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Intraocular pressure evaluation in healthy eyes and diseased ones using contact and non contact devices

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ABSTRACT

Purpose: To analyze and compare intraocular pressure (IOP) values measured in healthy subjects (HS), keratoconus (KC) patients and patients that underwent myopic photorefractive keratectomy (REF), using Goldmann applanation tonometry (GAT), dynamic contour tonometry (DCT), ocular response analyzer (ORA) and Corvis ST (CST).
Methods: The study included 76 eyes of 76HS, 15 eyes of 15 KC patients and 18 eyes of 18 subjects that underwent REF. Each participant underwent a complete ophthalmic evaluation, IOP measurement with GAT, DCT, ORA and CST.
Results: HS showed a mean GAT value of 15.62 ± 2.33 mm Hg, a mean DCT value of 17.44 ± 2.51 mm Hg, a mean ORA value of 15.99 ± 3.58 mm Hg and a mean CST value of 17.24 ± 3.44 mm Hg. KC showed a mean GAT value of 15.07 ± 1.83 mm Hg, a mean DCT value of 17.01 ± 1.96 mm Hg, a mean ORA value of 13.58 ± 2.99 mm Hg and a mean CST value of 14.37 ± 1.89 mm Hg. REF showed a mean GAT value of 14.06 ± 1.51 mm Hg, a mean DCT value of 15.12 ± 2.34 mm Hg, a mean ORA value of 16.85 ± 2.4 mm Hg and a mean CST value of 15.57 ± 1.77 mm Hg.
Conclusion: Our data suggest that ORA and GAT could be used interchangeably in HS; GAT, ORA and CST could be used interchangeably in KC patients and that GAT provides lower IOP values compared to the other devices in eyes previously submitted to myopic PRK.

1. Introduction

Glaucoma is a progressive optic neuropathy whose pathogenesis is not fully understood, and a leading cause of blindness in industrialized countries [1–4]. Intraocular pressure (IOP) is a very important parameter in the diagnosis and management of glaucoma [1–4].

The evaluation of IOP can be influenced both by morphological corneal proprieties, like central corneal thickness (CCT) and corneal curvature (CP) [5,6] and by biomechanical corneal proprieties, such as hysteresis, viscosity, elasticity, hydration and connective tissue composition [7].

The Goldman applanation tonometer (GAT) is currently considered to be the gold standard for IOP measurement and is widely used in clinical practice [8]. The original Goldman equation, based on the Imbert–Fick law, had the following assumptions: the radius of curvature and the corneal stiffness are constant, the eye is considered as a sphere and the aqueous humor is regarded to be still during the examination. Keeping these assumptions in mind today, in order to achieve IOP values as precise as possible using GAT, we usually correct them according to corneal morphological properties (CCT and CP), although the available formulas are not able to adequately adjust the measurement considering corneal biomechanical properties [8,9].

New tonometers have been developed to provide IOP values independent from the bias that geometric or biomechanical eye properties could induce.

Purpose of this study is to evaluate IOP measurements provided by four devices: GAT, dynamic contour tonometry (DCT), ocular response analyzer (ORA) and Corvis ST (CST), in healthy subject and in subjects with very different corneal shape such as keratoconus patients (KC) and patients that previously underwent myopic photorefractive keratectomy (REF), and to study the differences in relation to corneal morphological parameters. There are several published papers comparing IOP measurements derived from two

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or three different devices in patients affected by KC, glaucoma or patients who underwent refractive surgery [10–16] and there is one paper evaluating the 4 devices in healthy subjects [17], although this is the first study to compare IOP values provided by GAT, DCT, ORA and CST in healthy subjects, KC and REF patients.

2. Methods

In this study, 109 eyes of 109 subjects were analyzed: 76 eyes of 76 healthy subjects aged from 23 to 65 years (mean 36.8 ± 10.6 years) with a refractive error, measured as spherical equivalent, ranging from −7 to +3 D (mean −1.04 ± 2.26 D); 15 eyes of 15 patients affected by KC (stage 1, 2 and 3 according to Amsler Classification) and 18 eyes of 18 subjects (8 males and 10 females) that underwent myopic PRK with a refractive error, measured as spherical equivalent, ranging from −9.25 to −1.63 D (mean −5.48 ± 2.27 D). Demographic data of the participants at the time of the study are shown in Table 1. Subjects with systemic and/or ocular diseases that could interfere with IOP or corneal evaluation and bias the comparison between the devices, such as diabetes, connective tissue disorders, dry eye, uveitis and corneal opacities, were excluded from the study. Subjects wearing contact lenses were asked to discontinue using them at least 7 days before the evaluation.

