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The Effect of Thin, Thick, and Normal Corneas on Goldmann Intraocular Pressure Measurements and Correction Formulae in Individual Eyes

AQ: au *Serena J. K. Park, MBChB,[1] Ghee Soon Ang, FRCOphth,[2] Simon Nicholas, FRANZCO,[2] Anthony P. Wells, FRANZCO[1,2]*

Objective: To evaluate the usefulness of the central corneal thickness (CCT)-based correction formulae for stratified CCT groups, with intraocular pressure (IOP) from the Pascal dynamic contour tonometer (PDCT) as the reference standard.

Design: Retrospective case series.

Participants: Two hundred eighty-nine patients attending a specialist glaucoma practice and a mixture of normal subjects and subjects with confirmed glaucomatous optic neuropathy.

Methods: Intraocular pressure was measured using PDCT, Goldmann applanation tonometry (GAT), and the Ocular Response Analyzer (ORA; Reichert Corp, Buffalo, NY). The GAT readings were obtained before automated readings and were adjusted for CCT using 4 different correction formulae. Discrepancies between GAT and CCT-corrected GAT readings were evaluated after stratification into thin, intermediate, and thick CCT groups. The IOP measurements from GAT, the ORA, and CCT-adjusted IOP were compared against PDCT IOP measurements using Bland-Altman analysis.

Main Outcome Measures: Mean, 95% limits of agreement, and proportion of patients with IOP difference of 20% or more between PDCT IOP and each of GAT IOP, Goldmann-correlated IOP (IOPg), corneal-compensated IOP (IOPcc), and adjusted IOP using CCT-based correction formulae.

Results: Average PDCT IOP values were higher than GAT, IOPg, IOPcc, and CCT-adjusted IOP. The GAT IOP readings demonstrated poor agreement with PDCT IOP (95% limits of agreement, ± 4.7 mmHg); however, IOPg, IOPcc, and adjustment of GAT IOP with CCT-based formulae resulted in even poorer agreement (range of 95% limits of agreement, ± 5.1 to 6.7 mmHg). If PDCT was used as the reference standard, there was a 26% to 39% risk of making an erroneous IOP adjustment of magnitude of 20% or more at all levels of CCT. This risk was greatest in the patients with thicker corneas (CCT, ≥568 μm).

Conclusions: Adjusting IOP using CCT-based formulae resulted in poorer agreement with PDCT IOP when compared with unadjusted GAT IOP. If PDCT is the closest measure we have to intracameral IOP, there is a risk of creating clinically significant error after adjustment of GAT IOP with CCT-based correction formulae, especially in thicker corneas. This study suggests that although CCT may be useful in population analyses, CCT-based correction formulae should not be applied to individuals.

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Goldmann applanation tonometry (GAT) remains the most accessible and widely used method for intraocular pressure (IOP) measurement in the clinical setting. However, because GAT is based on corneal indentation produced by a fixed force, its accuracy depends on many factors, including corneal thickness and other structural and physiologic properties of the cornea—a concept that had been recognized since the invention of the instrument by Goldmann himself.[1–3] Some have raised concerns that patients with thicker corneas may be misclassified as having ocular hypertension and as a result are administered long-term therapy inappropriately.[4,5] Some authors have suggested pachymetry as a mandatory investigation in patients with glaucoma and ocular hypertension.[1,2,5–8] Several studies have attempted to produce nomograms or correction formulae to account for the variation in corneal thickness and its influence on IOP measurement.[9–13]

In recent years, there has been an increasing interest in the clinical application of the Pascal dynamic contour tonometer (PDCT; Swiss Microtechnology AG, Port, Switzerland). The PDCT is a new slit-lamp–mounted, nonapplanation, digital contact tonometer that claims to be independent of corneal structural properties.[4,14,15] When compared with intracameral IOP obtained via anterior chamber cannulation, IOP measurements from PDCT showed good concordance, with high accuracy and reproducibility.[16–18] AQ: 1

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Table 1. Summary of the Intraocular Pressure Correction Formulae for Goldmann Applanation Tonometry

