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Comparison between Corvis and other tonometers in healthy eyes

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ABSTRACT

Purpose: To determine the agreement of intraocular pressure (IOP) values in healthy eyes among Goldmann applanation tonometer, dynamic contour tonometer, ocular response analyzer and Corvis. Additionally, to study the relationship between their differences with central corneal thickness (CCT) and corneal curvature (CK).
Methods: Seventy-six eyes of 76 healthy subjects were examined. Every subject underwent a complete ophthalmic evaluation, a Pentacam scan and three consecutive IOP measurements with each instrument (DCT, GAT, ORA and CST). IOP measurements provided by each device were compared with each other and the differences between them were correlated with morphological parameters obtained by Pentacam (CCT and CK). Statistical analysis was performed using SPSS software, version 18.0.
Results: The mean age of enrolled subjects was 36.8 ± 10.6 years old. The mean IOP measurements that were obtained with GAT, DCT, ORA and CST was 15.62 ± 2.33 mmHg, 17.44 ± 2.51 mmHg, 15.99 ± 3.58 mmHg and 17.24 ± 3.44 mmHg respectively. The mean CCT was 543.63 ± 36.15 μm, the mean CK was 43.35 ± 1.23 D. GAT and ORA provided IOP values not showing a statistical difference; CST and DCT IOP measurements did not show a statistical difference whereas CST provided statistically higher IOP values both than GAT and both ORA.
Conclusions: According to our data, CST produces IOP values that are notably higher than GAT measures; therefore they cannot be used interchangeably. If CST should be used as the next gold standard, higher IOP values will come to be considered normal.
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1. Introduction

Intraocular pressure (IOP) is the referenced measure for the treatment of ocular hypertension [1]. It is the most important modifiable risk factor for the development and progression of open-angle glaucoma [1]. In fact, the main goal of anti-glaucomatous treatment is the reduction of IOP. The detection of IOP can be influenced by morphological corneal proprieties, like corneal thickness and corneal curvature [2,3], and by biomechanical corneal proprieties, such as hysteresis, viscosity, elasticity, hydration and connective tissue composition [4].

To date the Goldman tonometer (GAT) (Haag Streit, Könitz, Switzerland) is currently the gold standard for IOP measurement and is widely used in clinical practice [5]. The original Goldman equation, based on the Imbert-Fick law, had the following assumptions: the radius of curvature and the corneal stiffness are considered constant; the eye as a sphere and the aqueous humor is regarded to be still during the examination. With these assumptions in mind, today, in order to achieve a correct IOP evaluation using the GAT, it is considered important to correct the value of IOP for material properties of the cornea (central corneal thickness and corneal curvature), but the available formulae are not able to adequately correct the measurement of IOP for the corneal biomechanical properties [5,6].

New tonometers were created to provide an IOP measure that is independent of the geometric and biomechanical properties of the eye.

The dynamic contour tonometry (DCT, Swiss Microtechnology AG, Port, Switzerland) is based on the law of hydrostatic pressure, enumerated by Blaise Pascal, where pressure is defined as a uniform force distribution acting perpendicularly to all boundaries for freely relocation of molecules in liquids and gases. With this

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instrument, pressure is not defined between rigid and semi-rigid materials like the tonometer tip and the cornea, but rather, the key of DCT is a hypothetical corneal shape (contour) that is achieved when the pressure on both sides of the cornea is equal. The force that is needed to gently fit the corneal surface to that hypothetical contour counterbalances the force distribution generated by the IOP. Hence, a pressure sensor that is centrally and concavely embedded into the tonometer tip precisely measures the pressure of the eye, transcorneally [7].

The ocular response analyzer (ORA) is a non-contact tonometer that measures the biomechanical response of the eye to a jet of air at the cornea [8]. The device generates two metrics of corneal biomechanics: corneal hysteresis and the corneal response factor. These metrics are adopted in the IOP calculation, generating a corneal compensated IOP (IOPcc) measure, which has been shown to represent an IOP measurement that is weakly associated with CCT [9].

The Corvis ST (CST; Oculus, Wetzlar, Germany) is a new non-contact tonometry that provides information on IOP and investigates the deformation properties of the cornea. It allows investigation of the dynamic reaction of the cornea to an air impulse. It records the deformation process with 4330 frames/s, along an 8 mm horizontal corneal coverage, while an air puff indentation causes a corneal deformation. Therefore recording dynamic deformation of the cornea to calculate the IOP value. Its measurement range is from 1 to 60 mmHg. A high-speed Scheimpflug camera is equipped [10] to record the movements of the cornea, which are then displayed on the built-in control panel in ultraslow motion.

