Comparison between Goldmann, Icare Pro and Corvis ST tonometry

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\section*{Abstract}

\textbf{Purpose}: To compare intraocular pressure (IOP) between the new non-contact tonometer Corvis ST (CST), the Goldmann applanation tonometry (GAT) and Icare Pro rebound tonometer (PRO).

\textbf{Methods}: A total of 178 eyes of 178 healthy subjects were selected for the study. Measurements of IOP were made in a random order with GAT, PRO and CST. Central corneal thickness (CCT) was determined by ultrasound pachymetry. The mean of three valid measurements of each variable was used in the statistical analysis. The relationship between the tonometers was established using Bland–Altman plots.

\textbf{Results}: Mean IOP was 15.5 \pm 2.8 mmHg for GAT, 15.4 \pm 2.8 mmHg for CST, and 14.6 \pm 2.3 mmHg for PRO. The mean differences between pairs of tonometers were: GAT-PRO = 0.9 \pm 1.7 mmHg (p < .001), GAT-CST: 0.1 \pm 2.2 (p = .398), and PRO-CST: –0.8 \pm –0.7 mmHg, p < 0.001. A positive relationship was detected between CCT and the three tonometers: GAT: r = 0.325, p < .001; PRO: r = 0.385, p < .001, and CST: r = 0.428, p < .001.

\textbf{Conclusions}: The differences found between PRO and GAT were significantly higher than those found between CST and GAT, which showed non-significant differences. The measurements of the three tonometers were affected by the CCT.

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Concordancia entre la tonometría de Goldmann, Icare Pro y Corvis ST

**Resumen**

Objetivo: Comparar los valores de presión intraocular (PIO) del nuevo tonómetro de no contacto Corvis ST (CST) con la tonometría de aplanación de Goldmann (GAT) y la tonometría de rebote Icare Pro (PRO).

Material y métodos: Se seleccionaron 178 ojos de 178 voluntarios sanos a los que se les midió la PIO de manera aleatorizada con CST, PRO y GAT. Se midió el espesor corneal central (GCC) con paquimetría ultrasonica. Para cada variable, se tomaron 3 medidas y la media de las 3 fue introducida en el análisis estadístico. La concordancia entre los tonómetros se determinó mediante las gráficas de Bland-Altman.

Resultados: La PIO medias obtenidas con los 3 tonómetros fueron de 15,5 ± 2,8 mmHg para GAT, 14,6 ± 2,3 mmHg para PRO y 15,4 ± 2,8 mmHg para CST. La diferencia media entre pares de tonómetros fue: GAT-PRO = 0,9 ± 1,7 mmHg (p < 0,001); GAT-CST: 0,1 ± 2,2 (p = 0,398) y PRO-CST: −0,8 ± −0,7 mmHg, p < 0,001. En los 3 casos se encontró una correlación significativa con el GCC: GAT: r = 0,325, p < 0,001; PRO: r = 0,385, p < 0,001 y CST: r = 0,428; p < 0,001.

Conclusiones: Las diferencias encontradas entre el PRO y el GAT son significativamente mayores que entre el CST y el GAT, sin diferencias significativas entre las medidas de estos 2. Las medidas de los 3 tonómetros se ven afectadas por el GCC.

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**Introducción**

Increased intraocular pressure (IOP) is the major modifiable risk factor in development and progression of glaucomatous optic neuropathy. Currently, Goldmannplanation tonometry (GAT) is the most widely used method for measuring IOP; it is based on the Imbert-Flick principle. Therefore, IOP is proportional to the pressure applied on the cornea and corneal thickness (CCT). This influence of CCT and other corneal factors have led to the development of new tonometers in order to provide IOP values independent of corneal properties.

Icare Pro (PRO) rebound tonometry is based on cornea contact by magnetized probe to detect eye-caused deceleration and determine IOP.

Corvis ST (CST) (Fig. 1) gives IOP values corrected by corneal biomechanical parameters and incorporates a Scheimpflug camera (Optikeräte GmbH, Wetzlar, Germany) for real-time images of the anterior eye chamber, where corneal deformability is displayed in response to an air pulse. Corneal biomechanical parameters provided are: speed, time and length of first and second applanation, maximum concavity, strain amplitude and corneal radius.

