Clinical Comparison of the Icare Tonometer and Goldmann Applanation Tonometry

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Purpose: To compare a new method of intraocular pressure (IOP) measurement, using the Icare tonometer, with Goldmann applanation tonometry (GAT).

Patients and Methods: Two observers obtained IOP readings in 292 eyes (143 right and 149 left) of 153 subjects, using the Icare without topical anesthetic. A GAT reading was subsequently obtained by a consultant ophthalmologist, without the knowledge of the Icare readings. Central corneal thickness (CCT) was obtained on all eyes with ultrasound pachymetry. Patient comfort after IOP measurement was assessed in a consecutive subset of patients.

Results: The intraclass correlation coefficient between the two modalities of IOP measurement was \( r = 0.95 \) for the right and \( r = 0.93 \) for the left eye. The mean difference (Icare – GAT) between the IOP measured by the two methods was 0.4 mm Hg in the right eye (SD 3.0, 95% confidence interval –5.5 to 6.3), and 0.8 mm Hg in the left eye (SD 3.0, confidence interval –7.3 to 6.2). GAT measurements did not vary with CCT [correlation coefficient = 0.09 \((p = 0.25)\) right and 0.14 \((p = 0.09)\) left eyes]. However, IOP measured with Icare tonometry increased with increasing CCT [correlation coefficient = 0.16 \((p = 0.05)\) right and 0.21 \((p = 0.01)\) left eyes]. For every 100-μm increase in CCT, the difference (Icare – GAT) increased by 1 mm Hg. Of the 38 consecutive patients surveyed, 28 (73.7%) rated the Icare more comfortable than GAT, with only 2 (5.3%) rating it less comfortable \((p < 0.001)\).

Conclusions: There is good correlation between the two methods of IOP measurement; even at extremes of IOP, the Icare instrument was easy to use and recorded rapid and consistent readings with minimal training. It seems to be more comfortable than GAT and obviates the need for topical anesthesia.

Key Words: intraocular pressure, impact tonometer, rebound tonometer, Icare tonometer, Goldmann applanation tonometer

Accurate and consistent measurement of intraocular pressure (IOP) remains a key factor in the diagnosis and management of glaucoma. Despite numerous portable devices available, the majority of ophthalmologists rely solely on the Goldmann applanation tonometry (GAT) as the gold standard method of obtaining IOP, using it to guide decisions regarding patient management. However, accurate use of this instrument requires significant training, and inaccuracies are common in the hands of inexperienced examiners. Furthermore, GAT requires a slit lamp microscope, and the use of topical anesthetic with fluorescein dye. Topical anesthetic is unpleasant for the majority of patients due to stinging, and reflex blepharospasm makes accurate measurements difficult to obtain in a subset of patients.

Given the increasing time restraints placed upon many ophthalmologists, IOP measuring devices, which are accurate, portable, and can be easily used by various operators with minimal interoperator variability, are appealing. In situations where rapid assessment or screening is desirable, such as in remote community settings, the use of the GAT is impractical. Furthermore, in circumstances (such as within the emergency department) in which identification of either very low or high pressures can have significant management implications, accessibility to a simple reliable instrument is valuable.

The Icare tonometer (TA01; Tiolat Oy, Helsinki, Finland) is a recently developed hand-held portable tonometer, which relies on the induction rebound or impact principle. It is able to rapidly obtain IOP measurements without the need for topical anesthesia. Rebound or impact tonometry is based on making a moving object collide with an eye while monitoring the motion parameters of the colliding object. At low IOP, the deceleration of the probe is less than that observed at high IOP. Consequently, the higher the IOP, the shorter the duration of the impact. IOP is calculated from the measurement of impact duration and/or maximum deceleration. Use of the device is simple and can be rapidly taught. It may have a role in the setting of community screening, or in situations where GAT is difficult or not practical provided it can be shown to be accurate.

