• Clinical Research •

Evaluation of Corvis ST tonometer with the updated software in glaucoma practice

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Received: 2020-12-09 Accepted: 2021-01-29

Abstract

● **AIM:** To evaluate the agreement of biomechanically corrected intraocular pressure (b-IOP) and central corneal thickness (CCT) measurements obtained with the updated Corvis ST tonometer versus Goldmann applanation tonometry (GAT) and optical-based corneal pachymetry (OB-CCT) in controls, patients with ocular hypertension (OHT) and primary open angle glaucoma (POAG). Additionally, we examined the differences in corneal deformation parameters provided by the updated Corvis ST among the three groups.

● **METHODS:** For each participant, GAT IOP, OB-CCT and measurements with a Corvis ST with updated software were obtained. Bland-Altman analysis was used to assess the agreement between the two measurement methods.

● **RESULTS:** A consecutive series of 80 eyes from 80 participants (30 with POAG, 25 with OHT and 25 normal controls) were included in this prospective study. The mean GAT IOP of all eyes was 17.2±3.6 mm Hg, and the mean b-IOP was 15.9±3.7 mm Hg (Spearman's rho=0.767, P<0.001). The 95% limits of agreement (LoAs) ranged from -3.1 mm Hg to 5.5 mm Hg for GAT IOP and b-IOP. b-IOP was not correlated with OB-CCT (Spearman's rho=-0.13 P=0.917). Meanwhile there was a weak positive corelation between OB-CCT and GAT IOP–b-IOP difference (Spearman's rho=0.378, P=0.001). The mean OB-CCT was 549.5±36.4 μm, and the Corvis-CCT was 556.1±41.5 μm (Spearman's rho=0.900, P<0.001). No statistically significant difference in the new indices provided by the updated Corvis ST was detected among the three groups. Compared with control eyes, POAG eyes had a significantly reduced applanation time 2 after adjusting for OB-CCT and GAT IOP (P=0.048).

● **CONCLUSION:** Corvis b-IOP and CCT correlate well with GAT IOP and OB-CCT. b-IOP is not affected by CCT, which might be an advantage, especially in thick or thin corneas. Corvis ST yields shorter applanation time 2 measurements in patients with POAG, which might reflect altered corneal viscoelasticity.

● **KEYWORDS:** glaucoma; tonometry; intraocular pressure; ocular hypertension; corneal biomechanics

DOI:10.18240/ijo.2022.03.11

Citation: Halkiadakis I, Tzimis V, Gryparis A, Markopoulos I, Konstadinidou V, Zintzaras E, Tzakos M. Evaluation of Corvis ST tonometer with the updated software in glaucoma practice. *Int J Ophthalmol* 2022;15(3):438-445

INTRODUCTION

Reduction of intraocular pressure (IOP) is currently the sole undisputable method of glaucoma treatment. Goldmann applanation tonometry (GAT) is the gold standard for IOP measurement. However, GAT is influenced by corneal biomechanics and corneal properties, such as corneal curvature and central corneal thickness (CCT)[1-2]. The magnitude of this influence has not been precisely measured, as it depends on the biomechanical properties of particular individuals' corneal tissue[3].

These facts point out the need for the development of devices that accurately measure corneal biomechanical properties and provide IOP measurements that take into account these properties. The Corvis ST (OCULUS, Wetzlar, Germany) is a noncontact tonometer that uses a high-speed Scheimpflug camera to investigate the biomechanical properties of the human cornea *in vivo*. The system acquires high-speed Scheimpflug pictures of corneal deformation during an air pulse. The corneal biomechanical properties as well as the CCT and IOP are measured based on software analysis of these images. Several previous studies have shown that when

Table 1 Demographic and clinical characteristics of the study population

Characteristics	Controls (*n*=25)	POAG (*n*=30)	OHT (*n*=25)	*P*
Female/male	13/12	20/10	17/8	0.467
Age (y)	65.9±13.1 (34-92)	68.3±11(32-87)	67.0±11.5 (36-89)	0.646
GAT (mm Hg)	15.9±2.8 (10-20)	16.3±3.4 (11-25)	19.4±4.0 (10-27)	0.001
OB-CCT (μm)	557.9±30.5 (486-611)	537.0±32.4 (473-589)	556.0±42.8 (484-660)	0.083
No. of medicines		1.8±1.0 (1-4)	0.7±0.8 (0-3)	<0.001
Visual field index		72.5±26.5 (7-97)		

