Comparison of Goldmann Applanation Tonometer Intraocular Pressure Measurements with Non-Contact, Tono-Pen and Dynamic Contour Tonometer Intraocular Pressure Measurements

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ABSTRACT

Purpose: To compare intraocular pressure (IOP) measurements obtained using the Goldmann applanation tonometer (GAT), non-contact tonometry (NCT), Tono-Pen (TPT) and Pascal dynamic contour tonometry (DCT).

Methods: Fifty-eight eyes of 29 patients were included in the study. IOP measurements obtained with GAT were compared with those measured using NCT, TPT, and DCT in eyes with thin and thick corneas.

Results: The overall intraclass correlation coefficient (ICC) among the tonometers was 0.844. No statistically significant difference was observed between GAT and TPT measurements (P = 0.999). In contrast, DCT-IOP and NCT-IOP values were significantly higher than both GAT-IOP and TPT-IOP values (P < 0.001 for all comparisons). Bland–Altman analysis showed wide limits of agreement (LoA) between GAT and the other tonometers. At normal corneal thickness, a significant positive correlation was observed between central corneal thickness (CCT) and IOP measurements obtained with all tonometers.

Conclusıon: Although significant correlations were observed among different tonometry methods, clinically relevant differences in IOP measurements were noted between devices. These findings suggest that correlation does not necessarily indicate agreement, and IOP values obtained with different tonometers should be interpreted cautiously, considering corneal-related factors and measurement principles.

Keywords: Agreement, Central corneal thickness, Consistency, Intraocular pressure, Tonometer

INTRODUCTION

Measurement of intraocular pressure (IOP) is an important part of routine eye examination. The accuracy and reliability of IOP measurement is particularly critical in glaucoma, since IOP is the only controllable primary risk factor in this condition.[1-4]

Today, the Goldmann applanation tonometer (GAT) is widely used and accepted as the gold standard for IOP measurement.[5] However, this method has various disadvantages, including the need for a biomicroscope, dependency on patient cooperation and experienced operators, use of fluorescein strips (insufficient or excessive fluorescence), possibility for erroneous results due to ocular rea-

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sons (such as irregular astigmatism, corneal pathologies, corneal thickness) and the risk of contamination due to contact with the prism.[1,6-9] In order to address these disadvantages, various tonometer types have been introduced: Non-contact tonometer (NCT), Tono-Pen Tonometer (TPT, Tono-Pen XL, Medtronic, USA), Dynamic Contour Tonometer (DCT), Rebound Tonometer (RT), Ocular Response Analyzer (ORA). These methods were developed to reduce patient- and physician-related sources of error and to obtain measurements that are less affected by the biomechanical properties of the cornea; therefore, their use depends on accuracy, reliability, and safety. Although central corneal thickness (CCT) affects tonometric measurements, the magnitude and direction of this effect differ among devices.

The Goldmann applanation tonometer method has been almost unanimously accepted as a reference technique in studies exploring the reliability and repeatability of various tonometers.[10-15] Since GAT-IOP values are also influenced by CCT, the accuracy of GAT measurements should be carefully evaluated.[3,16,17] Even a difference of 1–2 mmHg may be critical for the follow-up of high-risk cases.[4,17] Because CCT is one of the most important risk factors for the conversion of ocular hypertension (OHT) to glaucoma and for glaucoma progression, several CCT-based IOP correction formulas have been proposed.[3,17] According to the European Glaucoma Society (EGS) guidelines, including the most recent 6th edition, CCT-based IOP correction algorithms lack sufficient clinical validation and show considerable population-dependent variability; therefore, their routine use is not recommended. [18]

In this study, intraocular pressure measurements obtained using NCT, TPT, and DCT were compared with those obtained using GAT. Agreement and consistency between the different tonometry methods were evaluated, and the relationship between intraocular pressure measurements and central corneal thickness was analyzed across different corneal thickness ranges.

METHODS

This retrospective, cross-sectional clinical study was approved by the Clinical Research Ethics Committee of Adana City Training and Research Hospital (29.07.2020/1000). A standard informed consent form prepared for this study was obtained from the participants. All steps and procedures were carried out in accordance with the principles of the Declaration of Helsinki.

