Original article

Comparison of Goldmann applanation and dynamic contour tonometry measurements: Effects of corneal morphometry


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ARTICLE INFO

Article history:
Received 3 August 2010
Accepted 15 April 2011
Available online 15 February 2012

Keywords:
Glaucoma
Dynamic contour tonometry
Goldmann applanation tonometry

ABSTRACT

Objectives: To compare intraocular pressure (IOP) measurements made by Goldmann applanation tonometry (GAT) and dynamic contour tonometry (DCT).

Methods: IOPs were measured by GAT and DCT in 63 eyes of 63 healthy subjects. A comparison was made by intraclass correlation coefficient. Passing–Bablok plot was constructed to establish the existence of systematic and/or proportional biases. Multivariate regression analysis was used to examine whether the measurements of both instruments were affected by the power of the steepest and flattest corneal axes, their orientation, age or central corneal thickness (CCT).

Results: The intra-class correlations (ICCs) were 0.57 (95% confidence interval [95% CI]: 0.29–0.74). Mean differences were 1.68 (DCT minus GAT) (95% CI: 0.92–2.44). Passing–Bablok analysis (X = DCT; Y = GAT) revealed a systematic bias (A = −14.35, 95% CI: −24.51 to [−9.14]) and a proportional bias (B = 1.74, 95% CI: 1.43–2.26). Multivariate regression analysis revealed that the DCT was independent of the corneal characteristics analyzed while GAT was biased by CCT (B = 0.042, 95% CI: 0.002–0.082).

Conclusions: While GAT was biased by corneal CCT; DCT readings were independent of corneal morphometry.

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* Please cite this article as: Sáenz-Francés F, et al. Concordancia entre la tonometría de aplanación de Goldmann y la tonometría de contorno dinámico: efectos de la morfometría corneal. Arch Soc Esp Oftalmol. 2011; 86:287–91

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Concordancia entre la tonometría de aplanación de Goldmann y la tonometría de contorno dinámico: efectos de la morfometría corneal

RESUMEN

Objetivos: Determinar la concordancia entre la presión intraocular (PIO) medida mediante tonometría de aplanación de Goldmann (TAG) y tonometría de contorno dinámico (TCD). Métodos: La PIO se midió mediante TAG y TCD en 63 ojos de 63 voluntarios sanos. La concordancia se determinó mediante coeficiente de correlación intraclase (CCI). Se empleó el método de Passing-Bablok para establecer la presencia de sesgos proporcionales y/o sistemáticos. El análisis de regresión multivariable se empleó para determinar si las diferencias estaban condicionadas por la potencia de los ejes mayor y menor de la córnea, por su orientación, por el grosor corneal central (GCC) y por la edad. Resultados: El CCI fue 0,57 (intervalo de confianza [IC] al 95%: 0,29-0,74). La diferencia media entre los dos instrumentos fue 1,68 mmHg (TCD menos TAG) (IC 95%: 0,92-2,44). El análisis de regresión multivariable mostró una correlación cercana entre la TAG y el GCC (B = 0,042 CI 95%: 0,002-0,082). Conclusiones: La TAG se mostró independiente de las características morfométricas de la córnea mientras que la TAG se afectó por el GCC.

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Introduction

Intraocular pressure (IOP) is the main risk factor for the development and progression of glaucoma. In addition, it is the only factor in which therapeutic intervention has demonstrated to improve the control of the disease. Nowadays, Goldmann applanation tonometry (GAT) constitutes the gold standard for measuring IOP, although subject to various morphometric characteristics of the cornea such as corneal central thickness (CCT), the power of the major and minor axes and the orientation thereof.2,3

In recent years IOP measuring instruments have been developed with the aim of overcoming the shortcomings of the GAT results. These include the bounce tonometer, the ocular response analyzer and the dynamic contour tonometer (DCT) or Pascal tonometer,4 which is the object of this paper.

The DCT has a tip similar to the GAT cone, equipped with a concave surface designed to adapt to the corneal surface, maintain its shape and curvature in order to cause minimum corneal distortion in contrast with the distortion caused by GAT applanation. A digital sensor inserted in the contact surface carries out transcorneal IOP measurements. In this way, theoretically the DCT measurements are independent of the corneal characteristics which affect the GAT.4

The objective of this study is to assess the match between GAT and DCT in normal subjects as well as to determine the influence of CCT, corneal curvature radius and age on the measurement of both tonometers.

Subjects, material and methods

Volunteers were recruited between workers and relatives of patients of the San Carlos Clinical University Hospital of Madrid, Spain. The inclusion criteria comprised the ability to sign an informed consent, normal ophthalmological exploration results including IOP below 22 mmHg and the absence of systemic diseases. In all patients, the eye to be analyzed was decided by automatic randomization (www.randomization.com).

