the group with  $CCT < 600 \mu m$  was not detected with any of the tonometry methods. In thicker corneas, a positive correlation was found for GAT and mean keratometry values ( $R = 0.369$ ;  $P = 0.005$ ).

**CONCLUSION:** The same method should always be chosen for routine IOP control, and measurements obtained by different methods cannot be compared. All analysed tonometry methods are dependent on CCT; thus, CCT should be taken into consideration for both diagnostics and monitoring.

**KEYWORDS:** intraocular pressure; Goldmann applanation tonometer; Pascal dynamic contour tonometer; ICare rebound tonometer; central corneal thickness; corneal curvature; healthy individuals

**INTRODUCTION**

Intraocular pressure (IOP) is one of the most fundamental ophthalmological examinations. In many cases, the result is used to determine an accurate therapeutic approach. The IOP distribution in the general population ranges from 11 up to 21 mm Hg with a mean value 15-16 mm Hg. Normal IOP values may oscillate depending on the time of day, body position, heart rate, used drugs, and fluid intake (1). Among many available methods of measurement, Goldmann applanation tonometer (GAT) remains the gold standard. This method is based on the Imbert Fick rule that was introduced in 1950 and over time has become the most widely used and reliable method of measurement. Unfortunately, it has been proven that measurements made with this method may be burdened with an error related to corneal thickness. Furthermore, other negative factors, such as necessity of using anaesthetic or fluorescein drops, and the need for highly experienced examiner were also significant. This led researchers to look for newer, more accurate, less invasive and faster methods of measuring intraocular pressure. Pascal dynamic contour tonometer (DCT) seems to be a promising alternative to GAT. It is supposed to be less dependent on corneal properties and does not require fluorescein application. The measurement technique itself seems to be easier and faster to perform but still requires local anaesthesia. The DCT is equipped with a special sensor that instead of exerting pressure on the cornea adapts to its shape (the concave shape of the sensor) and sends an electrical signal corresponding to the IOP (2). Another useful alternative is the ICare-rebound tonometer (RT). The measurement is performed using a disposable probe that moves forward and bounces off the surface of the cornea. Acceleration and deceleration of the probe during measurement are measured. Strengths of this device include handiness, small size, simplicity and shortened time of use, facilitation of measurement in children and people with impaired mobility, and lack of a need for local anaesthesia and fluorescein instillation. Moreover, the RT claims to be less dependent on corneal properties, but actual reports contradict this notion (3,4).

According to the available data, the usage of any tonometry techniques is restricted by many conditions related to corneal morphology and biomechanical properties. Various studies have shown that corneal parameters, such as central thickness, elasticity, rigidity and curvature, can act as a measurement bias (1,5,6).

In connection with the above findings, the question arises regarding which method should be chosen for routine ophthalmologic examination. The aim of the study was to compare intraocular values obtained with three different

tonometers. Additionally, the impact of central corneal thickness (CCT) and corneal curvature on IOP measurements was assessed.

## **SUBJECTS AND METHODS:**

In total, 132 healthy eyes of 66 patients examined in The First Department of Ophthalmology at Pomeranian Medical University in Szczecin were included in the study. Exclusion criteria were acute inflammation, history of glaucoma or any eye surgery in the examined eye, and age under 50 and more than 85 years. In all participants slit lamp examination and fundus evaluation were performed. Written informed consent was obtained from all subjects before examination. The study was in compliance with the tenets of the Helsinki's Declaration. First, the examination of corneal curvature and CCT were performed sequentially. Then, the IOP examination was performed with three different tonometry techniques in following order: RT, DCT and GAT. All measurements were performed by the one examiner.

Measurements using the GAT method (Haag Streit International, Koeniz, Switzerland)

All GAT measurements were performed after using topical anaesthetic (Alcaine®; Alcon Laboratories Inc., Fort Worth, TX, USA) and placing single, dry fluorescein strip over the inferior tear meniscus. Examination was performed under a cobalt blue-filtered light, and disposable prisms were used. After staining the cornea, the tip of the prism was moved so that it was in contact with the central surface of the cornea. Next, the dial of the tonometer was turned clockwise until two half circles appeared and formed a horizontal letter S. The inner edges of both half circles touched gently. The final result was the average of three consecutive measurements.