The working hypothesis is that our new CST air tonometer provides IOP values similar to those obtained with GAT and PRO and its IOP value is independent of CCT.

**Materias y métodos**

A total of 178 eyes from 178 healthy volunteers were selected. Each participant signed an informed consent form. The study protocol adhered to the rules of the Declaration of Helsinki and was approved by the Clinical Research Ethics Committee of the Hospital Clínico San Carlos. Inclusion criteria for patients were: adulthood, ability to collaborate with the tests to be performed, ability to give informed consent, refractive errors less than 5 diopters of spherical equivalent or one cylinder less than 2 diopters. We excluded subjects with a history of ocular surgery or trauma, severe or poorly controlled systemic disease, physical or mental difficulties to perform the tests. For each participant, one eye was selected randomly unless only one eye met inclusion criteria.

An automatic randomization sequence was generated by the tool available at www.randomization.com to establish measurements with GAT, CST and PRO. We took three measurements with each tonometer, waiting at least 3 min between measurements, and 5 min between tonometers. After taking IOP measurement with the three tonometers, CCT was measured with ultrasonic pachymetry (Dicon P55, Paradigm Medical Industries Inc., UT, USA), three CCT measurements were taken, and the average of the three was used as a value for statistical analysis. All measurements were performed by the same observer.

Goldmann tonometry (GAT, Haag-Streit, Koeniz, Switzerland): Measurements were taken after instilling fluorescein sodium 2.5 mg/ml and oxybuprocaine hydrochloride 4 mg/ml in aqueous solution (Fluotest eye drops, Alcon Cusi, Barcelona, Spain). We conducted three measurements and used their average.

Corvis ST (Optikeräte GmbH, Wetzlar, Germany) and Icare PRO (Icare®, Tiolat Oy, Helsinki, Finland): We conducted three valid measurements with CST and PRO and used the average of the three for statistical analysis.

Icare tonometry Pro (Icare, Tiolat Oy, Helsinki, Finland): Rebound tonometry with 1 mm contact surface between probe and corneal apex. We took three measurements with high reliability with this tonometer, knowing that each measurement is the average of six readings. We used the average of the three for statistical analysis.
Suitable calculations and statistical tests for processing and analyzing each variable were performed using SPSS statistical software, version 18.0 for Windows (SPSS Inc., Chicago, IL, USA). The level of statistical significance was set at $p < 0.05$.

Mean and standard deviation (SD) were used to describe the characteristics of subjects and parameters obtained with the tonometers. Normality of distributions was checked using the Kolmogorov–Smirnov test. Measurements obtained using the GAT, PRO and CST tonometers were compared using the Student t test for paired data. Bland–Altman plots were developed to establish the correlation between the three tonometers and identify possible biases.

IOP values were correlated from each tonometer with CCT to examine the possible effect of corneal thickness on IOP measurements.

### Results

178 eyes of 178 healthy subjects who met the inclusion criteria were studied.

Mean age was $46.1 \pm 16.8$ years. Gender distribution was 60% female and 40% male. We examined 99 right eyes (56%), and 79 left eyes (44%). Average corneal thickness was $558.3 \pm 53 \mu m$.

Mean IOP ($\pm SD$) obtained with the three tonometers from the 178 subjects was: GAT $15.5 \pm 2.8$ mmHg, whereas with PRO it was $14.6 \pm 2.3$ mmHg, and $15.4 \pm 2.8$ mmHg with CST. Average difference between measurements from the three tonometers was: GAT–PRO $= 0.9 \pm 1.7$ mmHg ($p < 0.001$) (Fig. 2), GAT–CST: $0.1 \pm 2.2$ ($p = 0.398$) (Fig. 3) and PRO–CST: $-0.8 \pm 0.7$ mmHg, $p < 0.001$ (Fig. 4).