GAT: Goldmann applanation tonometry; OB-CCT: Optical-based corneal pachymetry; POAG: Primary open angle glaucoma; OHT: Ocular hypertension.

compared with ultrasound pachymetry or GAT measurements, uncorrected Corvis ST IOP and CCT measurements are accurate and have very good repeatability in healthy subjects and in patients with ocular hypertension (OHT) and primary open angle glaucoma (POAG)[4-9]. There are reports indicating that certain corneal biomechanical parameters provided by the Corvis ST can differentiate glaucomatous from normal eyes[10-16] as well as eyes with various stages of glaucoma[14]. Finally, several previous studies correlated Corvis ST corneal deformation parameters with optic nerve head morphological findings[17-18] and visual field indices[19]. Although these studies agree that corneal deformation parameters provided by the Corvis ST indicate that the corneas of POAG patients have different biomechanical properties from healthy corneas, there is no good agreement between studies regarding which Corvis ST parameters can differentiate glaucoma patients.

Recently, a new version of software (version 1.3r1538) was introduced, providing additional parameters that can better define corneal properties. The updated software also provides a biomechanically corrected IOP (b-IOP) measurement that is designed to moderate the effect that age and corneal biomechanical properties have on the measurement of IOP[20-23].

The purpose of the present study was to evaluate the agreement of b-IOP and CCT measurements obtained with the updated Corvis ST, GAT IOP and optical-based corneal pachymetry (OB-CCT) in patients with OHT and POAG. Additionally, we examined the difference in corneal deformation parameters measured with the updated Corvis software, particularly the newest indices, between normal controls and patients with OHT or POAG.

SUBJECTS AND METHODS

Ethical Approval All patients gave informed consent. Approval for the study was obtained from the Ethics Committee of Ophthalmiatrion Athinon.

Consecutive patients diagnosed with POAG or OHT who presented in the Glaucoma Clinic and age-matched controls who presented in the General Clinic of Ophthalmiatrion Athinon were included in the present study. Each subject underwent a complete ophthalmic examination, visual field (VF) tests and optical coherence tomography (OCT) of the retinal nerve fibre layer (RNFL) with a Spectralis-OCT (Heidelberg-Engineering).

POAG eyes had an untreated GAT measurement greater than 21 mm Hg and abnormal VF and OCT-RNFL exams. OHT patients had normal VF and OCT-RNFL exams with an untreated GAT measurement greater than 21 mm Hg. Healthy controls had GAT measurements lower than 21 mm Hg, healthy discs, normal OCT and no other ophthalmic disease. The demographic and ocular characteristics of the patients are shown in Table 1.

VF tests were performed with the Humphrey Field Analyser II (Carl Zeiss Meditec) by means of the 24-2 SITA standard strategy, and the VFs were evaluated by previously described criteria[24]. Patients with keratopathy, irregular astigmatism or prior ocular surgery were excluded from the study. One eye per individual was randomly included in the analysis of the results. Measurements were performed in the following sequence: pachymetry, Corvis ST and GAT with a 7-10-minute break between them. Previous studies suggest that a rest time of five minutes ensures recovery from the aqueous outflow caused by noncontact tonometers[25]. GAT was the last measurement in accordance with previous studies on the subject[26-27]. A slit lamp mounted optical pachymeter (Optical Low Coherence Reflectometry OLCR- Haag Streit®, Bern, Switzerland) was used for the measurement of CCT. Only results with a standard deviation <5 μm were included. Two GAT readings were acquired by one of the authors (Halkiadakis I). If they differed greater than 2 mm Hg, a third measurement was taken, and the mean of the closest two readings was recorded. Measurements with the Corvis ST were carried out by an observer (Tzimis V) blinded to the pachymetry measurements, three times per patient, and the average of all three measurements was used in the statistical analyses.

