Comparison of ICare, dynamic contour tonometer, and ocular response analyzer with Goldmann applanation tonometer in glaucoma

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PURPOSE. To compare the intraocular pressure (IOP) readings taken by ICare, Pascal dynamic contour tonometer (DCT), and ocular response analyzer (ORA) with those taken by Goldmann applanation tonometer (GAT). We sought to evaluate the influence of central corneal thickness (CCT) on IOP measurements and to compare patients’ preferences for the four tonometers.

METHODS. In this prospective study, 93 eyes from 93 patients were examined. Patients were randomly divided into 4 groups to vary the order in which the tonometers were applied. CCT was measured with an ultrasound pachymeter.

RESULTS. The average CCT was 558±47.4 µm. The mean ± standard deviation IOP for GAT, ICare, DCT, and ORA (Goldmann-correlated IOP) (ORAg) were 15.1±4.8, 15.7±5.7, 18.3±5.1, and 18.3±6.6 mmHg, respectively. There was no significant difference between the mean IOP obtained with GAT and ICare (p=0.14). There was also no difference in IOP levels between the mean IOP obtained with DCT and ORA (p=0.26). There was no correlation between IOP measurements and CCT for the four instruments. Bland-Altman graphs showed disagreement between the measurements taken by GAT and the other instruments. There was no significant difference in patients’ preference among the 4 instruments (p=0.48).

CONCLUSIONS. IOP readings from ICare were consistent with those from GAT, whereas DCT readings correspond well to ORAg measurements. DCT and ORA readings both overestimated the GAT readings. There was no correlation between the IOP measurements and the CCT for the 4 instruments. There was no significant difference in patients’ preference among the 4 instruments (Eur J Ophthalmol 2009; 19: 1).

KEY WORDS. Dynamic contour tonometer, Glaucoma, ICare tonometer, Intraocular pressure, Ocular response analyzer

INTRODUCTION

Glaucoma is a major cause of blindness in Western countries (1). Intraocular pressure (IOP) is the most important risk factor for developing glaucoma. The major risk factors for progression of glaucoma include increased IOP levels and possibly increased IOP fluctuation (2). Tonometry remains the cornerstone of clinical management and follow-up of glaucoma. Goldmann applanation tonometry (GAT) has been the gold standard for tonometry since the mid-1950s (3). The effect of central corneal thickness (CCT) on tonometric measurements was first identified by Goldmann (4). The findings have prompted the development of numerous formulas and nomograms to compensate for the effect of corneal thickness on GAT, but none of these methods has been entirely satisfactory (5, 6). Nevertheless, several new tonometers have been developed from recent efforts to mitigate some of the limitations of conventional tonometry. These alternative methods include new electronic applanation tonometers such as the Tono-Pen and the Proton (7, 8), noncontact tonometers (9), rebound tonometry (ICare) (10,
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In order to ensure the accuracy of these new tonometry methods, a new standard was established by the International Standard Organization (ISO). This ISO standard, ISO 8612:2001 (International Standard: Ophthalmic Instruments–Tonometers, 1st ed. Geneva, Switzerland: ISO Copyright Office; 2001: Reference Number: ISO 8612: 2001 [E]), together with ISO 15004:1997, specifies the minimum requirements for tonometers intended for routine clinical use. The ISO standard requires accuracy of the tonometer to be better than ±5 mmHg for ±1.96 standard deviation (SD) compared to GAT as the reference method (14). The percentage of IOP readings within ±3 mmHg of GAT, which would be clinically relevant, were calculated. Therefore, the aims of this study were 1) to compare the IOP readings taken with the ICare, Pascal DCT, and ORA with the IOP readings taken with the GAT in patients with glaucoma, 2) to evaluate the effect of CCT on IOP measurements, and 3) to compare the patients’ preference for each of the four tonometers.

MATERIALS AND METHODS

This prospective observational study included 92 patients, 79 of whom have primary open-angle glaucoma, 6 secondary glaucoma, 5 chronic angle-closure glaucoma, and 2 ocular hypertension. All subjects were examined at the glaucoma unit of our university hospital. The research was conducted according to the guidelines of the Tenets of the Declaration of Helsinki. Institutional Review Board approval was also obtained for the study. All patients gave written informed consent before participat-
ing in the study. All patients underwent an ophthalmic examination that included measurements of best-corrected visual acuity, refractive error, and corneal curvature (mean K). Slit-lamp examination and fundus biomicroscopy with a 90-diopter lens were also performed. The exclusion criteria included patients younger than 18 years, astigmatism higher than 3 D, presence of corneal diseases, inability to perform Goldmann tonometry, history of corneal surgery, ocular inflammation, and contact lens wear. Patients with glaucoma were defined as having characteristic optic disc damage with concomitant visual field loss. To make a diagnosis of primary open-angle glaucoma, an IOP of 21 mmHg or greater was required. All measurements from ICare, DCT, and ORA were taken by the same examiner, who was masked to other measurement values. The GAT was measured by another experienced examiner, who was masked to measurements taken with the other tonometers. Patients were randomly divided into four groups according to a randomized order in which the tonometers were applied on the patients (randomization list obtained from www.randomization.com). Both eyes were measured, but only the right eye was included in the analysis.