There was a statistically significant correlation between CCT and the three tonometers: GAT: $r = 0.325$, $p < 0.001$; PRO: $r = 0.385$, $p < 0.001$ CST and $r = 0.428$, $p < 0.001$.

We found no complication with using the tonometers.

### Discussion

The publication of the study on ocular hypertension treatment recalled the influence that CCT may have on determining IOP.$^4,5$ Goldmann himself recognized from the outset that the physical assumptions used in designing the tonometer (considered the gold standard since the mid-20th century) were based on central corneal thickness of $500 \mu s$, and tonometry in very thick or very thin corneas may result in measurement overestimation or underestimation, respectively. Numerous studies subsequently corroborated these results.$^2,6,7$

Along with CCT, other factors such as corneal curvature or axial length have also been identified as possible error sources for measuring pressure with applanation tonometers.$^8,9$

All these factors have led to the development of various linear correction factors, formulas and nomograms trying to...
eliminate any possible influence from these confounding factors; none of them has been fully satisfactory to be used in daily clinical practice.\textsuperscript{10,11} With the same goal in mind, new tonometers have been developed in recent years to circumvent the aforementioned limitations of applanation tonometry.

Thus, the CST tonometer has been developed, which measures corneal biomechanical properties, just like the ocular response analyzer (ORA) does. Corneal deformability parameters measured by CST and the measurement technology are different than ORA. ORA is also different, in that CST allows controlling eye fixation by direct visualization of the eye through a screen. In automatic mode, the CST expels an air pulse when the eye is in the correct position. In our study, the patient blinked in 4 occasions just at the time the measurement was being taken; therefore, the measurement was invalid and the real time image showed eyelid deformation.

Several studies have shown that CCT is one of the largest sources for error in measuring IOP with applanation tonometry.\textsuperscript{6} In fact, many authors consider CCT a risk factor independent of the development of glaucoma.\textsuperscript{12} We hypothesize that greater CCT is a protective factor for neuropathy development and progression.

In several studies, the PRO rebound tonometer has demonstrated excellent correlation with GAT.\textsuperscript{13} However, we have found that it overestimates pressures slightly regarding GAT.\textsuperscript{14} In our study, as seen in the Bland–Altman plot (Fig. 2), we obtained a mean difference between PRO and GAT which remained constant throughout the measurement range. As with applanation tonometry, measurements obtained with the rebound tonometer are influenced by CCT, overestimating pressure in thick corneas and underestimating it in thin corneas. Recently, it has been suggested that other corneal properties, such as corneal hysteresis and corneal resistance factor, could influence measurements obtained with the rebound tonometer.\textsuperscript{15}

To date, there is only one study comparing CST values with those of GAT.\textsuperscript{16} In it, Hong et al. found that IOP values provided by CST are reproducible and similar to those provided by GAT, although it tends to underestimate them slightly. They did not find total IOP value independence from CST with corneal biomechanical properties.

In our study, we found that the average difference between GAT IOP and CST IOP remained constant throughout the measurement range (Fig. 3), as well as mean difference between CST and PRO (Fig. 4), and between GAT and PRO (Fig. 2). Regression lines were not statistically significant; therefore, we can say that there was no proportional error. However, differences between PRO and GAT are significantly greater than between CST and GAT, with no significant differences between the measurements from these two. We found that the three tonometers are influenced by CCT. GAT overestimates IOP in thick corneas and underestimates it in thin corneas; similarly, it affects CST for PRO and for CST, with a weak positive correlation between the three tonometers’ CCT and IOP.

A possible limitation of our study is that it is done only on normal subjects. It would be interesting in the future to expand the study to the entire range of glaucomatous disease, including ocular hypertension and incipient, moderate and advanced glaucoma.

In conclusion, our results are similar to those found in the Hong study, with a larger patient sample. To the best of our knowledge, this study is the first to compare CST with PRO in humans. CST may be useful for measuring IOP in patients with corneal irregularities where applanation fails to provide entirely reliable values. Its corneal biomechanical parameters require further study to describe their possible involvement in the development and progression of glaucomatous disease.

**Conflicts of interest**

There is no commercial interest from the authors.

**REFERENCES**