Measurements using RT (Tiolat Oy, Helsinki, Finland)

The principle of RT tonometer is based on the inductive method for measuring the probe's reflection force. This method allows quick and accurate measurement of intraocular pressure without the use of anaesthetics. Before the examination, each patient was asked to look straight ahead. The device was settled near the patient's eye so that the disposable probe is positioned horizontally, forming a right angle with the central surface of the cornea. The distance between the surface of the cornea and the tip of the probe was 4-8mm. Forehead support provided stabilization of the tonometer during the examination. Then, by pressing the button, the probe slides forward to make contact with the cornea and rebounds from its surface. The final result was the average of six consecutive measurements.

Measurements using DCT (SMT Swiss Microtechnology AG, Port, Switzerland)

The DCT measures pulsing IOP in a direct and continuous (dynamic) manner. The device is attached to the slit lamp and consists of a pressure-sensing tip. During the examination, the sensor tip touches the central corneal surface, and integrated baroreceptors measure IOP without corneal applanation. Before the examination, topical anaesthetic was instilled on the eye (Alcaine®; Alcon Laboratories Inc., Fort Worth, TX, USA). The patient was asked to look straight ahead with eyes wide open and not move for a few seconds. A disposable sensor cap was applied on the sensor tip and moved forward until it touched the surface of the central cornea. The signal sound informed about the detected IOP, and the result was presented on digital display after 5 seconds. Additionally, with every measurement, ocular pulse amplitude (OPA) and a quality score (Q) were presented. The quality score ranges from Q1 to Q5, and Q1 and Q2 correspond to the most reliable results. Hence, only Q1 or Q2 results were included in statistical analysis.

Corneal curvature

Corneal curvature measurement was performed using KR-800 Auto Kerato-Refractometer (Topcon, Tokyo, Japan). For each eye, the values of flat (R1) and steep (R2) meridians of corneal curvature were assessed and presented in dioptres (D) and mm. Averaged R1 and R2 values were considered for further statistical analysis (7).

Central corneal thickness (CCT)

CCT was measured with the Reichert ultrasonic pachymeter (Reichert iPac, Reichert, Inc. Depew, NY, USA). Before the examination, the pachymeter tip was sterilized, and topical anaesthetic was instilled on the eye. The patient was instructed to look straight ahead with eyes wide open. The pachymeter tip was settled perpendicularly to the central cornea with a minimal contact with its surface. The final result was displayed after a series of beeps. The mean of three consecutive readings was recorded.

Statistical analysis

The normality of the continuous variables was evaluated with the Shapiro-Wilk test. The differences in IOP values between DCT or RT and GAT were analysed using the T-test. Bland-Altman plots were used to evaluate the agreement between the methods with 95% limits of agreement (LoA) calculated as the mean difference  $\pm (1.96 \times SD)$ . Simple and multivariate linear regression analyses were used to study the relationship between variables, such as corneal thickness and curvature, with IOP measurements. For all tests and measurements, the statistical significance was set at 0.05. Descriptive statistics are presented as the mean  $\pm$  standard deviation.

## **RESULTS**

One hundred thirty two nonglaucomatous eyes of 37 women and 29 men were enrolled. The mean (SD) age of the participants was  $70.95 \pm 7.76$  years. The CCT varied from 501 to 830  $\mu\text{m}$  with a mean value of  $586.07 \pm 55.75 \mu\text{m}$ . The average keratometry for the whole group was  $43.93 \pm 1.46$  ( $7.69 \pm 0.26$  mm) dioptres. The results of IOP measurements were presented in Table 1. The highest IOP values were obtained with the DCT (mean  $\pm$  SD:  $17.34 \pm 3.69$  mmHg), while the lowest values were observed for RT (mean  $\pm$  SD:  $13.56 \pm 4.33$  mmHg). It is worth noting that the statistical analysis showed significant differences in IOP readings between all assessed measurement methods. GAT measurements were significantly lower than DCT measurements ( $p < 0.0001$ ) and significantly higher than RT measurements ( $p < 0.0001$ ).