Rebound tonometry was performed by using the new induction-based impact tonometer ICare (Tiolat Oy, Helsinki, Finland), which has been thoroughly described elsewhere (15). Briefly, the tonometer is a small (250 g), hand-held device made up of a single-use probe and a solenoid. Electronic components that allow for probe movement are initiated by the solenoid coil and measured by the sensing coil. A small probe is pushed against the cornea to make contact and creates a rebound motion with the eye. The movement of the probe induces a small induction current. This induction current enables the impact duration. To take IOP measurements, the device is positioned near the patient’s eye with the forehead being used as a base support. The tip of the probe is maintained at a distance of approximately 5 to 8 mm from the cornea. Local anesthesia is not required. Since the probes are disposable, the risk of microbial contamination is avoided. The software is pre-programmed for 6 measurements: the highest and the lowest readings are automatically discarded, and the average IOP value is calculated from the remaining readings. After the sixth measurement, the letter P appears on the display followed by the mean IOP reading. The ICare tonometer uses different symbols after the letter P to indicate the type of measurements taken. ICare readings that were not considered and thus repeated had one of the following: 1) P– (line down), indicating that the SD of different measurements is slightly higher than normal but the effect on the result is unlikely to be relevant; 2) P– (line in the middle), indicating that the SD of different measurements is much higher than normal but the effect on the result is usually not relevant (in this case a new measurement is recommended if the IOP is more than 19 mmHg); 3) a blinking P, indicating that the SD is greater than normal; or 4) P– (line up), indicating that the SD of different measurements is high. For this study, any measurement that showed any type of error sign was discarded. The display showed the average IOP and a measure of the SD. There were four consecutive
measurements taken, and the display showed the average IOP, which was what was recorded. The Pascal DCT is supplied by Swiss Microtechnology AG, Port, Switzerland. The physics and the manometric accuracy of this device have been described elsewhere (16, 17). Briefly, the Pascal tonometer is a slit-lamp–mounted device for contact tonometry that involves corneal contact without applanation. As a result, DCT minimizes corneal deformation (18, 19). A contour-matched pressure-sensing tip is applied to the corneal surface with a small constant force to allow for direct transcorneal IOP measurements. The so-called contour-matched tonometer tip has a concave surface that allows the cornea to assume its natural shape when the pressure on both sides of the cornea is equal and the distortion of the cornea is minimal (12). Putting a miniaturized pressure sensor close to the contour of the cornea is thought to be able to measure diastolic IOP directly. Ocular pulse amplitude (OPA) and the quality of data (Q1–Q5) are reported on a digital display. Two readings were obtained and only those with quality of Q1, Q2, and Q3 were recorded.

The ORA is supplied by Reichert Inc., Depew, NY. The ORA is able to measure the biomechanical properties of the cornea and to use this information to adjust IOP measurements based on these biomechanical 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 to its normal configuration and passes through a second applanation state. An electro-optical system monitors the deformation of the cornea throughout the entire process. Two independent values obtained for the inward and outward applanation events are delayed, which results in two different pressures. The averages of these two pressures provide a reproducible Goldmann-correlated IOP, and the difference between the two pressures is called corneal hysteresis (13). Corneal-compensated IOP (ORAcc) is a pressure measurement that utilizes the new information provided by the corneal hysteresis measurement to provide an IOP that is less affected by the cornea. The corneal resistance factor, also derived from corneal hysteresis, is an indicator of the overall resistance of the cornea, which, according to previous data, seemed to be related to CCT. GAT-determined IOP but not corneal-compensated IOP (Luce D, Taylor D. Reichert Ocular Response Analyzer measures corneal biomechanical properties and IOP: provides new indications for corneal specialties and glaucoma management. Ocular Response Analyzer White Paper. Available at: http://www.ocular-responseanalyzer.com/downloads.html (20). [QUERY: Please complete the preceding sentence.]. Two readings were obtained, and the four variables were recorded.

For GAT (Carl Zeiss Meditec AG, Jena, Germany), two readings were taken by the same investigator and the mean was calculated. If the difference between the two measurements was >2 mmHg, a third measurement was taken, and the median was recorded. The maximum GAT was defined as the maximum IOP measured with GAT in a patient without glaucoma medication.

