Ocular Response Analyzer versus Goldmann Applanation Tonometry for Intraocular Pressure Measurements

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PURPOSE. To establish correlations between intraocular pressure (IOP) measurements obtained with the ocular response analyzer (ORA) and the Goldmann applanation tonometer (GAT). The effects of central corneal thickness on the measures obtained were also examined.

METHODS. This was a cross-sectional study. IOP was determined in 48 eyes of 48 patients with glaucoma In all patients, central corneal thickness (CCT) was measured by ultrasound pachymetry.

RESULTS. ORA readings were consistently higher than GAT measurements (Goldmann-correlated IOP − IOP GAT mean difference, 7.2 ± 3.5 mm Hg; corneal-compensated IOP – IOP GAT mean difference, 8.3 ± 4.0 mm Hg) However, differences were not constant and increased with increasing IOP GAT readings, both with respect to Goldmann-correlated IOP (slope = 0.623, $P < 0.0001$) and corneal-compensated IOP (slope = 0.538, $P < 0.0001$). Both pressure measurements provided by the ORA showed significant correlation with CCT (CCT versus Goldmann-correlated IOP: $r = 0.460$, $P = 0.001$; CCT versus corneal-compensated IOP: $r = 0.442$, $P = 0.001$). No significant effects of corneal curvature or refraction on any of the pressures were observed.

CONCLUSIONS. The ORA significantly overestimates IOP compared with the GAT. Differences between both sets of measures increase as the GAT-determined IOP increases. ORA readings seem to be affected by central corneal thickness. (*Invest Ophthalmol Vis Sci.* 2006;47:4410–4414) DOI:10.1167/iovs.06-0158

It has been widely documented that Goldmann applanation tonometry (GAT) measures can be affected by several ocular properties such as corneal curvature, axial length, and central corneal thickness.[1-5] Recent studies focusing on the treatment of ocular hypertension[6,7] have reconfirmed the importance of corneal thickness on pressure measurements.

These findings have prompted the development of numerous formulas and nomograms designed to compensate for the corneal thickness effect on GAT, but none of these methods has been entirely satisfactory.[8,9] Similarly, as a result of efforts to mitigate some of the limitations of conventional tonometry, several new tonometers have appeared on the scene.

One such recently marketed instrument, the Ocular Response Analyzer (ORA; Reichert Inc., Depew, NY), is able to establish the biomechanical properties of the cornea and use this information to adjust IOP measurements according to these properties.

The ORA provides four variables: the Goldmann-correlated IOP, corneal-compensated IOP, corneal resistance factor, and corneal hysteresis. A precisely metered collimated air pulse causes the cornea to move inward, past applanation, and into a slight concavity. Milliseconds after applanation, the air pump shuts off, and the cornea gradually recovers its normal configuration, passing through a second applanation state. An electro-optical system monitors the deformation of the cornea throughout the entire process, and two independent values are obtained for the inward and outward applanation events. Because of energy absorption, or damping, in the cornea, the inward and outward applanation events are delayed, resulting in two different pressures. The average of these two pressures provides a reproducible Goldmann-correlated IOP, and the difference between the two pressures is called corneal hysteresis.[10]

Corneal hysteresis is an indication of viscous damping in the cornea, reflecting the capacity of corneal tissue to absorb and dissipate energy. Previous studies have revealed that this measure ascribed to corneal tissue is independent of the radius of curvature of the cornea, corneal astigmatism, visual acuity, or axial length.[11]

Corneal-compensated IOP is a pressure measurement that utilizes the new information provided by the corneal hysteresis measurement to provide an IOP that is less affected by corneal properties.[11]

The Corneal Resistance Factor, also derived from corneal hysteresis, is an indicator of the overall resistance of the cornea, which, according to previous data, seems to be related to central corneal thickness and GAT-determined IOP but not to corneal-compensated IOP.

The purpose of the present study was to examine using the ORA the biomechanical properties of the cornea in a group of patients with primary open-angle glaucoma and to correlate the IOP measurements provided with those obtained via conventional applanation tonometry.