Authors	Year	Formula for Actual Intraocular Pressure	Mean Central Corneal Thickness±Standard Deviation (μm)	Study Design
Doughty and Zaman[9] (300 data sets)	2000	GAT IOP+25 [(545–CCT)/545]	534	Meta-analysis (eyes with chronic disease)
Shimmyo et al[11] (n = 1482 eyes)	2003	GAT IOP+(550–CCT)/18$e^{-0.005\times GAT\ IOP}$	52.6±34.5	Retrospective study of refractive surgery eyes
Whitacre et al[10] (n = 15 eyes)	1993	GAT IOP+12.28–(0.02283×CCT); if CCT<520: GAT IOP+22.38–(0.04644×CCT)	390–570	In vivo manometric study
Ehlers et al[12] & Stodtmeister[13] (n = 29 eyes)	1975	(GAT IOP–b)/(0.561+0.000781×CCT)	520±0.3	In vivo manometric study (b was ascertained experimentally)

CCT = central corneal thickness; GAT = Goldmann applanation tonometry; IOP = intraocular pressure.

Clinicians who care for patients with glaucoma are used to managing glaucoma based on GAT IOP. Hence, it is arguable that knowing central corneal thickness (CCT) or PDCT IOP does not necessarily help with decision making for an individual patient.[19] If we can show, in an individual patient, that progression is occurring by robust structural or functional means, or both, then clearly the IOP needs to be lowered, regardless of the measurement performed and bias or error that may be included in that measurement. However, if IOP assessment is a pivotal part of the management decision, there is a significant potential for false reassurance or unnecessary treatment of an individual patient, particularly in the current era of risk calculators and Ocular Hypertension Treatment Study (OHTS)-influenced management.

From a previous study, the authors found that CCT-based correction formulae were not useful in a glaucoma suspect or a glaucoma population when PDCT IOP was used as the reference standard.[20] This study compared the IOP measurements from GAT, the Ocular Response Analyzer (ORA; Reichert Corp, Buffalo, NY), and adjusted IOP derived using various CCT-based correction formulae, again with IOP measurements from PDCT used as the reference. The aim was to determine whether the usefulness of CCT-based correction formulae and the IOP output parameters from the ORA varies according to different CCT values by stratifying the CCT into 3 groups: thin, intermediate, and thick.

Methods

This was a retrospective cross-sectional case series of 289 consecutive patients who sought treatment on a nonacute basis to a specialist glaucoma practice for ophthalmic assessment over a 30-month period, from February 2007 through August 2009. Patients were identified from the electronic patient database and for the purposes of the study and were classed in to normal or glaucoma groups. The diagnosis of glaucoma was based on the glaucomatous appearance of the optic disc, supported by consistent visual field defects characteristic of glaucoma, and was verified by the glaucoma specialist (A.P.W.) over 2 visits or more. Exclusion criteria were corneal diseases, systemic connective tissue disorders that may affect the cornea, secondary glaucoma, and previous ocular trauma.

At the specialist clinic visit, all patients underwent a full ophthalmic examination. This included visual acuity assessment, gonioscopy, perimetry, and measurement of CCT and IOP. Intraocular pressure was measured using GAT first, followed by PDCT and then the ORA. The ORA also produced values for corneal hysteresis, Goldmann-correlated IOP (IOPg), and corneal-compensated IOP (IOPcc). Optic disc and retinal nerve fiber layer imaging and dilated funduscopy were also carried out if appropriate.

For this study, only 1 Goldmann applanation tonometer (Haag-Streit, Koeniz, Switzerland), calibrated every month, was used to measure IOP. The CCT was measured by ultrasound pachymetry with the Pachmate DGH55 Portable Pachymeter (DGH Technologies, Inc., Exton, PA). For each IOP measurement, PDCT also displays the quality score, which ranges from 1 (excellent) to 5 (poor). The PDCT measurements were accepted only if the quality score was 3 or less. Corneal hysteresis, IOPg, and IOPcc values were obtained from the average of at least 2 readings from the ORA. AQ: 2