The principles of the Corvis ST have been described in detail elsewhere[20]. Briefly, a high-speed Scheimpflug camera takes over 4300 images per second to monitor the corneal response to an air-puff pulse. During the pulse, the cornea initially moves inward until it reaches the first applanation and

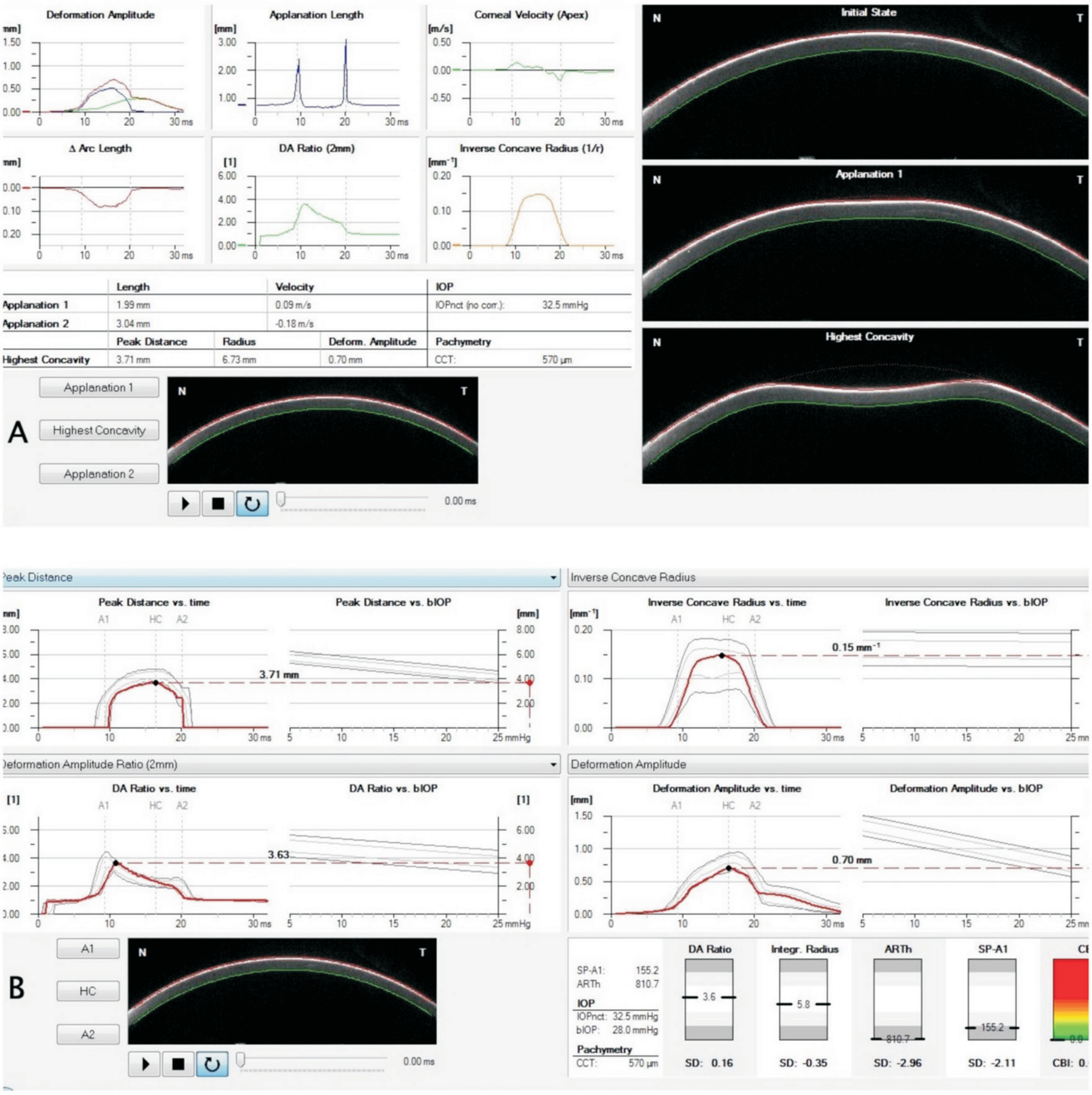

Figure 1 Corvis ST measurement with Vinciguerra's screening report for an eye with OHT.

subsequently enters a concavity phase. Then, the cornea moves in the outward direction and undergoes a second applanation before returning to its resting position. Several parameters are calculated by the device during this process (Figure 1).

The definition of the parameter examined (CST software ver. 1.3r1538) is provided in Table 2. Previous studies reported good repeatability and reliability of these parameters in healthy eyes[28-30].