METHODS

Patients with a diagnosis of glaucoma were recruited from the Glaucoma Department of the Hospital Clínico San Carlos, Madrid. The study was discussed in detail with each patient, and informed consent was obtained from all participants in accordance with the tenets of the Declaration of Helsinki. The need for formal approval was waived by

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TABLE 1. Baseline Characteristics of the Study Population

Age, y (mean ± SD)	65.1 ± 14.5
Gender (M/F)	22/26
Visual acuity (mean ± SD)	0.9 ± 0.1
Visual field mean deviation, dB (mean ± SD)	−7.3 ± 4.1
Cup-disc ratio (mean ± SD)	0.5 ± 0.2
Glaucoma medication*	
Prostaglandin analogues	32
β-Blockers	18
α2-Adrenergic agonists	5
Topical CAIs	3

* 38/48 (79.2%) eyes were under treatment with one drug, and 10/48 (20.8%) eyes received combined therapy (two drugs).

our Institutional Review Board. For inclusion, the patients were required to have had a diagnosis of glaucoma in any of its forms and to show reproducible visual field defects. We excluded patients with refractive defects greater than 6 D of spherical equivalent and/or more than 5 D of astigmatism, and a best corrected visual acuity less than 20/25. Patients with any type of corneal disease, or those having undergone any type of eye surgery were also excluded. Only one eye, fulfilling all the inclusion criteria and none of the exclusion criteria, was designated as the study eye. When this was true of both eyes of a patient, the study eye was chosen at random.

In all patients, central corneal thickness was determined by ultrasound pachymetry (Dicon P55; Paradigm Medical Industries Inc., UT). IOP was then determined using the ORA and the GAT (Haag-Streit, Köniz, Switzerland). Each patient also underwent an examination to establish his or her refractive error (sphere, cylinder, and spherical equivalent) and corneal curvature (mean *K*).

Patients were randomly divided into two groups to vary the order in which the tonometers were applied using a randomization list obtained from www.randomization.com. All measurements were made by two examiners, one using each tonometer, who were masked to the results obtained with the other tonometer.

The ORA was used to obtain four measurements in each patient, and the mean of these four readings was used in the analysis according to the manufacturer's instructions. The GAT readings used were two IOP measurements per person, or three measurements if the difference between the first two IOPs was greater then 2 mm Hg. Mean IOP was used in the analysis.

All statistical tests were performed on computer (SPSS 12.0 software for Windows; SPSS Inc., Chicago, IL). The Kolmogorov-Smirnov test was used to check for a normal distribution of quantitative data, which are provided as the mean and SD. Differences between the measurements obtained using the two instruments were evaluated using the Student's paired *t*-test, whereas intermethod reliability was established by calculating intraclass correlation coefficients (*r*). A Bland-Altman plot[12] of the difference between the ORA and GAT readings against the average of the two was drawn to assess agreement between the two methods and the presence of systemic bias. The level of significance for each contrast was set at *P* < 0.05. The effect of multiple comparisons was corrected by the a posteriori Bonferroni test.

RESULTS

The series examined comprised 48 eyes of 48 patients with primary open-angle glaucoma of mean age 65.1 ± 14.5 years. Table 1 shows the characteristics of the study population. Refractive error, corneal curvature, and central corneal thickness recorded for each patient are provided in Table 2.

The mean IOP obtained using the GAT was 16.8 ± 3.4 mm Hg (range, 10–25 mm Hg), whereas those provided by the ORA were 24.1 ± 5.2 mm Hg (range, 14–40 mm Hg) for Goldmann-correlated IOP (*P* < 0.0001) and 25.1 ± 5.4 mm Hg

(range, 13–41 mm Hg) for corneal-compensated IOP (*P* < 0.0001).

The Bland-Altman plots in Figures 1 and 2 show the differences in pressure measurements obtained with ORA and GAT. These differences were not constant across the pressure range examined, but increased as the pressure values determined using the GAT increased (Goldmann-correlated IOP versus IOP GAT: slope = 0.623, *P* < 0.0001; corneal-compensated IOP versus IOP GAT: slope = 0.538, *P* < 0.0001). Only in 4.2% of the eyes (two eyes) was the difference between Goldmann-correlated IOP and IOP GAT less than 2 mm Hg, whereas differences between corneal-compensated IOP and IOP GAT under 2 mm Hg were recorded in 6.2% of eyes (three eyes).

Significant correlation was also detected between the two pressure measurements provided by the ORA (Goldmann-correlated IOP versus corneal-compensated IOP: *r* = 0.909, *P* < 0.0001; Fig. 3). The mean difference between these two pressures was 1.0 ± 2.3 mm Hg.