This study included healthy and OHT eyes of patients aged ≥18 years in whom IOP measurements could be obtained using all devices. Fifty-eight eyes (45 normal eyes, 13 eyes with ocular hypertension) of 29 consecutive patients who applied to our clinic between January 2019 and May 2020 were included in the study. A complete ophthalmologic examination was performed by examining the patients' age, gender, uncorrected and best corrected visual acuity, autorefractometry values, biomicroscopic anterior segment and posterior segment with dilatation examinations. The CCT measurements were conducted using NCT. Eyes were divided into three groups according to CCT result: below 520 microns (thin cornea), 520-580 microns (normal) and over 580 microns (thick cornea).

Intraocular pressure measurements were performed in a fixed sequence with 10-minute intervals between each measurement. NCT (Canon TX-20P™, Canon Medical Systems Europe BV) was used according to the manufacturer's measurement principle, which incorporates corneal thickness into its algorithm. However, no additional CCT-based mathematical correction was applied during the clinical interpretation of the results. Intraocular pressure measurements were obtained using Tono-Pen tonometry (TPT; Tono-Pen XL, Medtronic, USA), Dynamic contour tonometry (DCT; Pascal Dynamic Contour Tonometer, Ziemer Ophthalmic Systems AG, Switzerland), and Goldmann applanation tonometry (GAT; Inami L-5110, Inami, Tokyo, Japan). The same fixed measurement sequence was used for all participants to maintain protocol standardization. For DCT, the measurement quality score (Q; Q1-Q5) was recorded for each IOP measurement.[19] Q scores of Q1-Q3 indicate reliable measurements, whereas Q4–Q5 represent lower-quality readings that require cautious interpretation or repetition. All measurements were performed by the same glaucoma specialist (V.N.O.). To avoid the effects of daily fluctuations in IOP, all measurements were performed and completed between 10-11 a.m. Tonometers were periodically calibrated according to the manufacturer's instructions. Topical anesthetic drops were not used for the measurements made with the NCT method. The IOP measurement with GAT was performed after applying topical

anesthesia (Alcaine®, 0.5% proparacaine hydrochloride ophthalmic solution, USP) under a biomicroscope with cobalt blue light using sterile strips soaked in fluorescein sodium. The patients were asked to keep their eyes open and breathe freely. The TPT device was calibrated daily and a sterile disposable cover was used for IOP measurement. Topical anesthesia was applied before measurement. In the DCT method, patients were in the facing position under topical anesthesia. The tip of the tonometry touched the cornea for about 5-6 seconds and the measured Q score was recorded. Eyes included in the study were divided into two groups with IOP values of 10-21 mmHg (normal IOP) and 22-30 mmHg (high IOP). All IOP measurements obtained with NCT, TPT, and DCT were compared with those obtained using GAT.

Having any ocular disease other than OHT, a history of ocular surgery, use of intraocular and/or periocular steroids during the study or within the previous 3 months, use of any systemic medication affecting IOP, contact lens use, presence of dry eye, failure to complete measurements for any reason, a DCT measurement with a Q4–Q5 score, refractive errors greater than ±3.00 D or cylindrical errors greater than ±2.00 D, and pregnancy were considered exclusion criteria for the study.

Statistical analysis

Intraclass correlation (ICC) was used to evaluate the consistency between the four IOP measurement instruments (GAT, NCT, TPT, and DCT). Bland–Altman analysis was applied to assess the agreement between the IOP values measured by three instruments (NCT, TPT, and DCT) relative to the GAT method. Generalized estimating equations (GEE) were used to account for potential intra-subject correlation due to the inclusion of both eyes. The estimated covariance was minimal and did not meaningfully influence the results. All analyses were performed using IBM SPSS Statistics Version 20.0 statistical software package. The pre-determined statistical threshold of significance for all tests was $P \leq 0.05$.

RESULTS

Fifty-eight eyes of 29 patients were included in the study. Average age was 40.41 ± 17.15 (range, 18-74 years), 10 were men and 19 were women. Measured IOP values were: 19.53 ± 5.82 (range, 10-34) mmHg with NCT, 17.24 ± 4.61 (range, 9-28) mmHg with TPT, 20.29 ± 4.59 (range, 11.5-32) mmHg with DCT and 17.34 ± 4.86 (range, 11-30) mmHg with GAT. The mean Q was found to be 1.50 ± 0.78 in DCT measurements. There was no statistically significant difference between TPT and GAT measurements and between NCT and DCT measurements ($P = 0.999$, $P = 0.379$, respectively). NCT and DCT results were significantly higher than TPT and GAT results ($P < 0.001$ for all comparisons). Statistically significant pairwise correlations were observed, with correlation coefficients (r) ranging from 0.828 to 0.878. The overall ICC was 0.844. Pairwise ICC values were 0.878 for GAT vs NCT, 0.830 for GAT vs TPT, and 0.861 for GAT vs DCT. When the deviation from GAT results was determined for each tonometer, it was seen that the percentage of measurements with a deviation of ±3 mmHg and greater was highest with the DCT method, and this result was replicated in the percentage of measurements with a deviation of ±5 mmHg and greater (**Figure 1**).