Statistical Analysis The Kolmogorov-Smirnov test was used to assess normality. Quantitative data are presented as the mean±SD (min, max). For the demographic and clinical characteristics of the study population, associations between qualitative variables were investigated with the Chi-square test. Levels of quantitative parameters were compared with analysis of variance (ANOVA), the Kruskal-Wallis test (for 3-group comparisons), or the Mann-Whitney test (for 2-group comparisons). GAT IOP and b-IOP in the three groups of patients were compared using paired *t*-test. OHT and POAG groups were compared to the control group in terms of corneal response parameters using analysis of covariance (ANCOVA) adjusting for GAT IOP and OB-CCT in accordance with previous reports[12] with Bonferroni correction. Correlations between GAT IOP, b-IOP and their difference with OB-CCT were assessed using Spearman correlation analysis. A Bland-Altman plot was used to visually investigate the agreement between GAT measurements, OB-CCT and the Corvis measurement. A two-sided P-value <0.05 was considered statistically significant. All statistical analyses were conducted with IBM SPSS v. 25 (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp)

RESULTS

Eighty eyes from 80 consecutive patients (30 with POAG, 25 with OHT and 25 normal controls), 30 males and 50 females, comprised the study population. The mean age of the patients was 66.7±11.7 (32-92)y. The mean GAT IOP and mean OB-CCT were 17.2±3.6 (9-27) mm Hg and 549.5±36.4 (473-660) μm,

Table 2 Corvis ST parameters

Parameters	Definition
App T1	The length of time from the initiation of the air puff to the first (when the cornea is moving inwards) applanation
App T2	The length of time from the initiation of the air puff to second applanation (when the cornea moves outwards)
App L1	The length of the flattened cornea at the first applanation;
App L2	The length of the flattened cornea at the first or second applanation
App V1	The corneal velocity during the first applanation;
App V2	The corneal velocity during the second applanation
HCT	The length of time from the start of deformation to the point when the cornea reaches highest concavity
HCC	The central curvature radius at the highest concavity
DA	The movement of the corneal apex from the start of deformation to the highest concavity
CR	Radius of curvature of the cornea at the time of maximum concavity
New parameters	
DA 2	The ratio between vertical displacement at apex and at 2 mm
SP-A 1	Parameter reflecting bending stiffness of the cornea as defined by force/replacement
IR	The area under the inverse concave Radius *vs* time curve.
ARTH	The quotient of corneal thickness at the thinnest point of the horizontal meridian and the thickness change
CBI	The overall biomechanical index for keratoconus detection

App T: Applanation time; App L: Applanation length; App V: Applanation velocity; HCT: Highest concavity time; HCC: Highest concavity curvature; DA: Maximum deformation amplitude; CR: Curvature radius; SP-A 1: A parameter reflecting bending stiffness; IR: Integrated ratio; ARTH: Ambrosio relational thickness to the horizontal profile; CBI: Corvis biomechanical index.

respectively. All patients were Caucasian. No statistically significant differences in age or sex occurred in the three groups of patients. Patients with OHT had higher GAT IOPs than patients with POAG (*P*=0.003) and normal controls (*P*=0.005).

Intraocular Pressure The mean difference in GAT IOP and b-IOP was 1.2±2.2 mm Hg. A statistically significant correlation between GAT IOP and b-IOP was observed (Spearman's rho=0.767 *P*<0.001). The 95% LoA Bland-Altman plot ranged from -3.1 mm Hg to 5.5 mm Hg (Figure 2).

The agreement between GAT IOP and b-IOP in various groups of patients is presented in Table 3. Biomechanically corrected IOP was not correlated with CCT (Spearman's rho=-0.13, *P*=0.917). Meanwhile there was a weak positive corelation between OB-CCT and GAT IOP–b-IOP difference (Spearman's rho=0.378, *P*=0.001).

Central Corneal Thickness The mean difference between OB-CCT and Corvis-CCT was -6.9±17.0 μm, while the 95% LoA Bland-Altman plot ranged from -40.0 to 26.2 μm (Figure 3). A statistically significant correlation between OB-CCT and Corvis ST measurements was observed (Spearman's rho =0.900, *P*<0.001).

Corneal Deformation Parameters After correcting for GAT and OB-CCT applanation time 2 was the only parameter that remained significantly different between controls and POAG patients (*P*=0.048; Table 4).