Repeatability, reproducibility and correlations of the parameters provided by CST have been studied by Hon and Lam [11], while differences among CST, no contact tonometry and GAT have been analyzed by Hong et al. [10]. Furthermore it was recently published an interesting study to evaluate the agreement of IOP and central corneal thickness (CCT) using CST, GAT and ultrasound-based corneal pachymetry [12]. However, to the best of our knowledge, this is one of the first papers, that compares IOP values provided by CST in healthy subjects with those provided by GAT, DCT and ORA and examines the differences in relation to corneal morphological parameters.

2. Methods

In this retrospective study, data from 76 eyes of 76 subjects (44 males and 32 females) were analyzed, when they were screened to undergo refractive surgery. They had a mean age of 36.8 ± 10.6 years (from 23 years old to 65 years old) and a mean refraction of −1.04 ± 2.26 D (from −7 D to +3 D), measured as spherical equivalent (SE). All subjects with systemic and/or ocular diseases that could interfere with IOP or corneal evaluation and to bias the comparison of the devices, such as diabetes, connective tissue disorders, dry eye, uveitis, corneal opacities and glaucoma, were excluded from the study. Subjects wearing contact lenses were asked to stop using them at least 3 days before the evaluation.

Each subject underwent a complete ophthalmic evaluation and corneal tomography scan with a Pentacam (Oculus, Wezlar, Germany) and three consecutive IOP measurements for each device (DCT, GAT, ORA and CST) were taken. Finally, the measurement mean was used as value for statistical analysis.

All subjects started with Pentacam evaluation and then underwent the ORA, CST, DCT and GAT in this order to reduce bias in morphological measurements, since the applanation could introduce errors in the following IOP measurements.

All visits were performed from 2:00 pm and 4:00 pm and both slit lamp evaluation and Pentacam scan were repeated to every eye at the end of the visit in order to detect any eventual corneal alteration (corneal thickness increase, corneal disepithelization, corneal curvature anomalies) that could be caused by IOP measurements and to exclude these eyes from the study.

The Oculus Pentacam is a corneal tomographer, utilizing a rotating Scheimpflug camera and a monochromatic slit light source (blue led at 475 nm), which rotate together around the optical axes of the eye to calculate a three-dimensional model of the anterior segment, including data from anterior and posterior corneal topography and pachymetry, as well as measurements of anterior chamber depth, lens opacity and lens thickness. Within 2 s, the system rotates 180° and acquires 25 or 50 images (depending on the user settings) that contain 500 measurement points on the front and back corneal surfaces, in order to draw a true elevation map. For this study, the option to use 25 images per scan was chosen. The parameters evaluated in this study were: CCT at pupil center and anterior corneal curvature measured with Sim'K (CK).

The study was performed in accordance with the ethical standards stated in the 1964. Declaration of Helsinki and approved by the local clinical research ethics committee; informed consent was obtained from all subjects before examination.

2.1. Statistical analysis

The normal distribution of the data was verified by the Kolmogorov–Smirnov test. For data that did not meet normality standards, non-parametric tests were used to evaluate differences and correlations. In particular, the comparisons among measures from different devices were evaluated with the non-parametric Wilcoxon test for paired data. Moreover, the correlations between IOP measures and corneal anatomical-structural parameters were evaluated using parametric (Pearson) or non-parametric (Spearman) tests. For all tests, the level of significance was set at $p < 0.05$. All analyses were performed using SPSS software (IBM Corp., Armonk, New York) version 18.0.

Despite the fact that all patients underwent bilateral evaluation, only the right eye results were considered in the statistical analysis to eliminate any potential intra-subject effect that could have occurred if both eyes were included.

3. Results

Details of the morphological parameters of the study subjects are shown in Table 1 and comparisons of average values of IOP found by the different devices are shown in Table 2 and Fig. 1. In general GAT values showed good agreement with those obtained from ORA, while DCT and CST provided higher IOP measures. To confirm this and to verify the linearity of inter-instrument gaps, values provided by the tested devices have been plotted (Fig. 2). ORA showed a quite small IOP overestimation compared with GAT (+0.38 mmHg equal to +2.4%) and was not significant (Fig. 2A). On the other hand, differences between DCT and GAT (+1.82 mmHg equal to +11.7%; Z: −5.754; $p < 0.000$; Wilcoxon test) (Fig. 2B) and between CST and GAT (+1.63 mmHg equal to +10.4%; Z: −3.028; $p < 0.003$) (Fig. 2C) were greater and significant.

Table 1
Clinical and morphological parameters of patients.

Characteristic	Mean ± SD	Range
Age (year)	36.83 ± 10.63	From 23 to 65
Spherical equivalent (D)	−1.04 ± 2.26	From −7 to +3
CK (D)	43.35 ± 1.23	From 40.9 to 45.9
Corneal pachymetry at pupil center (μm)	543.63 ± 36.15	From 467 to 614

SD: standard deviation.

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