The differences between tonometer measurements and GAT results are illustrated using Bland-Altman plots **(Figure 2a-c)**. The mean of the differences between corresponding measurements (NCT value minus GAT value) was 2.19 ± 2.79 mmHg (Limits of Agreement, -3.29 to +7.67 mmHg). A positive linear relationship was observed between NCT and GAT ($r^2 = 0.771$, $P < 0.001$) **(Figure 2a)**. The mean of the differences between corresponding measurements (TPT value minus GAT value) was -0.10 ± 2.77 mmHg (Limits of Agreement, -5.53 to +5.33 mmHg). A positive linear relationship was observed between TPT and GAT ($r^2 = 0.689$, $P < 0.001$) **(Figure 2b)**. The mean of the differences between corresponding measurements (DCT value minus GAT value) was 2.95 ± 2.51 mmHg (Limits of Agreement, -1.96 to +7.86 mmHg). A positive linear relationship was observed between DCT and GAT ($r^2 = 0.741$, $P < 0.001$) **(Figure 2c).** Mean differences, correlation coefficients, and limits of agreement for all device comparisons are summarized in **Table 1.** At normal IOP levels, all tonometers showed positive correlations with GAT, with correlation coefficients of 0.725 for NCT, 0.705 for TPT, and 0.687 for DCT. NCT showed higher correlation with GAT at normal IOP (r=0.725), whereas DCT showed higher correlation at elevated IOP (r=0.786).

Mean CCT was 544.29 ± 44.64 (range, 412-617 microns). There was no significant correlation between tonometer measurements and CCT in thin corneas. Positive correlations were observed between CCT and IOP measurements obtained with all tonometers in eyes with normal corneal thickness (r = 0.391, P = 0.030; r = 0.570, P = 0.001; r = 0.457, P = 0.010 and r = 0.533, P = 0.002 for NCT, TPT, DCT and GAT, respectively). In thick corneas, only NCT results were found to be correlated with CCT values (r=0.587, P = 0.045).

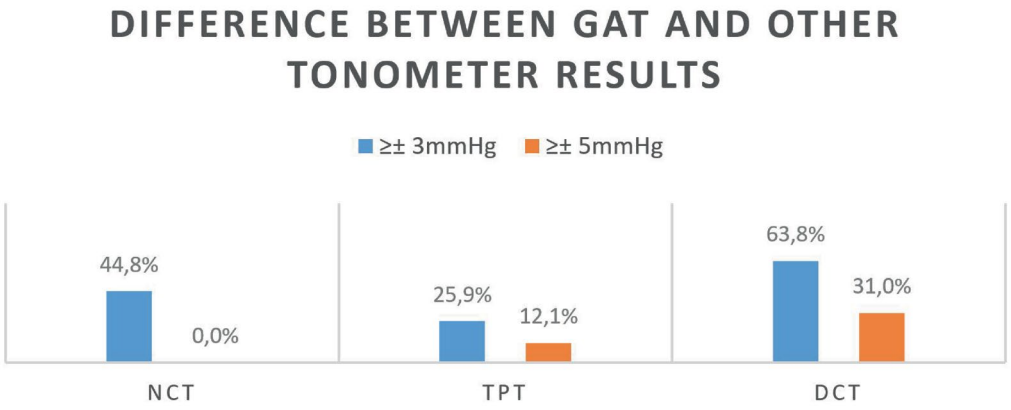

Figure 1. *The proportional distribution of ≥3 mmHg and ≥5 mmHg deviations from Goldmann applanation tonometry (GAT) result.*