Mean corneal hysteresis and corneal resistance factor were 8.8 ± 2.1 (range, 3.9–14.7) and 11.5 ± 2.1 (range, 5.7–18.5), respectively. These variables correlated significantly (*r* = 0.698, *P* < 0.0001).

Corneal hysteresis showed correlation with corneal-compensated IOP (*r* = 0.573, *P* < 0.0001), whereas the corneal resistance factor correlated with IOP GAT (*r* = 0.437, *P* < 0.001) and with central corneal thickness (*r* = 0.503, *P* < 0.0001).

When we analyzed the effects of corneal thickness on the measures provided by the ORA, both the Goldmann-correlated IOP and corneal-compensated IOP showed weak yet significant correlation with central corneal thickness: central corneal thickness versus Goldmann-correlated IOP: *r* = 0.460, *P* = 0.001; central corneal thickness versus corneal-compensated IOP: *r* = 0.442, *P* = 0.001. The IOPs obtained with the GAT showed no significant correlation with central corneal thickness (*r* = 0.263, *P* = 0.07).

None of the pressure measurements was significantly affected by refraction or corneal curvature. No complications arising from the use of either tonometer was recorded.

DISCUSSION

To date, no factor used to correct for central corneal thickness in intraocular pressure measurements has been completely satisfactory.[13] Many of these correction factors are based on the changes in corneal thickness and IOP observed after refractive surgery. Besides corneal thinning leading to reduced IOP determined by applanation tonometry, surgery has other effects on corneal architecture (rigidity, deformability changes) that are not accounted for by correction factors. This is probably why these factors cannot be applied to IOP determinations in patients with glaucoma.

Over the past few years, several new instruments have been tried in an effort to resolve the limitations of conventional tonometry. Recent studies performed using the new dynamic contour tonometer (DCT) seem to indicate less dependence on

TABLE 2. CCT, Refractive Error, and Corneal Curvature in this Series of 48 Eyes of 48 Patients with Glaucoma

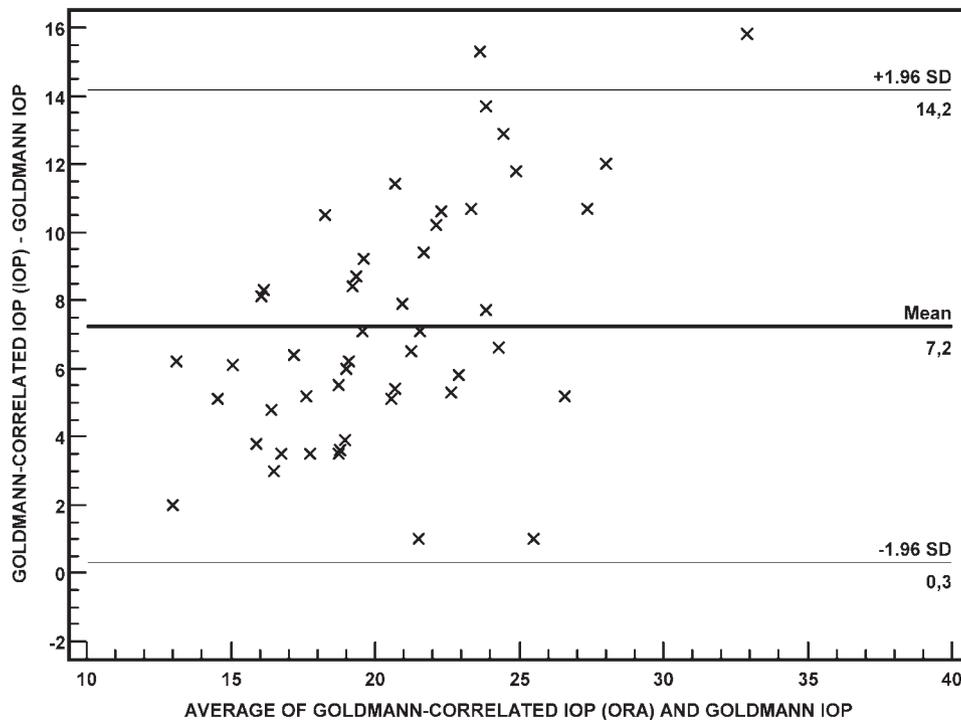|	Minimum	Maximum	Mean ± SD
CCT (μm)	475.0	640.0	555.3 ± 41.2
Mean *K*	39.4	48.2	43.7 ± 1.8
Sphere (D)	−5.2	6.0	−0.1 ± 2.6
Cylinder (D)	−3.2	0	−1.4 ± 0.8
Spherical equivalent	−6.0	5.5	−0.7 ± 2.5