Each subject underwent a complete ophthalmic evaluation, a Pentacam scan and three consecutive IOP measurements with each instrument (DCT, GAT, ORA and CST), the mean measurement was used for the statistical analysis.

All patients started with the Pentacam examination and then underwent the ORA, CST, DCT and GAT evaluation in this sequence, in order to reduce bias in morphological measurements considering that the applanation determined by GAT could introduce errors in the following IOP determinations. Devices were used by four different physicians, trained in IOP measurements and no one was aware of the other's results, a fifth one collected all the data and analyzed them. A 10 min interval was observed between every IOP estimation.

Ophtalmic assessments were performed between 2:00 and 4:00 pm, both slit lamp evaluation and Pentacam scan were repeated for each eye at the end of visits, in order to check the eye conditions after measuring IOP.

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.

DCT (Swiss Microtechnology AG, Port, Switzerland) is based on the law of hydrostatic pressure enumerated by Blaise Pascal where pressure is defined, for freely re-locatable molecules in liquids and gases, as a constantly distributed force acting perpendicular to all boundaries. With this instrument, the pressure is not defined between rigid and semirigid material 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 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 [18,19].

The ORA is a non-contact tonometer that measures the biomechanical response of the eye to a jet of air at the cornea [20]. The device generates 2 metrics of corneal biomechanics: corneal hysteresis and corneal response factor. These metrics are adopted in the IOP calculation, generating a corneal compensated IOP measure (IOPcc), which has proven to be weakly associated with CCT [21].

The CST (Oculus, Wetzlar, Germany) is a noncontact tonometer that allows investigation of the dynamic reaction of the cornea to an air impulse and quantifies the deformation properties of the cornea to calculate the IOP [22–24].

The device records the deformation process with 4330 frames/sec, along an 8 mm horizontal corneal coverage, while an air puff indentation causes corneal deformation. Its measurement ranges from 1 to 60 mm Hg. A high-speed Scheimpflug camera is equipped to record the movements of the cornea, which are then displayed on the built-in control panel in ultraslow motion [22–24].

The Oculus Pentacam (Oculus, Wezlar, Germany) 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 [25]. For this study, the option to use 25 images per scan was chosen. The parameters, provided by Pentacam, that we evaluated in this study were CCT at pupil center and anterior corneal power measured with Sim'K (CP).

2.1. Statistical analysis

The data normal distribution was verified by Kolmogorov–Smirnov test. For data which did not meet normality, appropriate non parametric tests were used to evaluate differences and correlations. In particular, the comparison among measurements provided by the different devices was evaluated using parametric Student's *t*-test or non parametric Wilcoxon test for paired data. Moreover the correlation between IOP measures and corneal anatomical-structural parameters was evaluated using parametric (Pearson) and 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.

3. Results

Demographic data of the participants are shown in Table 1. In healthy subjects (Fig. 1) GAT values showed a good alignment with ORA ones, while DCT and CST provided higher IOP values. In

Table 1
Mean, standard deviation (SD), minimum and maximum of age, spherical equivalent (SE), corneal power (CP) and corneal pachymetry at pupil center (CPP) in healthy subjects, subjects that underwent myopic photorefractive keratectomy (REF) and subjects affected by keratoconus (KC).

	Healthy subjects				Ref.				KC			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
AGE (years)	36.83	10.63	23.0	65.0	34.50	7.39	25.0	49.0	25.80	5.85	18.0	37.0
SE (D)	−1.04	2.26	−7.0	3.0	0.19	0.39	−1.0	0.8	−1.72	2.12	−6.8	2.0
CP (D)	43.36	1.29	40.9	45.9	40.11	2.40	36.1	43.9	46.15	2.80	40.7	50.0
CPP (D)	543.63	36.15	467.0	614.0	472.50	52.69	378.0	609.0	494.73	53.09	426.0	640.0