The GAT measurement for each eye was adjusted with 4 different correction formulae that were derived from clinical data. The formulae were described by Doughty and Zaman,[9] by Whitacre et al,[10] by Shimmyo et al,[11] and by the IOP correctional table provided by the manufacturer of the ultrasound pachymeter (IOP_{PACH}). This correction table was based on work by Ehlers et al[12] and by Stodtmeister.[13] Table 1 summarizes these correction formulae. For the purposes of the study, a 20% difference from DCT IOP was set arbitrarily as being clinically significant. Only 1 eye per patient was included in the study. If both eyes were eligible, then measurements from the right eye were used. T1,AQ:3

Statistical analysis was conducted using Microsoft Excel (Microsoft, Seattle, WA) and SPSS software version 19 (SPSS, Inc., Chicago, IL). Comparison of means was performed with the *t* test. The 95% limits of agreement (LOA) were calculated using the method of Bland and Altman.[21]

To examine the role of CCT in IOP measurement by different methods and the accuracy of CCT-based IOP correction formulae, the study sample was stratified into tertiles according to CCT (Table 2). A *P* value less than 0.05 was considered to be statistically significant. T2

This study was approved by the Central Regional Ethics Committee of New Zealand and was conducted in accordance with the tenets of the Declaration of Helsinki.

Table 2. Central Corneal Thickness Stratified into Tertiles

	No.	Mean (Standard Deviation), μm	Range, μm	No. of Patients with Glaucoma (%)
Total	289	552.8 (38.8)	460–666	83 (28.7)
Thin	97	511.6 (18.0)	460–535	42 (43.3)
Intermediate	95	550.5 (9.1)	537–567	24 (25.0)
Thick	97	596.2 (21.8)	568–666	17 (17.5)

Results

T3 Table 3 summarizes the demographic characteristics of the 289 patients who sought treatment at the authors' specialist glaucoma practice during the study period. Of these patients, 172 (59.5%) were female, the mean age was 59.2±13.5 years (range, 16–89 years), and 83 (28.7%) had confirmed glaucomatous optic neuropathy.

Overall, all the methods of IOP measurement (GAT, IOPg, and IOPcc) demonstrated poor agreement with PDCT IOP, as did the T4 adjusted IOP using CCT-based correction formulae (Table 4). The PDCT IOP measurements on average were higher than the IOP measurements obtained from other methods and were higher than AQ: 4 adjusted IOP. The mean differences ranged from 1.5 mmHg with IOPcc to 2.7 mmHg with IOP_{PACH}, and all of these differences were statistically significant. The 95% LOA were ±4.7 mmHg between PDCT and GAT. This range increased to ±5.1 to ±6.7 mmHg with other IOP measurement and adjustment methods. Of the unadjusted GAT IOP readings, 23.9% had a difference of 20% or more from PDCT IOP; adjustment resulted in an increase in this proportion with all of the formulae (range, 26.0% to 39.1%).

Agreement between PDCT and GAT, IOPg, and IOPcc, as well as IOP after adjustment with CCT-based correction formulae remained poor at all levels of CCT. In all 3 tertiles, mean PDCT IOP again remained higher than IOP obtained from other measurement methods and the adjusted IOP. The 95% LOA were narrowest between PDCT and GAT compared with other IOP measurement and adjustment methods.

In the thinnest tertile (Table 5), available at http://aaojournal.org), 2 of the CCT-based correction methods, the formula described by Shimmyo et al[11] and IOP_{PACH}, produced mean IOP values that were very close to the mean PDCT IOP (0.2 mmHg [$P = 0.351$] and 0.4 mmHg [$P = 0.083$], respectively). In this tertile, 36.1% of unadjusted GAT IOP measurements had a difference of 20% or more from PDCT IOP. Adjustment of GAT IOP resulted in decrease in this proportion with all of the CCT-based correction formulae (range, 14.4%–34.0%).

In the intermediate tertile (Table 6), available at http://aaojournal.org), the mean PDCT IOP was 1.7 mmHg higher than mean GAT IOP. The differences in mean IOP between PDCT and other IOP measurement and adjustment methods ranged from 1.2 mmHg (IOPcc) to 2.4 mmHg (IOPg). All of these differences were statistically significant. In this tertile, 22.1% of unadjusted GAT IOP measurements had a difference of 20% or more from PDCT IOP. This proportion remained similar with other methods of IOP measurement or adjustment (range, 17.9%–25.3%), with the exception of IOPg (38.9%).