The study protocol was approved by the Ethical Committee of the San Carlos University Clinical Hospital of Madrid. All the patients signed an informed consent included in said protocol.

All the patients submitted to a full ophthalmological assessment, comprising best corrected visual acuity (Marte-sian logarithmic scale), anterior segment biomicroscopy, gonioscopy, IOP measurements with Goldmann applanation tonometer and dynamic contour tonometer, funduscopy, Octopus TOP-G1X automated perimetry.

The match was determined with the intraclass correlation coefficient (ICC). The Passing–Bablok method was utilized to establish the presence of proportional and/or systematic bias. Two multivariate regression analyses were utilized, one for each tonometer, to determine whether the measurements of both were influenced by the power of the major and minor axes of the cornea, by the orientation, the central corneal thickness (CCT) and by age. In both models, the predictive values were the power of the major cornea axis, the minor cornea axis, the orientation of the minor axis and the age of patients. In order to choose the best regression equation, adjusted $R^2$ was utilized as criterion.

All the statistical analyses were made utilizing the SPSS software version 15.0 for Windows (SPSS Inc., Chicago, IL, USA). The Kolmogorov–Smirnov test was utilized to certify the normality of quantitative data distribution. The required statistical significance level was set at $p<0.05$. 
Results

Sixty-three healthy volunteers were included in this study. It was randomly decided (www.randomization.com) to analyze the left eye of each patient. Of the 63 volunteers, 31 were males and 32 females, all Caucasian. The characteristics of the analyzed quantitative variables are summarized in Table 1; the orientation of the minor cornea axis is shown in Table 2; the IOP distribution measured with both tonometers can be seen in Fig. 1 and the CCT distribution is shown in Fig. 2.

The ICC (absolute match) was of 0.57 (confidence interval [CI] at 95%: 0.29–0.74). The difference between the mean measurements of both instruments (t-test for paired data) was of 1.68 mmHg (DCT minus GAT) (CI 95%: 0.92–2.44) (Fig. 1). The Passing–Bablok regression straight line analysis (Fig. 3) was the result of comparing the DCT measurements (abscissa axis) with the GAT measurements (coordinates axis) revealed the presence of a systematic bias ($A = -14.35$. CI 95%: $-24.51$ to $-9.14$) and a proportional ($B = 1.74$. CI 95%: $1.43–2.26$), therefore being the lesion of this straight line: $GAT = -14.35 + 1.74 \times DCT$.

Multivariate regression analysis allowed to determine the absence of interaction and of confusion phenomena between the predictive variables. In addition, on the basis of the adjusted $R^2$ determination coefficient, it allowed us to determine that the best regression equation to predict the IOP did not include any predictive variable (independent of the corneal characteristics) for DCT and only included CCT in the case of GAT (adjusted $R^2 = 0.11$; $p = 0.04$; $B = 0.042$ CI 95%: 0.002–0.082).

Discussion

Even though at the present time GAT is the gold standard for assessing IOP, it is known that certain anatomic or

Table 1 – Statistics describing the analyzed variables.

<table>
<thead>
<tr>
<th>Variable description</th>
<th>Mean</th>
<th>Average</th>
<th>Std. dev.</th>
<th>25</th>
<th>50</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>63.52</td>
<td>68.00</td>
<td>16.93</td>
<td>52.00</td>
<td>68.00</td>
<td>78.00</td>
</tr>
<tr>
<td>Major axis potential</td>
<td>44.65</td>
<td>44.60</td>
<td>1.73</td>
<td>43.70</td>
<td>44.60</td>
<td>45.70</td>
</tr>
<tr>
<td>Minor axis potential</td>
<td>43.17</td>
<td>43.70</td>
<td>3.80</td>
<td>42.70</td>
<td>43.70</td>
<td>44.70</td>
</tr>
<tr>
<td>DCT IOP</td>
<td>17.90</td>
<td>18.00</td>
<td>2.70</td>
<td>15.80</td>
<td>18.00</td>
<td>19.70</td>
</tr>
<tr>
<td>GAT IOP</td>
<td>16.22</td>
<td>16.00</td>
<td>4.14</td>
<td>14.00</td>
<td>16.00</td>
<td>18.00</td>
</tr>
<tr>
<td>CCT</td>
<td>555.08</td>
<td>560.00</td>
<td>31.09</td>
<td>531.00</td>
<td>560.00</td>
<td>575.00</td>
</tr>
</tbody>
</table>

CCT: central corneal thickness; IOP: intraocular pressure; GAT: Goldmann applanation tonometry; DCT: dynamic contour tonometry.

Table 2 – Orientation of the minor corneal axis.