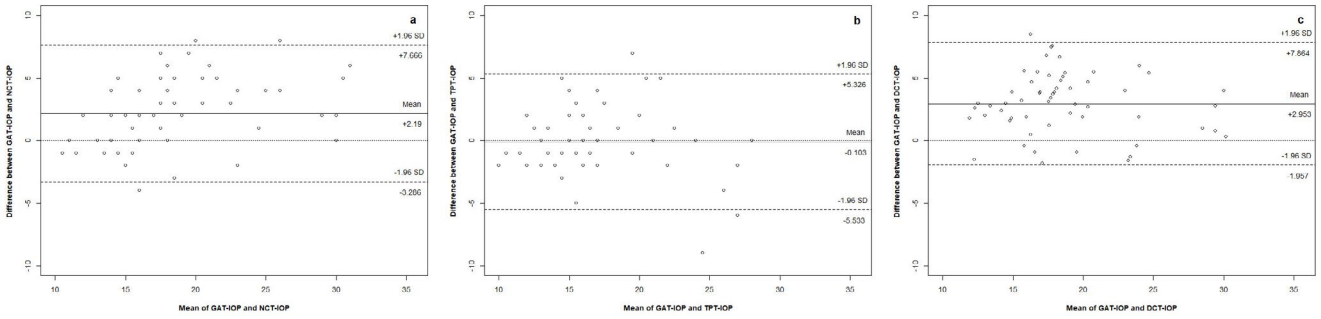

Figure 2. *Bland-Altman plots showing agreement between intraocular pressure measurements by non-contact tonometry (NCT, a), Tono-Pen (TPT, b), and dynamic contour tonometry (DCT, c) versus Goldmann applanation tonometry (GAT); solid lines indicate mean difference and limits of agreement (±1.96 SD), and dashed lines show 95% confidence intervals of the limits.*

Table 1. *Comparison of intraocular pressure (IOP) measurements between tonometers and Goldmann applanation tonometry (GAT)*

Device Comparison	Mean Difference ± SD (mmHg)	Limits of Agreement (mmHg)	Correlation (r)
NCT vs GAT	2.19 ± 2.79	−3.29 to +7.67	0.878
TPT vs GAT	−0.10 ± 2.77	−5.53 to +5.33	0.830
DCT vs GAT	2.95 ± 2.51	−1.96 to +7.86	0.861

DISCUSSION

The correlations between tonometer results and the differences between measurements are important for the accurate measurement of IOP. In our study, IOP results obtained with the NCT, TPT and DCT methods were compared with GAT-IOP. Statistically significant correlations were observed among the tonometer measurements; however, correlation alone did not imply agreement. It was observed that NCT and DCT results were higher than GAT, and the tonometer that deviated the most from the GAT values and produced the highest results was DCT. NCT showed a higher correlation with GAT results, while TPT showed a lower correlation. Although statistically significant correlations were observed, the wide limits of agreement indicate that these tonometry methods cannot be considered directly interchangeable with GAT.

In a large systematic review, where 8 different tonometers were compared, it was reported that the NCT and Handheld applanation tonometry (HAT) methods produced the closest values to GAT measurement, while other tonometers had a measurement difference of more than 2 mmHg compared to GAT.[16] It has been observed in various studies that DCT-IOP values are higher than that of other tonometers and the difference between DCT and GAT measurements are reported to vary between 0.17–2.34 mmHg. [20-28] In our study, the mean DCT-GAT difference was 2.95 mmHg. This difference was slightly higher than that reported in the literature. When DCT measurement results were assessed with regard to GAT, 63.8% of the eyes were found to have a deviation of more than 3 mmHg and 31% of the eyes had a deviation of more than 5 mmHg. The variability in reported DCT–GAT differences across studies may be related to differences in study populations. [21,23,25,26,28] In addition, it was thought that the glaucoma drugs used in studies involving eyes with glaucoma may have had an effect on CCT changes.[29]

Similar to our study, the literature reports a higher correlation between GAT and NCT at normal IOP, and various studies suggested that GAT and NCT could be used interchangeably in the presence of normal IOP.[2,13,30] Similar to our study, it has been reported in the literature that there is an increase in the differences between GAT and NCT at high IOP.[1,30] Mohan et al. reported that there was a ± 3 mmHg IOP difference in 86.4% of the eyes they assessed. [30] In our study, there was a ± 3 mmHg IOP difference in 44.8% of eyes. This difference may be due to racial differences but it is also possible that the IOP classification utilized by Mohan et al. caused biased results. Interestingly, Gupta et al. found a good correlation between GAT and NCT at normal and high IOP in their study comprised of eyes with glaucoma.[31] Tamçelik et al. reported that significant inconsistencies could occur between devices when IOP deviated from normal values.[11] It was thought that the differences between publications may be due to the fact that studies were not standardized.