In the thickest tertile (Table 7), the mean PDCT IOP was 2.0 mmHg higher than mean GAT IOP. Both IOPg and IOPcc had mean IOP differences less than this (1.6 and 1.9 mmHg). Adjustment with correction formulae increased the mean difference, from 2.8 mmHg (formula described by Whitacre et al[10]) to 5.6 mmHg (IOP_{PACH}). All of these differences were statistically significant. In this group, 13.4% of unadjusted GAT IOP measurements had a difference of 20% or more from PDCT IOP. Both IOPg (19.6%) and IOPcc (27.8%) resulted in increase in this proportion, as did all of the correction formulae (range, 25.8%–76.3%).

A subgroup analysis also was performed for patients with confirmed glaucomatous optic neuropathy (Table 8, available at http://aaojournal.org), with similar results as in the overall analysis. Adjusted IOP from the CCT-based correction formulae tended to be closer to PDCT IOP in the thinnest tertile, whereas in the thickest tertile, CCT-based correction tended to increase the mean difference between adjusted IOP and PDCT IOP. In all 3 groups, the agreement between PDCT IOP and GAT IOP, IOPg, IOPcc, and CCT-adjusted IOP measurements remained poor.

Unlike in the overall analysis, however, GAT IOP was not always associated with the narrowest range of the LOA (i.e., best agreement) when compared with PDCT IOP. Although the 95% LOA worsened after CCT-based adjustment in thin and thick tertiles, in the intermediate tertile, adjustment resulted in the slight improvements in the LOA. Also, IOPg and IOPcc exhibited poorer agreement with PDCT IOP than GAT IOP in the thin and intermediate tertile, but the agreement was better than GAT IOP in the

Table 3. Demographic Characteristics of the Patients (n = 289)

Demographic Characteristics	
Mean age (SD), yrs	59.2 (13.5)
Gender, no. (%)	
Male	117 (40.5)
Female	172 (59.5)
Diagnosis, no. (%)	
Normal	206 (71.3)
Glaucoma	83 (28.7)
Mean central corneal thickness (SD), μm	552.8 (38.8)
Mean corneal hysteresis (SD), mmHg	9.8 (1.9)
Mean Goldmann applanation intraocular pressure (SD), mmHg	17.3 (4.9)
Mean Pascal dynamic contour tonometry intraocular pressure (SD), mmHg	19.5 (5.0)

SD = standard deviation.

Table 4. Adjusted Goldmann Applanation Tonometry Intraocular Pressure Measurements in Comparison with Pascal Dynamic Contour Tonometry Intraocular Pressure Measurements for All Patients (n = 289)

Intraocular Pressure Correction Formula	Mean Difference in Intraocular Pressure (SD), mmHg (Intraocular Pressure–Pascal Dynamic Contour Intraocular Pressure)	*P* Value	95% Limits of Agreement, mmHg	% Patients with Intraocular Pressure Difference ≥20%
GAT IOP (unadjusted)	–2.2 (2.4)	<0.001	–6.8 to 2.5	23.9
IOPg	–2.4 (2.9)	<0.001	–7.8 to 3.5	38.1
IOPcc	–1.5 (2.8)	<0.001	–7.7 to 3.3	22.8
IOP_{DOUG} (Doughty and Zaman[9])	–2.5 (2.8)	<0.001	–7.6 to 3.3	30.4
IOP_{WHIT} (Whitacre et al[10])	–2.4 (2.6)	<0.001	–7.2 to 2.9	26.0
IOP_{SHIM} (Shimmyo et al[11])	–2.5 (3.4)	<0.001	–8.8 to 4.5	36.0
IOP_{PACH} (Ehlers et al[12] & Stodtmeister[13])	–2.7 (3.4)	<0.001	–8.8 to 4.5	39.1