DISCUSSION

The Corvis ST with the new software provides corneal

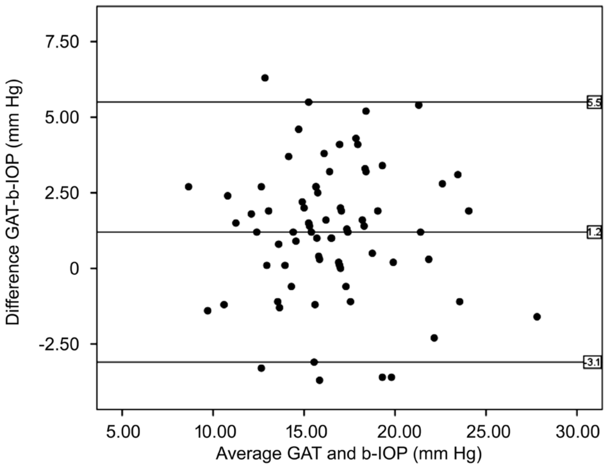

Figure 2 Bland-Altman plot for Goldmann IOP and Corvis b-IOP measurements.

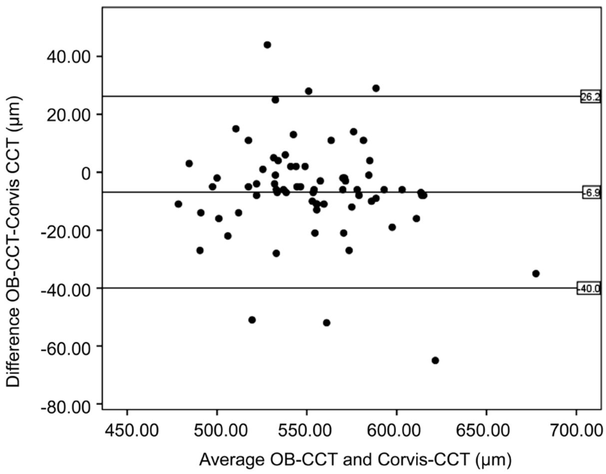

Figure 3 Bland-Altman plot for OB-CCT and Corvis CCT measurements.

Table 3 Agreement between GAT and Corvis b-IOP measurements

Participants	GAT	b-IOP	GAT–b-IOP	*P*
Entire group	17.2±3.6 (9-27)	15.9±3.7 (7.3-28.6)	1.2±2.2 (-3.7 to 6.3)	<0.001
Controls	15.9±2.8 (9-20)	13.8±2.6 (7.3-16.9)	2.0±2.0 (-1.4 to 6.3)	0.004
OHT	19.4±4.0 (10-27)	17.5±3.9 (10.5-28.6)	1.8±2.1 (-1.6 to 5.4)	<0.001
POAG	16.3±3.4 (11-25)	16.0±3.6 (9.6-24.1)	0.4±2.2 (-3.7 to 3.7)	0.365

GAT: Goldmann applanation tonometry; b-IOP: Biomechanically corrected intraocular pressure; OHT: Ocular hypertension; POAG: Primary open angle glaucoma.

Table 4 Corneal deformation parameters in the three groups

Parameters	Control	OHT	POAG	*P* (control *vs* OHT)	*P* (control *vs* POAG)
App T1 (ms)	7.37±0.38	7.87±0.50	7.57±0.45	0.414	0.241
App L1 (mm)	2.59±0.61	2.16±0.3	2.18±0.28	0.251	0.178
App V1 (m/s)	0.14±0.02	0.12±0.02	0.14±0.03	0.999	0.999
App T2 (ms)	21.61±0.47	21.00±0.61	21.28±0.49	0.162	0.048
App L2 (mm)	2.26±0.36	2.1±0.30	2.00±0.41	0.005	0.053
App V2 (m/s)	-0.25±0.04	-0.23±0.05	-0.25±0.06	0.999	0.718
HCT (ms)	17.22±0.46	16.91±0.52	16.85±0.63	0.318	0.067
DA (mm)	1.03±0.11	0.94±0.12	1.00±0.14	0.999	0.999
PD (mm)	4.78±0.26	4.34±0.79	4.62±0.54	0.574	0.999
Radius (mm)	7.85±1.00	7.58±1.05	7.21±1.32	0.999	0.176
DA 1	4.10±0.38	4.31±0.55	4.10±0.44	0.480	0.178
IR	7.30±0.97	6.95±1.13	7.92±1.82	0.999	0.233
ARTH	560.5±168.8	576.8±248.2	527.1±166.5	0.999	0.999
SP-A 1	104.6±17.6	114.1±30.5	107.4±22.3	0.999	0.999
CBI	0.14±0.25	0.1±0.24	0.1±0.24	0.999	0.999