**Table 1. The results of intraocular pressure measurements [mmHg]**

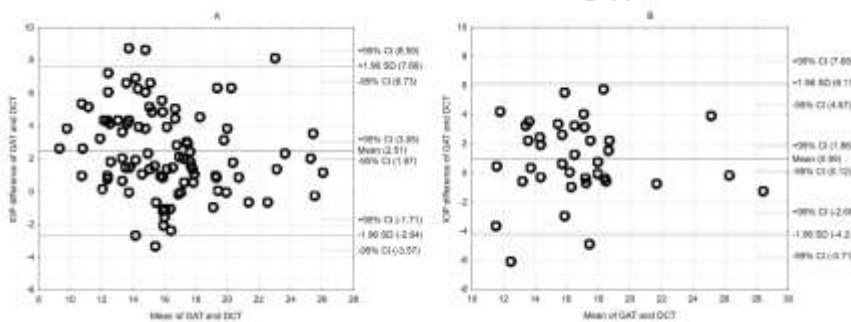
	all	<600 $\mu\text{m}$	$\geq 600 \mu\text{m}$	p value
DCT	$17.34 \pm 3.69$	$17.41 \pm 3.95$	$17.18 \pm 3.97$	$p < 0.0001^*$
GAT	$15.27 \pm 4.06$	$14.90 \pm 4.07$	$16.19 \pm 3.95$	
RT	$13.56 \pm 4.33$	$13.29 \pm 4.07$	$14.24 \pm 4.93$	$p < 0.0001^*$

\*comparison with GAT. Abbreviations: DCT, dynamic contour tonometer; GAT, Goldmann applanation tonometer; RT, rebound tonometer

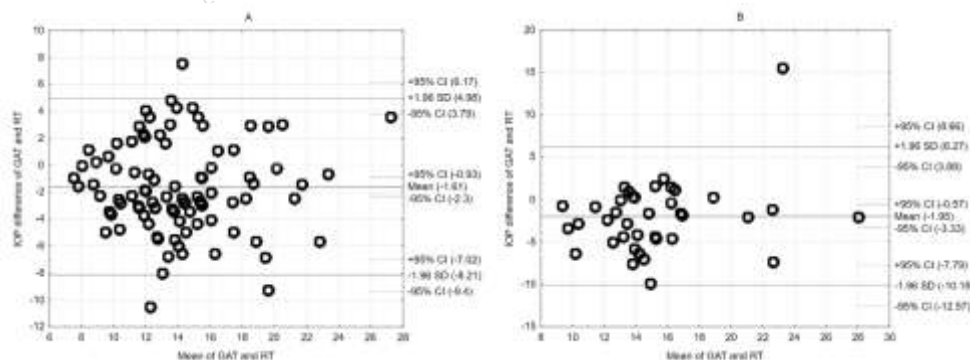
In the next part of the statistical analysis, the study group was divided into two groups depending on corneal thickness: less than 600  $\mu\text{m}$  ( $n = 47$ ) and greater than 600  $\mu\text{m}$  ( $n = 19$ ).

Bland–Altman plots were used to evaluate the agreement among RT, Pascal DCT and reference GAT readings. Figure 1A shows the agreement of the measurements performed with the DCT method in relation to the reference method, namely GAT in eyes with CCT < 600  $\mu\text{m}$ . In this group, DCT IOP measurements were on average 2.51 mmHg higher than those obtained by GAT. Interestingly, agreement between GAT and DCT IOP values was significantly higher in eyes with CCT > 600  $\mu\text{m}$ . The results obtained with DCT were only 0.99 mmHg higher than those obtained by GAT, as shown in Figure 1B.