GAT = Goldmann applanation tonometry; IOP = intraocular pressure; IOPcc = corneal-compensated intraocular pressure as measured from the Ocular Response Analyzer; IOP_{DOUG} = intraocular pressure after adjustment with the correction formula described by Doughty and Zaman; IOPg = Goldmann-correlated intraocular pressure as measured from the Ocular Response Analyzer; IOP_{PACH} = intraocular pressure after adjustment based on the correction table provided with the Pachmate DGH55 Portable Pachymeter; IOP_{SHIM} = intraocular pressure after adjustment with the correction formula described by Shimmyo et al; IOP_{WHIT} = intraocular pressure after adjustment with the correction formula described by Whitacre et al; SD = standard deviation.

thickest tertile. As seen in the overall analysis, CCT-based adjustment formulae decreased the proportion of patients with a 20% or more difference from PDCT IOP in the thinnest tertile; this proportion remained fairly similar in the intermediate tertile; this increased dramatically in the thickest tertile. Although the IOPg performed poorly in the thin cornea, with 41.7% of patients having an IOP difference of 20% or more from PDCT IOP, this proportion decreased progressively in the intermediate (24%) and thickest (11.8%) groups. This trend was reversed with IOPcc, with this proportion progressively increasing from the thinnest group (9.3%) to the thickest group (17.7%). However, because of the smaller number of subjects in each group, the results of this subgroup analysis should be interpreted with caution.

Discussion

In this study, which included both normal subjects as well as subjects with confirmed glaucomatous optic neuropathy, PDCT tended to measure IOP 2.2 mmHg higher than GAT, and the 95% LOA between PDCT and GAT IOP measurements were ±4.7 mmHg. This is comparable with the findings of similar studies, which report persistently higher mean PDCT IOP (range, 0.7–2.6 mmHg) and 95% LOA between ±3.3 and ±5.1 mmHg.[4,15,20,22–26] Although the agreement between PDCT and GAT IOP generally was poor, it was better (i.e., narrower range of limits) than those between PDCT and other methods of IOP measurements tested, namely, IOPg and IOPcc, as well as after adjustment with CCT-based correction formulae. In fact, with the exception of IOPcc, all of the IOP measurement and adjustment methods evaluated increased the risk of creating clinically significant error, which was set arbitrarily at a 20% or more difference, when PDCT IOP was used as the reference. The authors previously reported similar results in a study of 200 glaucoma and glaucoma suspect patients that showed that correcting GAT IOP based on CCT led to

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Table 7. Adjusted Goldmann Applanation Tonometry Intraocular Pressure Measurements in Comparison with Pascal Dynamic Contour Tonometry Intraocular Pressure Measurements in Patients with Central Corneal Thickness of More Than 567 μm (n = 97)

Intraocular Pressure Correction Formula	Mean Difference in Intraocular Pressure (Standard Deviation), mmHg (Intraocular Pressure–Pascal Dynamic Contour Intraocular Pressure)	*P* Value	95% Limits of Agreement, mmHg	% Patients with Intraocular Pressure Difference ≥20%
GAT IOP (unadjusted)	–2.0 (2.4)	<0.001	–6.7 to 2.7	13.4
IOPg	–1.6 (2.9)	<0.001	–7.2 to 4.0	19.6
IOPcc	–1.9 (2.8)	<0.001	–7.4 to 3.6	27.8
IOP_{DOUG} (Doughty and Zaman[9])	–4.2 (2.6)	<0.001	–9.4 to 0.9	51.5
IOP_{WHIT} (Whitacre et al[10])	–2.8 (2.5)	<0.001	–7.6 to 2.0	25.8
IOP_{SHIM} (Shimmyo et al)[11]	–5.3 (3.0)	<0.001	–11.0 to 0.5	67.0
IOP_{PACH} (Ehlers et al[12] & Stodtmeister[13])	–5.6 (2.9)	<0.001	–11.3 to 0.1	76.3