The CCT was measured last using an ultrasound pachymeter (Pachmate, DGH). The pachymeter probe was placed on the center of the cornea, and a mean of 10 readings was calculated for each eye. In order to minimize the effect of diurnal variations in IOP, all measurements were taken between 8:30 AM and 12:00 AM.

Pain and discomfort were scaled from 0 to 5 (0 = none, 1–2 = slight, 3–4 = moderate, 5 = severe) for the four tonometers, and patients were asked which tonometer they preferred.

The mean IOP values measured with ICare, DCT, ORA, and GAT as well as the mean CCT were considered in the analysis. The GAT measurements were used as gold standard. All analyses have been performed on data gathered from the right eye. A multivariate regression model was used to evaluate the differences in IOP obtained with various instruments. This model has been extended with CCT used as a predictor, thereby ensuring that the effect of CCT was instrument-specific (hence, the interaction between CCT and instrument is verified). A square root transformation has been used for IOP to obtain a symmetric distribution of the residuals. To avoid a loss of all information on a particular subject, the SAS procedure PROC MIXED was used. Bland-Altman plots were used to evaluate the agreement between GAT and the three other tonometers. Spearman correlations were used to explore associations between continuous variables. A Friedman test was used to compare preference scores among the instruments. A one-sample chi-square test was used to compare the forced preference. The alpha level was set at 5%. All p values were two-sided. All analyses were performed using the statistical package SAS (version 9.1).
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**DISCUSSION**

Using Bland-Altman graphs, the current study showed poor agreement among the ICare, DCT, ORA, and GAT. There was a significant difference in IOP between all tonometers, including ICare, even though the average IOP was not different between ICare and GAT. With ICare, we found 95% limits of agreement ranging from +7.1 to –5.9 mmHg, which was close to the standards set by the ISO. Pakrou et al (21) also found a close agreement between ICare and GAT. Fur-

**RESULTS**

The mean age of the study subjects was 62±15 years (range, 18–91 years). Of the 92 patients studied, 32 (34.8%) were male, and 60 (65.2%) were female. The average CCT was 557±47 µm (range, 448–773; 95% CI, 528–588 µm).

Table I displays the minimum/maximum, the mean, and the standard deviation of IOP measurements obtained with the four instruments. There was a significant difference in IOP among the five methods (p<0.0001). There was also a significant difference in IOP between GAT and ICare, as well as DCT, ORAg, and ORAcc (p=0.026). On average, there was an IOP overestimation of more than 3.1 mmHg by DCT and ORAg and of more than 3.6 mmHg by ORAcc. The absolute differences between the corresponding measurements (GAT and the other measurements, respectively) are shown in Table II.

Bland-Altman plots showed disagreement between the measurements taken by GAT and the three other instruments (Fig. 1).

Table II shows the percentage of measurements within ±3 mmHg of GAT.

Table III displays the percentage of measurements within ±3 mmHg of GAT.

Table IV summarizes the correlation between IOP and CCT.

**TABLE I - IOP MEASUREMENTS**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Mean IOP (mmHg)</th>
<th>SD</th>
<th>Range (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAT</td>
<td>15.1</td>
<td>4.8</td>
<td>6–34</td>
</tr>
<tr>
<td>ICare</td>
<td>15.7</td>
<td>5.7</td>
<td>4.5–35</td>
</tr>
<tr>
<td>DCT</td>
<td>18.2</td>
<td>5.1</td>
<td>5–34</td>
</tr>
<tr>
<td>ORAg</td>
<td>18.3</td>
<td>6.6</td>
<td>6.6–37.5</td>
</tr>
<tr>
<td>ORAcc</td>
<td>18.7</td>
<td>6.3</td>
<td>6.3–38.8</td>
</tr>
</tbody>
</table>

**TABLE II - DIFFERENCES BETWEEN GAT AND ICARE, DCT, ORAG, AND ORACC**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>ΔIOP (mmHg)</th>
<th>SD</th>
<th>Range (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICare</td>
<td>2.5</td>
<td>2.3</td>
<td>0.0–10.5</td>
</tr>
<tr>
<td>DCT</td>
<td>3.6</td>
<td>2.5</td>
<td>0.0–9.6</td>
</tr>
<tr>
<td>ORAg</td>
<td>4.0</td>
<td>3.0</td>
<td>0.2–13.5</td>
</tr>
<tr>
<td>ORAcc</td>
<td>4.4</td>
<td>3.1</td>
<td>0.0–14.8</td>
</tr>
</tbody>
</table>

**TABLE III - PERCENTAGE OF MEASUREMENTS WITHIN ±3 MMHG OF GAT**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICare</td>
<td>66.3</td>
</tr>
<tr>
<td>DCT</td>
<td>44.1</td>
</tr>
<tr>
<td>ORAg</td>
<td>41.8</td>
</tr>
<tr>
<td>ORAcc</td>
<td>35.2</td>
</tr>
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</table>