FIGURE 1. Bland-Altmann plot of Goldmann-correlated IOP (ORA) minus Goldmann IOP (GAT) versus the mean of both (slope = 0.623, $P < 0.0001$).

central corneal thickness of its pressure measurements, compared with those of conventional tonometry.[14,15]

The ocular response analyzer was developed with a similar purpose in mind. This instrument evaluates several biomechanical properties of the cornea and then corrects the IOP according to these properties.

One of the variables measured by the ORA is the corneal hysteresis, which reflects the capacity of corneal tissue to absorb and dissipate energy. In eyes with keratoconus or Fuchs' dystrophy or those undergoing corneal refractive surgery, the corneal hysteresis is significantly reduced with respect to eyes with normal corneas.[10] This corneal property is
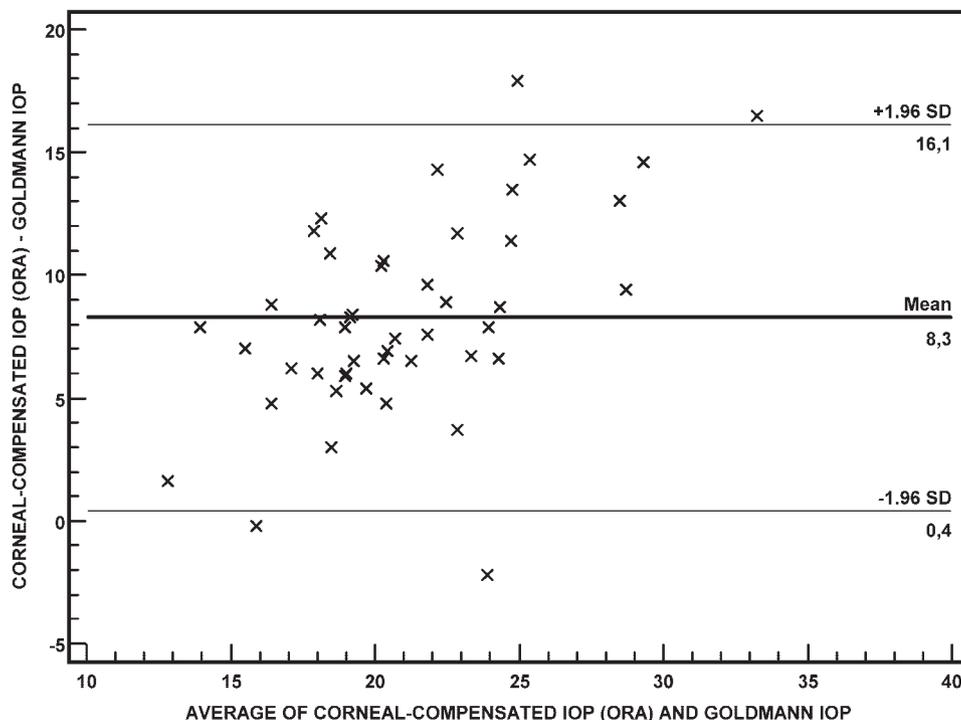