<table>
<thead>
<tr>
<th>Orientation of the minor cornea axis</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc sector 0–30°</td>
<td>14</td>
<td>22.2</td>
</tr>
<tr>
<td>Arc sector 30–60°</td>
<td>6</td>
<td>9.5</td>
</tr>
<tr>
<td>Arc sector 60–90°</td>
<td>11</td>
<td>17.5</td>
</tr>
<tr>
<td>Arc sector 90–120°</td>
<td>8</td>
<td>12.7</td>
</tr>
<tr>
<td>Arc sector 120–150°</td>
<td>7</td>
<td>11.1</td>
</tr>
<tr>
<td>Arc sector 150–180°</td>
<td>17</td>
<td>27.0</td>
</tr>
<tr>
<td>Total</td>
<td>63</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Fig. 1 – Box diagrams showing the distribution of intraocular pressure measured with dynamic contour tonometry and Goldmann applanation tonometry.

Fig. 2 – Box diagrams showing central corneal thickness distribution.
morphometric characteristics such as CCT or corneal curvature can influence its measurements. A number of studies have evidenced the limitations of GAT, with CCT being the main factor influencing its measurements.²⁻⁵ The importance of pachymetry in glaucoma was emphasized in the Ocular Hypertension Glaucoma Study (OHTS), which demonstrated that CCT was a predictive factor for the conversion of ocular hypertension (OHT) into glaucoma.⁶⁻⁹ This fact, together with the CCT differences found between ocular hypertensive corneas and those of patients diagnosed with normotensive glaucoma, as well as the inefficiency of nomograms developed for correcting the effect of pachymetry in TAG measurements,¹⁰⁻¹² have determined the need of seeking new tonometry systems more independent of CCT and other corneal morphometric parameters.

DCT has been broadly analyzed in various studies, which demonstrated DCT is a highly reproducible tonometer.¹³⁻¹⁴ The relationship of DCT with GAT has also been extensively studied. Accordingly, in contrast with our results, Realin et al.¹⁵ compared GAT and DCT measurements in normal and glaucomatous populations, finding in the former a weak correlation between GAT and CCT but independently of DCT. In glaucomatous patients, these authors did not find a relationship between the GAT measurements and CCT, although they did find a weak reverse association between DCT and pachymetry. Lanza et al.¹⁶ found that the differences between the measurements of both instruments were affected by CCT but not by the corneal radii. In a sample of normal subjects, Jordao et al.¹⁷ found a strong correlation between CCT and GAT and, in contrast with our findings, a weak correlation between DCT and CCT. Surprisingly, Halkiadakis et al.¹⁸ did not find any correlation between CCT with GAT and DCT in a population of glaucomatous and ocular hypertensive patients. Hamilton et al.¹⁹ found a weak correlation between the differences between GAT and DCT with corneal thickness changes derived from secondary edema due to the use of contact lenses (the CCT variations in relation to the use of contact lenses exhibited a mean value of 48.3 μm SD 14.4 μm). Milla et al.²⁰ found that the optimum match (ICC of 0.54) between both instruments occurred with CCT between 540 and 545 μm but diminished drastically beyond said range of values. Even though Cerruti et al.²¹ matched our results, they did not find a correlation between DCT and CCT; however, they did observe that the measurements of this instruments were influenced by corneal curvature. In contradiction with these findings as well as with our observations, Grieshaber et al.²² observed a similar influence of CCT on GAT and DCT.

From the above it can be deduced that there is no consensus in scientific literature about the dependency of DCT vis-à-vis CCT and keratometry; moreover, there is no absolute agreement about the relationship of GAT vis-à-vis said parameters. However, there is a general consensus on the fact that DCT tends to overestimate IOP vis-à-vis TAG,⁴⁻¹³⁻²² of fact verified in this study.

Our results in relation to the degree of agreement between both instruments match those found in the literature. In our study, it was considered of interest to construct a multivariate regression model which includes, in addition to age and central corneal thickness, keratometry-related variables. With this model it was possible to establish the absence of interaction and confusion effect between the analyzed predictive variables. In addition, we found complete independence of DCT vis-à-vis CCT, keratometry powers, the orientation thereof and age while we observed dependency of the GAT measurements on the CCT values. This suggests that DCT performs more independently of the corneal characteristics than GAT and accordingly the former may be adequate as a new gold standard. If this is assumed, it would be necessary to change the IOP paradigm and to redefine the threshold between normality and OHT because the overestimation of the new tonometry system vis-à-vis the current reference method would become obvious.

**Funding**

Carlos III Health Institute, “Cooperative Research Thematic Network. Project RD07/0062: Ocular pathology of aging, visual quality and quality of life”.

**Conflict of interest**

The authors have no conflict of interests to declare.

**REFERENCES**