GAT = Goldmann applanation tonometry; IOP = intraocular pressure; IOPcc = corneal-compensated intraocular pressure as measured from the Ocular Response Analyzer; IOP_{DOUG} = intraocular pressure after adjustment with the correction formula described by Doughty and Zaman; IOPg = Goldmann-correlated intraocular pressure as measured from the Ocular Response Analyzer; IOP_{PACH} = intraocular pressure after adjustment based on the correction table provided with the Pachmate DGH55 Portable Pachymeter; IOP_{SHIM} = intraocular pressure after adjustment with the correction formula described by Shimmyo et al; IOP_{WHIT} = intraocular pressure after adjustment with the correction formula described by Whitacre et al; SD = standard deviation.

poorer agreement and increased risk of making clinically significant error compared with unadjusted GAT IOP.[20]

The mean CCT in this study, 552.8±38.8 μm, was similar to that found in other studies based on ultrasonic pachymetry[7,9,11,22,23,25–27] and slightly lower than that found in the OHTS.[5,28] Because the OHTS study population consisted exclusively of individuals with elevated GAT IOP, it is possible that it unintentionally selected for those individuals with thicker corneas.[1,29] The investigators of the OHTS recognized that OHTS subjects have thicker corneas than the general population and suggested that as many as 50% of OHTS subjects could have had so-called true IOP values of less than 21 mmHg.[1,28,29]

The OHTS identified CCT as an important predictive factor for the development of primary open-angle glaucoma, with participants with thinner corneas (CCT ≤555 μm) having 3-fold greater risk of glaucoma developing.[1,5,28,29] Since then, some authors have advocated using CCT for interpretation of GAT IOP measurement, for stratification of patient risk, and for guiding therapeutic decisions.[1,2,5–8] Such approaches involve identifying those patients with thinner corneas who may be at an increased risk of developing glaucoma even at a so-called normal IOP and recognizing that the patients with higher CCT may have artifactually elevated GAT IOP. However, the findings of the present study caution against such approach, especially in patients with thicker corneas. When the current subjects were stratified into tertiles by CCT, CCT-based correction formulae performed worst in the thickest group with CCT of 567 μm or more compared with the thin CCT or the intermediate CCT groups. In those corneas with the thickest CCT, adjustment of IOP resulted not only in poorer agreement with PDCT IOP, but also in a 12.4% to 62.9% increase in the risk of creating an error that may be of clinical significance compared with taking the so-called unadjusted GAT IOP reading.

The poor usefulness of CCT-based correction method in the patients with thicker cornea also was observed when the patients with confirmed glaucomatous optic neuropathy were analyzed separately. As it was the case in the overall group, the CCT-based correction method tended to underestimate the IOP in the thickest tertile when PDCT was used as the reference. These results suggest that adjustment of GAT IOP for patients with greater CCT may result in AQ: 6 significant underestimation of the actual IOP, which in turn may lead to delayed treatment; this risk may outweigh that of patients being misclassified as having ocular hypertension and administered long-term therapy inappropriately.

The PDCT measures IOP using the principle of contour matching instead of applanation. The tonometer tip of the PDCT has a concave surface that theoretically allows the cornea to assume its natural shape and minimizes the distortion of the cornea. When the tonometer tip matches the corneal surface, all of the forces are directed to the solid-state pressure-sensor embedded in the sensor tip. This provides the direct measurement of the transcorneal IOP, neutralizing the tangential forces and minimizing the systematic errors resulting from the force-to-pressure translation.[14,15,30] Cadaver and manometric studies have demonstrated that PDCT provides the closest approximation to the true intracameral IOP.[16,17,25] Numerous studies also have supported the relative independence of PDCT IOP measurement from various structural properties of the eye, demonstrating either no significant association or a weak correlation between PDCT readings and CCT, AQ: 7 corneal hysteresis, corneal curvature, corneal hydration state, astigmatism, anterior chamber depth, and axial length.[4,15,16,18,22,23,24–27] Therefore, this study used the PDCT IOP as the reference IOP, with the presumption that among the various IOP measurement methods currently in use, it is the closest measure to the true intracameral IOP.