FIGURE 2. Bland-Altmann plot of corneal-compensated IOP (ORA) minus Goldmann IOP (GAT) versus the mean of both (slope = 0.538, $P < 0.0001$).
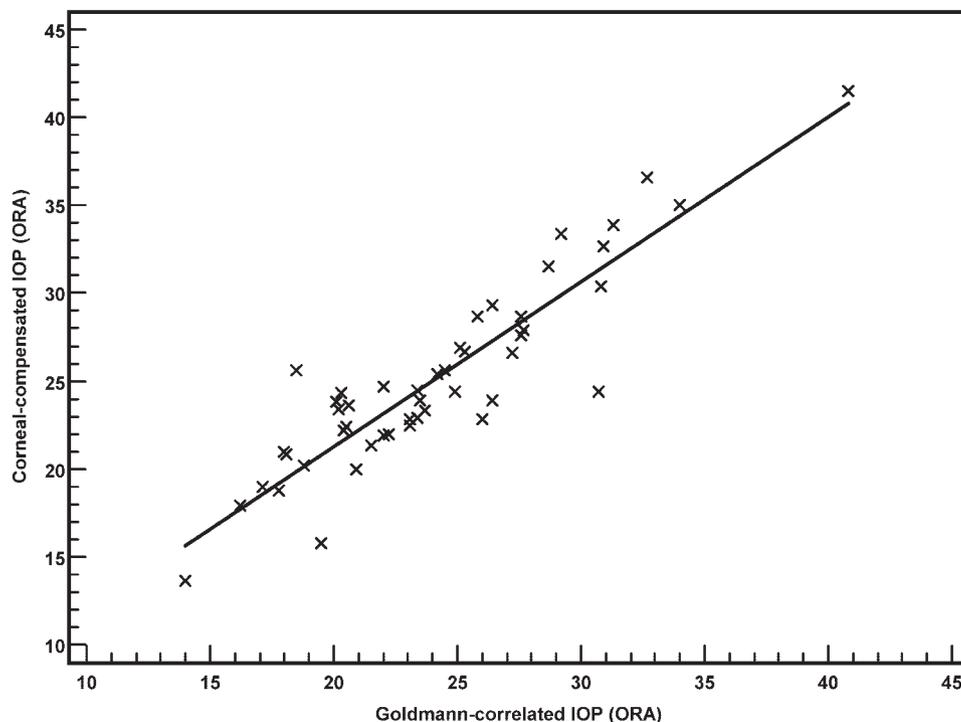
FIGURE 3. Correlation between Goldmann-correlated IOP (ORA) and corneal-compensated IOP (ORA; $r = 0.909$, $P < 0.0001$).

thought to be independent of IOP and is used by the instrument to calculate corneal-compensated IOP, the main variable provided by the ORA. In our series, corneal hysteresis effectively proved to be independent of the IOP GAT and correlated significantly with corneal-compensated IOP.

Another variable measured by the ORA that reflects the cornea's biomechanical properties is the corneal resistance factor, which indicates the overall resistance of the cornea. Our data confirm the findings of Luce[10] indicating that corneal-compensated IOP is unaffected by the corneal resistance factor, the latter being significantly correlated with central corneal thickness and IOP GAT. In other words, the thicker the cornea and/or the higher the IOP GAT, the greater the corneal resistance factor.

Both Goldmann-correlated IOP and corneal-compensated IOP significantly overestimated IOP measured with the Goldmann tonometer, with mean differences of 7.2 and 8.3 mm Hg, respectively, observed in this study. These differences are more relevant if we consider that they did not remain constant across the entire range of pressures recorded in our series, such that the discrepancy between the two tonometers becomes larger for the higher GAT-determined IOPs. This observation precludes the use of a linear correction factor to equate ORA-determined pressures with those obtained by conventional tonometry.

The ORA theoretically corrects the Goldmann-correlated IOP according to the two new factors that define the biomechanical properties of the cornea (corneal hysteresis and corneal resistance factor). In this study, we provide data that could, on the one hand, support, and on the other, contradict this presumptive correction.

Contrary to this correction, our results indicate significant correlation between the two pressure measurements provided by the ORA and central corneal thickness, along with excellent correlation between Goldmann-correlated IOP and corneal-compensated IOP ($r = 0.909$, $P < 0.0001$) and minimal differences between them (1 mm Hg), which would seem insuffi-

cient to justify an adequate correction for the wide range of corneal thicknesses used in this study.

In favor of the ORAs correction method, we found a significant correlation between the corneal-compensated IOP and corneal hysteresis that was not found for the Goldmann-correlated IOP, which would indicate a certain degree of correction of this last measure according to the corneal hysteresis to give rise to the corrected pressure. Accordingly, it seems that effectively the corneal-compensated IOP is corrected for by the corneal hysteresis, but that this correction is subtle and perhaps insufficient to compensate for the central corneal thickness effect on pressure measurements.

In our opinion, the main limitation of the ORA for its use in daily clinical practice is the considerable overestimation of IOP with respect to applanation tonometry and the fact that these differences progressively increase as the applanation pressure measurements increase. Thus, for patients with glaucoma, the real utility of the two new variables provided by the ORA (corneal hysteresis and corneal resistance factor) has yet to be established.

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