Kato et al. compared the GAT, iCare, Icare PRO, NCT and TPT methods in healthy eyes and found a high degree of compatibility between GAT, NCT and rebound tonometers; whereas the authors noted that the TPT method demonstrated the worst compatibility with other tonometers.[14] In our study, it has been observed that TPT is correlated with GAT at normal IOP; whereas their results are incompatible at high IOP.[2,6,15,20,32] This result has been attributed to TPT being less affected by CCT.[2,10,20,33,34]

Many studies report that all tonometers are more or less affected by CCT.[10,11,35] It has been reported that NCT is the tonometer most affected by CCT. [12,21,35-37] In our study, none of the tonometers in thin corneas showed a significant correlation with CCT. There was a significant positive correlation in all tonometers of normal corneal thickness. There was only a correlation between NCT and CCT in the thick cornea. This situation has been associated with the static nature of GAT measurement, the deformation of a larger corneal area during IOP measurement via NCT, and the elasticity of the cornea.[1,31]

No correlation was found between DCT and CCT in thin and thick corneas, and a correlation was found in normal corneal thickness in our study. It has been claimed that DCT is less affected by corneal thickness and corneal biomechanics.[25, 38, 39] The lower level of CCT-related effects with DCT measurement can be attributed to the measurement technique of the device and the fact that the corneal thicknesses of our cases were within the range of 300-700 microns.[40]

There was no significant correlation between TPT measurements and CCT in thin and thick corneas, and a significant positive correlation was observed in eyes with normal cor-

neal thickness. There are studies showing that TPT is not affected by CCT.[2,20,32,34] There are also studies reporting that TPT measurements are affected by CCT, but lesser degree than GAT and NCT.[10,22,33,35] TPT's lack of correlation with CCT in thin and thick corneas has been attributed to the fact that the area in contact with the cornea is smaller in the TPT method compared to GAT (1.5 mm for TPT XL).[2]

In the meta-analysis by Doughty and Zaman, the effect of CCT on IOP measurements was reported to range between 0.19 and 0.50 mmHg per 10-µm change in corneal thickness.[8] Although earlier studies suggested that IOP correction might be considered when CCT deviates from normal values,[8,9] objective clinical validation of CCT-based IOP correction algorithms remains limited.[41] Previous studies have also shown that reliance on such correction formulas may be problematic, particularly in high-risk clinical situations.[42-44] Kwon et al. reported more severe glaucoma progression in patients whose corrected IOP values were calculated using the Ehlers formula, especially in eyes with a history of corneal refractive surgery, suggesting that underestimation of IOP may lead to insufficient treatment intensity.[44] Similarly, Wachtl et al. demonstrated increasing discrepancies between formula-corrected GAT measurements and DCT-IOP in patients with thin corneas and advanced glaucoma, indicating that CCT-based correction may be misleading in certain clinical settings.[41] Park et al. further reported that errors in corrected IOP values increased with increasing CCT in both healthy and glaucomatous eyes, emphasizing that correction formulas should not be used as standalone tools in clinical decision-making.[43] Consistent with the 6th EGS guidelines, which state that CCT-based IOP correction formulas are not clinically validated and show considerable population-dependent variability, these findings support the recommendation to avoid the routine application of mathematical IOP correction based on CCT in clinical practice.[18]

Although no tonometry method can directly measure true intracameral pressure, differences in measurement principles may influence the obtained IOP values. It has been reported that the widely used GAT tends to underestimate true intracameral IOP by approximately 3 mmHg in vitro and up to 5 mmHg in vivo. Cadaver and experimental studies have suggested that DCT, which is less dependent on corneal deformation, may provide IOP measurements closer to actual intracameral pressure.[45,46] These observations indicate that systematic differences between tonometry techniques may reflect methodological characteristics rather than true differences in intraocular pressure and should therefore be interpreted with caution in clinical practice.

Intraocular pressure measurements may be influenced by multiple factors, including the type of tonometer used, CCT, operator experience, and the measurement technique. [37] In addition, methodological differences such as the order of tonometer use, time intervals between measurements, calibration status, diurnal timing of IOP assessment, CCT measurement techniques (e.g., anterior segment optical coherence tomography, Pentacam, or ultrasound), and patient-related characteristics (healthy subjects, ocular hypertension, or glaucoma) may further contribute to variability across studies. Other factors, including age, systemic diseases, IOP classification methods, and standardization issues, such as analyzing both eyes versus a single eye per subject-also affect reported outcomes. Taken together, these considerations indicate that variability among studies comparing tonometry methods is multifactorial.[16]