App T: Applanation time; App L: Applanation length; App V: Applanation velocity; HCT: Highest concavity time; DA: Maximum deformation amplitude; PD: Peak distance; SP-A 1: A parameter reflecting bending stiffness; IR: Integrated ratio; ARTH: Ambrosio relational thickness to the horizontal profile; CBI: Corvis biomechanical index; OHT: Ocular hypertension; POAG: Primary open angle glaucoma.

compensated IOP measurements along with parameters that describe corneal biomechanical properties. Corvis b-IOP has many advantages when compared with GAT IOP, as it is noncontact, does not require anaesthesia and has an option to correct for age and corneal biomechanics as well as CCT[16]. However, few clinical studies have compared these two measurements in patients with POAG or OHT.

The present study examined consecutive patients with treated and untreated POAG and OHT with the new updated version of the Corvis. The mean difference between GAT IOP and b-IOP was 1.2 mm Hg, ranging between 0.4 mm Hg in POAG eyes and 2 mm Hg in normal eyes. There were not consistent results in previous studies regarding the mean difference between GAT IOP and b-IOP. A range of values from -3 mm Hg to 5.1 mm Hg has been reported. Previously, Vinciguerra *et al*[16] reported that GAT yields higher measurements than b-IOP in POAG, OHT, NTG and control eyes. The mean difference ranged from approximately 1.2 mm Hg in NTG eyes to 5.1 mm Hg in OHT eyes, which is a much greater difference than the difference calculated in the present study. The results of the present study are in accordance with those of a recent study by Matsuura *et al*[30]. They reported a mean difference between GAT IOP and b-IOP of -0.2 mm Hg with a 95% LoA from approximately -4 mm Hg to 4 mm Hg. Similar to the findings of the present study, b-IOP was not correlated with CCT according to Matsuura *et al*[30], and the difference between GAT IOP and b-IOP increased at higher IOPs (R^2=0.071, P<0.001) and with greater CCTs (P=0.001). Their study population was different from the study population included in the present report, as it did not include patients with OHT. Furthermore, the mean GAT IOP in their study population was 13.1 mm Hg. In contrast to previous studies, Ye *et al*[31] reported that b-IOP was higher than GAT IOP with a mean bias between tonometers of 1.17 mm Hg and a 95% LoA of -2.66 to 5.01 mm Hg. The authors reported that b-IOP was influenced by CCT. Two studies focusing on healthy eyes also had contradictory results. Sedaghat *et al*[26] reported a mean difference between GAT IOP and b-IOP of -3 mm Hg with a 95% LoA between -8 mm Hg and 2 mm Hg. In contrast, Ramm *et al*[27] reported a mean difference of 0.60±2.7 mm Hg, which is in accordance with the present study. Our results indicate that b-IOP is not influenced by CCT. Furthermore, the difference between GAT IOP and b-IOP increases in thicker corneas, which reflects the fact that GAT overestimates IOP in eyes with thicker corneas and underestimates IOP in thinner ones.

Regarding CCT, there was excellent agreement between the two instruments. The correlation between Corvis ST and slit lamp OLCR CCT measurements has not been previously reported. Tai *et al*[32] compared CCT measurements provided by the Scheimpflung camera in a Pentacam (OCULUS, Wetzlar, Germany) and OLCR using optical biometry *via* a Lenstar LS 900 (Haag Streit®, Bern, Switzerland) and concluded that the two instruments could be used interchangeably. In contrast, Huerva *et al*[33] reported that the CCT measurements provided by the Lenstar LS 900 were thinner than those provided by the Scheimpflug device (Galilei G1® Ziemer Ophthalmic Systems AG, Port Switzerland) and suggested that the wide LoA (-35.01 to -0.03 μm) would be clinically significant in certain situations.