Figures 2A and B show the agreement between RT and GAT IOP readings in both groups (less than 600  $\mu\text{m}$  and greater than 600  $\mu\text{m}$ ), respectively. Based on the graphs, we can conclude that the IOP RT results were lower on average by 1.61 mmHg in the group with normal corneal thickness and 1.95 mmHg lower in the group of increased CCT compared to the reference method.



**Figure 1. Agreement between the Goldmann applanation tonometry (GAT) method and dynamic contour tonometry (DCT) in eyes with A: CCT < 600  $\mu\text{m}$ ; B: CCT > 600  $\mu\text{m}$**



**Figure 2. Agreement between the Goldmann applanation tonometry (GAT) method and rebound tonometry (RT) in eyes with A: CCT < 600  $\mu$ m; B: CCT > 600  $\mu$ m**

We conclude that the highest agreement was demonstrated for GAT and DCT IOP values in the group with CCT > 600  $\mu$ m and for GAT and RT results in the group with CCT < 600  $\mu$ m. The lowest consistency of measurements were demonstrated for GAT and DCT IOP readings in the group with CCT < 600  $\mu$ m.

Because available data suggest that corneal thickness may significantly affect IOP measurements, we analysed the relationship between IOP values obtained by different measurement methods and CCT. Simple regression analysis showed that CCT has a significant impact on IOP measured with all devices in groups with corneal thickness below 600  $\mu$ m. The strongest positive correlations were observed between CCT and RT IOP values ( $R=+0.351$ ;  $p=0.0005$ ). Similarly, positive correlations were also detected between CCT and GAT and DCT IOP measurements ( $R=+0.24$ ;  $p=0.019$  and  $R=+0.224$ ;  $p=0.029$ , respectively). This finding indicates that the IOP measurements are higher for thicker corneas. A similar relationship was not observed in the group of eyes with thicker corneas (greater than 600  $\mu$ m).

Another parameter that can significantly affect the IOP measurement is corneal curvature. To verify this relation, a correlation analysis between IOP measurements and values describing corneal curvature (D/mm) was performed. We found no correlation between IOP values and keratometry results in groups with CCT < 600  $\mu$ m independent of the IOP technique used. In parallel, some positive correlations were found between GAT IOP values and keratometry results in the group with CCT > 600  $\mu$ m ( $R=+0.369$ ;  $p=0.005$ ). This finding indicates that the steeper curvature of the cornea, the higher IOP values detected with GAT.

#### **DISCUSSION:**

Among the many available methods of IOP tonometry, GAT still maintains an unchanging position as the reference method. However, in some cases, measurements with this method may be difficult, for example due to the lack of cooperation (children) or irregularity of the corneal surface or even fluorescein allergy. Accordingly, other methods, such as DCT or RT, could be more convenient. Several studies have demonstrated that the measurements obtained with individual methods may differ significantly. In our study, similar to results reported by Rosentreter et al. (8), the highest IOP values were obtained with DCT, and the lowest were noted with the RT. We observed significant differences in IOP values among all three measurement techniques. The measurements performed with DCT were significantly higher in relation to GAT. A similar relationship was observed by other authors where DCT measurements were 0.9-5.4 mmHg higher than GAT values (8-13). On the other hand, we found that the measurements performed with RT were significantly lower than those gained by GAT, which is in accordance with previous reports (3,11). In contrast, in particular age groups or corneal statuses, several reports documented different tonometry methods as a reliable alternative for GAT (4,14,15). It can therefore be concluded that the same method should always be chosen for a routine intraocular pressure control, and measurements obtained by different methods cannot be compared.

Accordingly, the question arises regarding which method would most suitable instead of GAT when it is not possible to use this technique. Our results indicate that in patients with corneal thickness within normal limits, the RT measurement seems to be the closest to the reference method. Bland-Altman plots demonstrated that RT has the highest agreement with GAT in the group with CCT < 600  $\mu$ m. Similar data were reported by two independent research teams of Rosentreter et al. (8) and Özcürü et al. (15) showing that the agreement between GAT and RT measurements were higher compared with GAT and DCT. These findings are consistent with the results of our own research.