The present study has several limitations. Intraocular pressure measurements were performed in a fixed sequence across devices, which may have introduced an order effect. Both non-contact and contact applanation methods, such as NCT and TPT, can transiently influence IOP values, and differences in the timing of topical anesthesia administration between devices may also have affected the measurements. In addition, repeated contact tonometry may progressively alter the corneal surface. Therefore, a potential order effect cannot be completely excluded. Eyes with an IOP below 10 mmHg were not included in the study. The relatively small sample size may have limited the statistical power of multiple subgroup analyses, including comparisons between normal and ocular hypertensive eyes, thin, normal, and thick corneas, as well as low and high IOP ranges; accordingly, these results should be interpreted with caution. Eyes with high refractive errors and significant astigmatism were excluded, and axial length was not assessed. Although generalized estimating equations were applied to account for intra-subject correlation, the inclusion of both eyes from the same individual may still represent a potential source of bias and should be considered when interpreting the results. Despite these limitations, the

comprehensive comparison of multiple tonometry methods under different clinical conditions represents an important strength of this study.

CONCLUSION

In this study, a significant positive correlation between IOP and CCT was observed at normal corneal thickness across all tonometry methods. However, despite these positive correlations, meaningful differences between tonometer measurements were present, indicating that correlation alone does not imply agreement. These results suggest that corneal properties and measurement principles influence IOP assessment and should be taken into account when interpreting tonometry findings in clinical practice. Future studies including larger populations with a broader range of IOP values, diagnoses, and ocular characteristics may help further clarify the factors affecting the accuracy of IOP measurements. Consideration of additional parameters related to corneal biomechanics may also improve the clinical interpretation of IOP measurements. These findings are clinically relevant for follow-up, especially in patients at risk of glaucoma progression.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Mansoori T, Balakrishna N. Effect of central corneal thickness on intraocular pressure and comparison of Topcon CT-80 non-contact tonometry with Goldmann applanation tonometry. Clin Exp Optom 2018;101:206-12.
2. Yildiz A, Yasar T. Comparison of Goldmann applanation, non-contact, dynamic contour and tonopen tonometry measurements in healthy and glaucomatous eyes, and effect of central corneal thickness on the measurement results. Med Glas (Zenica) 2018;15:152-7.
3. Li H, Wang Y, Dou R, Wei P, Zhang J, Zhao W, et al. Intraocular Pressure Changes and Relationship With Corneal Biomechanics After SMILE and FS-LASIK. Invest Ophthalmol Vis Sci 2016;57:4180-6.
4. Gordon MO, Beiser JA, Brandt JD, Heuer DK, Higginbotham EJ, Johnson CA, et al. The Ocular Hypertension Treatment Study: baseline factors that predict the onset of primary open-angle glaucoma. Arch Ophthalmol 2002;120:714-20; discussion 829-30.
5. Allingham R, Damji K, Freedman S. Intraocular pressure and Tonometry. In: Freedman S, Moroi S, Shafranov G, eds. Shields Textbook of Glaucoma. New Delhi: Wolters Kluwer / Lippincott Williams & Wilkins; 2011: 24-40.
6. Ozcan A, Ciloglu E, Esen E, Undar I, Harbiyeli I, Simsek F. Comparison of rebound tonometer, dyna¬mic contour tonometer, tonopen XL with Goldmann applanation tonometer in normal eyes. Glaucoma- Cataract Journal 2013;8:225-30.
7. Kohlhaas M, Boehm AG, Spoerl E, Pürsten A, Grein HJ, Pillunat LE. Effect of central corneal thickness, corneal curvature, and axial length on applanation tonometry. Arch Ophthalmol 2006;124:471-6.
8. Doughty MJ, Zaman ML. Human corneal thickness and its impact on intraocular pressure measures: a review and meta-analysis approach. Surv Ophthalmol 2000;44:367-408.
9. Ehlers N, Bramsen T, Sperling S. Applanation tonometry and central corneal thickness. Acta Ophthalmol (Copenh) 1975;53:34-43.
10. Nakamura M, Darhad U, Tatsumi Y, Fujioka M, Kusuhara A, Maeda H, et al. Agreement of rebound tonometer in measuring intraocular pressure with three types of applanation tonometers. Am J Ophthalmol 2006;142:332-4.
11. Tamçelik N, Atalay E, Cicik E, Özkök A. Comparability of Icare Pro Rebound Tonometer with Goldmann Applanation and Noncontact Tonometer in a Wide Range of Intraocular Pressure and Central Corneal Thickness. Ophthalmic Res 2015;54:18-25.
12. Güler M, Bilak Ş, Bilgin B, Şimşek A, Çapkin M, Hakim Reyhan A. Comparison of Intraocular Pressure Measurements Obtained by Icare PRO Rebound Tonometer, Tomey FT-1000 Noncontact Tonometer, and Goldmann Applanation Tonometer in Healthy Subjects. J Glaucoma 2015;24:613-8.
13. Ogbuehi KC. Assessment of the accuracy and reliability of the Topcon CT80 non-contact tonometer. Clin Exp Optom 2006;89:310-4.
14. Kato Y, Nakakura S, Matsuo N, Yoshitomi K, Handa M, Tabuchi H, et al. Agreement among Goldmann applanation tonometer, iCare, and Icare PRO rebound tonometers; non-contact tonometer; and Tonopen XL in healthy elderly subjects. Int Ophthalmol 2018;38:687-96.
15. Wong B, Parikh D, Rosen L, Gorski M, Angelilli A, Shih C. Comparison of Disposable Goldmann Applanation Tonometer, ICare ic100, and Tonopen XL to Standards of Care Goldmann Nondisposable Applanation Tonometer for Measuring Intraocular Pressure. J Glaucoma 2018;27:1119-24.
16. Cook JA, Botello AP, Elders A, Fathi Ali A, Azuara-Blanco A, Fraser C, et al. Systematic review of the agreement of tonometers with Goldmann applanation tonometry. Ophthalmology 2012;119:1552-7.
17. Chihara E. Assessment of true intraocular pressure: the gap between theory and practical data. Surv Ophthalmol 2008;53:203-18.
18. European Glaucoma Society. European Glaucoma Society Terminology and Guidelines for Glaucoma, 6th Edition. Br J Ophthalmol. 2021;105(Suppl 1):1–169.