The ORA evaluates the biomechanical properties of a cornea by quantifying its response to an air pulse over a defined time span. It generates 2 separate IOP output parameters: IOPg, the average of the inward and outward air–applanation pressures and closely correlated with GAT IOP,[14,31] and IOPcc, which is derived from both IOP and corneal biomechanical data, and hence purportedly is independent of CCT.[20,31] In this study, IOPg tended to underestimate IOP and significantly increased the risk of creating clinically significant error than GAT IOP, especially in the thinnest tertile. Corneal-compensated IOP produced the mean IOP that was closest to that of PDCT IOP and decreased risk of creating clinically significant error compared with GAT IOP, except in the thickest tertile. However, both AQ: 8 methods demonstrated poorer agreement with PDCT IOP than that between GAT IOP and PDCT IOP, both in the overall analysis as well as when each of the CCT-stratified tertiles was analyzed separately. Similar results were seen when those patients with confirmed glaucomatous optic neuropathy were analyzed separately. Previous studies have reported conflicting results on the relationship between the ORA IOP output parameters, GAT IOP, and PDCT IOP. The reported mean differences between the ORA IOP and GAT IOP range from 0.33 to 7.2 mmHg for IOPg and −0.1 to 8.3 mmHg for IOPcc.[23,24,32] Some reports found a significant association between IOPcc and CCT,[20,24] whereas others found no association.[23,32,33] The present results, as well as the conflicting results from previous reports, suggest that there is little evidence to suggest that IOPg and IOPcc are more accurate or more independent of corneal biomechanical properties than GAT IOP.

These results suggest that clinicians need not necessarily change the long-standing practice pattern of managing glaucoma based on GAT IOP. Central corneal thickness is thought to be just one of several contributing factors in GAT IOP measurement error. Other ocular structural properties, such as axial length and corneal curvature, also influence the GAT IOP measurement.[1,24,27,33] In addition, a number of complex physical and physiological events are involved in the process of IOP measurement using applanation.[1,32,33] Unfortunately, our understanding of these factors that result in GAT IOP measurement errors or bias are far from complete. This study showed that attempts to correct GAT IOP by taking in account these possible sources of error or bias are not particularly useful. Therefore, it is reasonable that GAT IOP remains as the clinical gold standard, at least until another method of IOP measurement that is less dependent on the ocular properties (such as PDCT) becomes more accessible for most clinicians.

This study has a number of limitations. The subjects from which these measurements were obtained were not representative of the normal population, although the subjects did represent the most relevant population for issues regarding IOP measurement. The study was retrospective, and the relatively small sample size made it difficult to carry out further subgroup analyses with sufficient statistical power. Although data on ethnicity of the study population is not available, most of the patients at the authors' practice are white. The racial homogeneity of this study population may limit the generalizability of the study to more racially heterogeneous clinic populations. The PDCT and ORA IOP measurements, if carried out before GAT, would not have been masked to the examiner, introducing the possibility of observer bias for subsequent GAT IOP. However, the authors' standard practice is to perform GAT before PDCT and ORA. The authors also did not take into account the other factors that may influence IOP readings, such as axial length and corneal curvature. However, the main aim of this study was to evaluate the usefulness of IOPg, IOPcc, and various CCT-based IOP correction formulae and algorithms in routine clinical practice, rather than to investigate the influence of various ocular structural properties on different IOP measurement and adjustment methods.

In conclusion, adjusting IOP using CCT-based correction formulae resulted in poorer agreement with PDCT IOP when compared with unadjusted GAT IOP. If PDCT is the closest measure we have to intracameral IOP, there is a risk of creating clinically significant error after adjustment of GAT IOP with CCT-based correction formulae. This risk was greatest in the patients with thicker corneas, whose increased IOP may be interpreted as a GAT measurement artifact, thereby exposing this group of patients to risk of delayed diagnosis and undertreatment. This study suggests that although CCT may be useful in population-based analyses, CCT-based correction formulae should not be applied in the diagnosis and treatment of glaucoma in individual patients. AQ: 9

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[1] Eye Department, Wellington Hospital, Capital and Coast District Health Board, Wellington, New Zealand.

[2] Capital Eye Specialists, Wellington, New Zealand.

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Correspondence:
Serena J. K. Park, Eye Department, Wellington Hospital, Riddiford Street, Newtown, Wellington 6021, New Zealand. E-mail: sjkpark@gmail.com.