On the other hand, we observed the lowest consistency of measurements for GAT and DCT in the group with CCT < 600  $\mu$ m. The results presented by Andreanos et al. (9) indicate that the biggest differences between GAT and DCT IOP measurements were observed in the group with corneal thickness less than 500  $\mu$ m. Similar conclusions were drawn by Özcürü et al. (11) in case of patients with keratoconus (mean CCT in the examined group was  $423.06 \pm 59.64 \mu$ m), which is consistent with our study. It seems reasonable that the lower CCT, the larger the difference between the two methods. Interestingly, for eyes with CCT greater than 600  $\mu$ m, high agreement between GAT and DCT IOP values was observed in our study. The mean differences in IOP readings between both methods were respectively lower. We hypothesize that in cases of corneas with increased CCT due to decompensation or various dystrophies, both tonometry methods are comparable.

According to the literature, CCT influences not only GAT measurements but also other tonometry methods (3,9,11,15). It has been observed that biomechanical parameters of the cornea should be taken into consideration in IOP assessment. We considered the effect of two corneal parameters (CCT and corneal curvature) on IOP measurements in this study. Our observations have shown that CCT has a significant influence on IOP measurement using three different tonometers in groups of individuals with corneal thickness within normal limits and those with CCT under 600  $\mu$ m. This observation has been previously reported by other authors (3). Of note, IOP values measured

by the RT method present the highest positive correlation with CCT as described by Özcürü et al. (11,15). On the other hand, other reports that indicate that the CCT value does not impact DCT measurements and offers an advantage of DCT over GAT (9,10,16,17). Our study results show the CCT does not influence DCT measurements exclusively in individuals with thick corneas, whereas IOP readings positively correlate with CCT in eyes with corneal thickness within normal limits. A similar observation was introduced by Francis et al. (18) who described a correlation between DCT and CCT. It was later confirmed that the influence of CCT on DCT measurement is weaker than for GAT (19). However, this phenomenon seems to diminish with increase of CCT. Precise analyses revealed that the agreement between GAT and DCT measurements increases in thicker corneas (18-21). This finding is consistent with our results where we concluded that DCT could be an alternative for GAT in thicker corneas.

In this study, no significant correlations were observed between corneal curvature and tonometry findings in eyes with CCT less than 600  $\mu\text{m}$ . This finding is in concordance with the results of Özcürü et al. (15). Similarly, Lanza et al. (22) presented no significant correlation between corneal curvature and all tonometry methods analysed (GAT, DCT and RT). On the other hand, Salvetat et al. (3) observed a significant connection between corneal curvature and RT measurements for CCT  $557.6 \pm 34.9 \mu\text{m}$ , while no correlation with GAT findings was noted. Interestingly, we observed that in cases with CCT greater than 600  $\mu\text{m}$ , the refractive power of the cornea (steep corneal curvature) had a significant impact on GAT results. This finding could be attributed to increased hysteresis and distribution of the tear film in steeper corneas (23). In comparison, a positive correlation between corneal curvature and GAT measurements as an independent factor influencing GAT measurements has been described previously (24). This finding served as a basis for recommendations of double GAT measurements in cases of corneas with significant differences in the corneal radius between flat and steep meridians (25). Andreanos et al. (9) observed a significant difference between GAT and DCT, which was larger for flat corneas.

To summarize, significantly higher IOP values are obtained by DCT than by GAT in nonglaucomatous subjects. Accordingly, the lowest values were observed for RT. The limitations of the RT are highly related with CCT values in patients with CCT within normal limits. In contrast, the corneal curvature has no impact on IOP measurements assessed by different tonometry techniques in case of individuals with CCT under 600  $\mu\text{m}$ . The ophthalmologist needs to be aware of the impact of corneal parameters on the IOP measurement technique and should take it into consideration for both diagnostics and monitoring. The individualized approach for the patient seems reasonable.

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The authors declare that they have no competing interests.

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