19. Gencer B, Gürlü V. Evaluation of Parameters Affecting Measurement Quality of Dynamic Contour Tonometry. Balkan Medical Journal. March 2011;2011(3):229-231.

20. Eser E, Başer EF, Seymenoğlu G. Pascal Dinamik Kontur Tonometre, Goldmann Aplanasyon Tonometresi, Tonopen ve Nonkontakt Tonometre ile Göz İçi Basıncı Ölçümlerine Korneal, Refraktif ve Biyometrik Parametrelerin Etkisi. Glokom-Katarakt/ Journal of Glaucoma-Cataract 2008;3.

21. Pelit A, Altan-Yaycioglu R, Pelit A, Akova YA. Effect of corneal thickness on intraocular pressure measurements with the Pascal dynamic contour, Canon TX-10 non-contact and Goldmann applanation tonometers in healthy subjects. Clinical and Experimental Optometry 2009;92:14-8.

22. Francis BA, Hsieh A, Lai MY, Chopra V, Pena F, Azen S, et al. Effects of corneal thickness, corneal curvature, and intraocular pressure level on Goldmann applanation tonometry and dynamic contour tonometry. Ophthalmology 2007;114:20-6.

23. Kotecha A, White ET, Shewry JM, Garway-Heath DF. The relative effects of corneal thickness and age on Goldmann applanation tonometry and dynamic contour tonometry. Br J Ophthalmol 2005;89:1572-5.

24. Carbonaro F, Andrew T, Mackey DA, Spector TD, Hammond CJ. Comparison of three methods of intraocular pressure measurement and their relation to central corneal thickness. Eye (Lond) 2010;24:1165-70.

25. Broman AT, Congdon NG, Bandeen-Roche K, Quigley HA. Influence of corneal structure, corneal responsiveness, and other ocular parameters on tonometric measurement of intraocular pressure. J Glaucoma 2007;16:581-8.

26. Kaufmann C, Bachmann LM, Thiel MA. Comparison of dynamic contour tonometry with goldmann applanation tonometry. Invest Ophthalmol Vis Sci 2004;45:3118-21.

27. Schneider E, Grehn F. Intraocular pressure measurement-comparison of dynamic contour tonometry and goldmann applanation tonometry. J Glaucoma 2006;15:2-6.

28. Hager A, Loge K, Schroeder B, Füllhas MO, Wiegand W. Effect of central corneal thickness and corneal hysteresis on tonometry as measured by dynamic contour tonometry, ocular response analyzer, and Goldmann tonometry in glaucomatous eyes. J Glaucoma 2008;17:361-5.

29. Panos GD, Konstantinidis A, Mendrinos E, Kozobolis V, Perente I, Gatzioufas Z. Effect of tafluprost 0.0015% on central corneal thickness in patients with primary open-angle glaucoma. Curr Eye Res 2013;38:977-82.