The present study attempted to examine differences in biomechanical parameters among the three groups. Previous studies using previous versions of software concluded that there were differences in corneal biomechanical parameters between normal eyes and eyes with POAG, indicating that POAG eyes have less deformable corneas than normal eyes[12-14]. However, there is no parameter that can be readily used to diagnose POAG[13]. Initially, Salvetat *et al*[10] showed that after taking into account CCT and GAT, the parameters applanation time 2 and deformation amplitude were different in POAG patients. Tian *et al*[12] examined CCT and GAT matched eyes and reported that the parameters of the Corvis ST that were significantly different between POAG eyes and normal eyes were the first applanation velocity, second applanation time, peak distance and deformation amplitude. Furthermore, according to their study, the second applanation time was the best predictive parameter for differentiating the two groups. Wang *et al*[13] performed a Meta-analysis and concluded that the parameters that were significantly different between POAG patients and controls were deformation amplitude and applanation time 1 and 2. Finally, Jung *et al*[14] reported that after adjusting for IOP, CCT and axial length, the only parameter that was significantly different between POAG patients and controls was deformation amplitude. The authors did not include time parameters in their study. It is of note, however, that in their study, there were reduced deformation amplitudes in eyes with early POAG compared to eyes of controls as well as eyes with advanced glaucoma. In summary, most studies indicated that compared to normal eyes, POAG eyes have a smaller deformation amplitude and reduced second applanation time. The present study showed that eyes with OHT and POAG have reduced second applanation times after correcting for GAT, OB-CCT. This is in agreement with two previous studies[12-13].

One potential reason for the partial agreement between the studies is that most deformation parameters, including deformation amplitude and applanation time 2, are affected by the IOP. Eyes with increased IOPs have decreased corneal deformability. Another potential bias is caused by the effect of the use of prostaglandins on deformation amplitude and applanation time 2. Deformation amplitude increases in patients receiving prostaglandins, and applanation time 2 decreases[34-35]. Therefore, differences in the type and duration of medication among the eyes with POAG and OHT might have an impact on their corneal biomechanical parameters. Jung *et al*[14] reported that deformation amplitude is affected by the stage of glaucoma, being lower in early-stage glaucoma and higher in late-stage glaucoma. This fact might reflect the results of long-term treatment.

Regarding the new parameters in the updated software, the present study failed to detect any statistically significant difference among the three groups. Previously, Vinciguerra *et al*[16] reported differences between POAG and OHT patients using two new parameters: the inverse radius (IR) and deformation amplitude ratio. Neither parameter, however, was significantly different between controls and POAG patients. Recently, Sedaghat *et al*[36] displayed a reduction of IR as an indication of corneal stiffening after corneal crosslinking. The present study showed that IR was increased in POAG eyes compared to controls, but this difference did not reach statistical significance. Vinciguerra *et al*[16] reported that POAG eyes had increased IR compared to OHT eyes but not compared to normal eyes. In their study, normal tension glaucoma patients had significantly higher IR than patients in the other groups, indicating much softer corneas.

The present study has several limitations. A higher sample size including more patients without treatment with higher or lower IOPs would lead to stronger conclusions. This is particularly true for the ability of the present study to detect small differences in the new biomechanical indices among the three groups. Furthermore, POAG and OHT patients received several medications for different periods that could have affected their biomechanical parameters.

In conclusion, the present study indicated that Corvis tonometer with the updated software, provides useful and reliable measurements. b-IOP correlates well with GAT IOP and is not affected by CCT, which might be an advantage, especially in thick or thin corneas. In these corneas GAT-IOP may not be reliable. Furthermore, Corvis CCT measurements correlate well with slit lamp OLCR CCT measurements meaning that is an accurate optical pachymeter. However, most corneal biomechanical parameters provided by the updated software, even the new indices fail to differentiate OHT or POAG from control eyes. Nevertheless, the Corvis measures shorter second applanation times in patients with POAG and OHT, which might reflect altered corneal viscoelasticity.

ACKNOWLEDGEMENTS

Presented in part at the 36th Congress of the European Society of Cataract and Refractive Surgeons, Vienna, 22-26 September 2018.

Conflicts of Interest: Halkiadakis I, None; **Tzimis V,** None; **Gryparis A,** None; **Markopoulos I,** None; **Konstadinidou V,** None; **Zintzaras E,** None; **Tzakos M,** None.

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