**TABLE IV - CORRELATION BETWEEN IOP AND CCT**

<table>
<thead>
<tr>
<th></th>
<th>Spearman correlation coefficients</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAT</td>
<td>0.10</td>
<td>0.34</td>
</tr>
<tr>
<td>GATmax</td>
<td>0.14</td>
<td>0.20</td>
</tr>
<tr>
<td>ICare</td>
<td>0.18</td>
<td>0.09</td>
</tr>
<tr>
<td>DCT</td>
<td>0.07</td>
<td>0.57</td>
</tr>
<tr>
<td>ORAg</td>
<td>0.20</td>
<td>0.07</td>
</tr>
<tr>
<td>ORAcc</td>
<td>0.07</td>
<td>0.51</td>
</tr>
</tbody>
</table>

IOP = intraocular pressure; CCT = central corneal thickness; GAT = Goldmann applanation tonometry; DCT = Pascal dynamic contour tonometry; ORAg = Goldmann-corrected ocular response analyzer; ORAcc = cornea-compensated ocular response analyzer.

IOP = intraocular pressure; SD = standard deviation; GAT = Goldmann applanation tonometry; DCT = Pascal dynamic contour tonometry; ORAg = Goldmann-corrected ocular response analyzer; ORAcc = cornea-compensated ocular response analyzer.
have many more patients diagnosed with ocular hypertension and possibly overtreated. Therefore, it is important to collect a sufficient amount of robust data on the correlation between the IOP measured with DCT/ORA and manometric results before accepting a new gold standard.

The main advantage of ICare is that measurements can be taken without using topical anesthetics. Therefore, ICare may be useful in children. The results of the study by Sahin et al (24) showed that ICare is highly reproducible and is very comfortable for children. Self-measurement of IOP with this device is also possible. Furthermore, it is a low-cost, easy-to-use tonometer that allows measurements to be made in people with special needs such as persons confined to a bed or in a wheelchair.

Moreover, the percentage of IOP readings within ±3 mmHg of GAT, which would be clinically relevant, was highest in the ICare group (66.3%). This percentage was lower than the 80% (22) reported in a normal population and also lower than the 74.1% (23) reported in patients with glaucoma. There was also a significant difference in IOP between GAT and ICare, on one hand, and DCT, ORAg, and ORAcc, on the other (p=0.026). On average, there was an overestimation of IOP by more than 3.1 mmHg with DCT and ORAg, and by more than 3.6 mmHg with ORAcc. This was also found in other studies, with even higher overestimations found by Martinez de la Casa (7.2 and 8.3 mmHg between ORAg, ORAcc, and GAT, respectively) (20). If DCT and ORA were to be used today as the gold standard, we would
The effect of CCT on IOP measurements has been thoroughly studied. However, there is no satisfactory formula or nomogram to compensate for the effect of corneal thickness on GAT (5-6). Aside from CCT, which has been recognized as a significant risk factor for the development of glaucoma (based on the Ocular Hypertension Treatment Study [25]), the rigidity of corneal biomechanical architecture (26), physiologic behaviors of the eye such as corneal hysteresis (27), and modulus of elasticity (28) could also influence IOP measurements. Therefore, these should also be taken into account. In the last few years, several new instruments have been designed to overcome the limitations of GAT. These new instruments (DCT and ORA) have been claimed to measure IOP independently of potential corneal effects (18-20, 26, 29-30). However, some studies showed a correlation between DCT and CCT (31-32). ICare was correlated with CCT (23, 33-36) in some studies, but not in others (37).

In the current study, we compared ICare, DCT, ORA, and GAT in 92 eyes with nonpathologic corneas and assessed the influence of CCT on measurements taken by these instruments. We found no correlation between CCT and IOP taken with any of the four instruments. Even with GATmax, there was no correlation found with CCT. The finding that GAT did not correlate with CCT was published by several groups with a larger patient sample size (13, 30). It may be that the correlation between GAT and CCT depends on the population studied and that the correlation previously found in the normal population was less obvious in patients with glaucoma.

In our study, there was no significant difference in the patients’ preference for the four instruments (p=0.48). No patient reported more than moderate discomfort with any of the procedures. This result was unexpected. We might have had a different result if we performed the study in a normal population because patients with glaucoma are used to eyedrop instillations and undergoing several examinations. In summary, this study illustrates that in patients with glaucoma IOP readings from ICare, despite some variability, were in accordance with those from GAT, whereas DCT readings corresponded well to ORA measurements. There was an overestimation of IOP by more than 3.1 mmHg with DCT and ORAg, and by more than 3.6 with ORAcc when compared to GAT. The levels of agreement among the ICare, DCT, ORA, and GAT were poor. None of the four methods was significantly influenced by CCT in this population of patients with glaucoma.

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REFERENCES