30. Mohan S, Tiwari S, Jain A, Gupta J, Sachan SK. Clinical comparison of Pulsair non-contact tonometer and Goldmann applanation tonometer in Indian population. J Optom 2014;7:86-90.

31. Gupta V, Sony P, Agarwal HC, Sihota R, Sharma A. Inter-instrument agreement and influence of central corneal thickness on measurements with Goldmann, pneumotonometer and non-contact tonometer in glaucomatous eyes. Indian J Ophthalmol 2006;54:261-5.

32. Öztürk F, Küsbecİ T, Yavaş G, Ermİş S, Kaplan Ü, İnan ÜÜ. Pascal dinamik kontur tonometre ile ölçülen göz içi basınç değerlerinin goldmann applanasyon tonometresi, non kontakt tonometre ve tonopen ile karşılaştırılması ve santral kornea kalınlığının etkisi. Glokom Katarakt 2006;1:171-5.

33. Salvetat ML, Zeppieri M, Tosoni C, Brusini P. Comparisons between Pascal dynamic contour tonometry, the TonoPen, and Goldmann applanation tonometry in patients with glaucoma. Acta Ophthalmol Scand 2007;85:272-9.

34. Viestenz A, Langenbucher A, Viestenz A. [Reproducibility of dynamic contour tonometry. Comparison with TonoPenXL and Goldmann applanation tonometry - a clinical study on 323 normal eyes]. Klin Monbl Augenheilkd 2006;223:813-9.

35. Tonnu PA, Ho T, Newson T, El Sheikh A, Sharma K, White E, et al. The influence of central corneal thickness and age on intraocular pressure measured by pneumotonometry, non-contact tonometry, the Tono-Pen XL, and Goldmann applanation tonometry. Br J Ophthalmol 2005;89:851-4.

36. Ogbuehi KC, Mucke S, Osuagwu UL. Influence of central corneal thickness on measured intraocular pressure differentials: Nidek RKT-7700, Topcon CT-80 NCTs and Goldmann Tonometer. Ophthalmic Physiol Opt 2012;32:547-55.

37. Bhan A, Browning AC, Shah S, Hamilton R, Dave D, Dua HS. Effect of corneal thickness on intraocular pressure measurements with the pneumotonometer, Goldmann applanation tonometer, and Tono-Pen. Invest Ophthalmol Vis Sci 2002;43:1389-92.

38. Siganos DS, Papastergiou GI, Moedas C. Assessment of the Pascal dynamic contour tonometer in monitoring intraocular pressure in unoperated eyes and eyes after LASIK. J Cataract Refract Surg 2004;30:746-51.

39. Kniestedt C, Lin S, Choe J, Nee M, Bostrom A, Stürmer J, et al. Correlation between intraocular pressure, central corneal thickness, stage of glaucoma, and demographic patient data: prospective analysis of biophysical parameters in tertiary glaucoma practice populations. J Glaucoma 2006;15:91-7.

40. Kanngiesser HE, Kniestedt C, Robert YC. Dynamic contour tonometry: presentation of a new tonometer. J Glaucoma 2005;14:344-50.

41. Wachtl J, Töteberg-Harms M, Frimmel S, Roos M, Kniestedt C. Correlation Between Dynamic Contour Tonometry, Uncorrected and Corrected Goldmann Applanation Tonometry, and Stage of Glaucoma. JAMA Ophthalmol 2017;135:601-8.

42. Gunvant P, O'leary DJ, Baskaran M, Broadway DC, Watkins RJ, Vijaya L. Evaluation of tonometric correction factors. J Glaucoma 2005;14:337-43.

43. Park SJ, Ang GS, Nicholas S, Wells AP. The effect of thin, thick, and normal corneas on Goldmann intraocular pressure measurements and correction formulae in individual eyes. Ophthalmology 2012;119:443-9.

44. Kwon J, Sung KR, Jo J, Yang SH. Glaucoma Progression and its Relationship with Corrected and Uncorrected Intraocular Pressure in Eyes with History of Refractive Corneal Surgery. Curr Eye Res 2018;43:1136-44.

45. Mccafferty S, Levine J, Schwiegerling J, Enikov ET. Goldmann applanation tonometry error relative to true intracameral intraocular pressure in vitro and in vivo. BMC Ophthalmol 2017;17:215.

46. Kniestedt C, Nee M, Stamper RL. Dynamic contour tonometry: a comparative study on human cadaver eyes. Arch Ophthalmol 2004;122:1287-93.