The purpose of this study was to compare the accuracy of IOP measurement by Icare impact tonometry with that of GAT in an ophthalmology outpatient setting of a teaching hospital. The subjective comfort of both
methods of applanation was also assessed in a subset of patients to determine patient acceptability.

**MATERIALS AND METHODS**

Two hundred ninety-two eyes (143 right and 149 left) from 153 patients aged 18 to 86 years (mean 59.6, SD 21.2 y) were selected from the ophthalmology clinic at the Flinders Medical Centre, a South Australian teaching hospital. Participants included patients with and without glaucoma, and some patients with suspected extreme values of IOP were selectively included to assess Icare performance across the full range of IOPs. Informed consent was obtained from each participant. Patients with corneal pathology (eg, corneal epithelial defects, corneal stromal scarring, and corneal edema) were excluded.

Icare measurements were obtained by 1 of 2 ophthalmology residents (N.P., T.G.). To obtain a measurement, single-use probes were fitted into the apparatus. Subjects were instructed to fixate on a distant target while the probe of the Icare was held at a distance of 4 to 8 mm, and perpendicular to the central cornea. The measurement was initiated by the operator, with the probe being propelled against the central cornea.

Individual measurements are displayed digitally in mm Hg. Six rapidly consecutive measurements are obtained in each eye, yielding a mean reading with a SD on the LCD screen. As per manufacturer instructions, a mean reading displayed with a static P and no error bars (P) indicates a low SD of the 6 measurements. A mean with a flashing P and error bar indicates a less than optimal SD. An inferior error bar (P−) implies that the different measurements have a SD slightly larger than normal (judged acceptable according to the manufacturer); a mean with a middle error bar (P−) indicates a SD clearly greater than normal (a new measurement is recommended); and a mean with a superior error bar (P+) signifies that the SD is too large and a new measurement is required.

In our study, consecutive measurements were obtained from each eye until either a mean reading displaying a P with no bar (P) was acquired, or a total of 3 readings were performed, regardless of SD. The total number of attempts needed to achieve a P reading was recorded for each patient.

After the instillation of Fluorescein-Lignocaine solution (Minims; Chauvin Pharmaceuticals Ltd, Kingston-Upon-Thames, England), GAT (Haag Streit AG, Bern, Switzerland) was performed by 1 of 2 consultant ophthalmologists (J.C., R.M.), who were blinded to the IOP measurement obtained by the Icare. Central corneal thickness (CCT) measurements were obtained using a Tomey pachymeter SP-2000 (Tomey Corporation, Nagoya, Japan). A total of 5 measurements were obtained and the mean value used for further analysis.

Immediately after the completion of IOP evaluation, a subset of 38 consecutive patients were asked to indicate which of the 2 methods they found more comfortable. These subjects represented the last 38 participants in the study. Subjects were required to indicate whether they found:

1. The Icare much more comfortable (score 1)
2. The Icare more comfortable (score 2)
3. No difference between the 2 methods (score 3)
4. The Goldmann tonometer more comfortable (score 4)
5. The Goldmann tonometer much more comfortable (score 5)

A mean score was calculated based on the responses.

Statistical Analysis System 6.12 (SAS Institute Inc, Cary, NC) was used for statistical analysis including descriptive statistics, Student t test, paired t test, Wilcoxon signed rank test, intraclass correlation coefficient, and simple linear regression for univariate and multivariate analyses. In linear regressions, IOP and CCT were used as continuous variables. Intraclass correlation coefficient was used to assess the correlation between the Icare and Goldmann tonometry measurements. Paired differences with limits of agreement were calculated to evaluate the concordance of measurements obtained with the 2 instruments.

The difference in IOP measured with the Icare and GAT was plotted against the IOP measured with GAT. This is a slight modification of the Bland-Altman plot. A P value of < 0.05 was considered statistically significant.

**RESULTS**

There were 153 patients in the sample, 81 males and 72 females (143 right eyes and 149 left eyes). The average age of patients was 60 years (SD 21 y, range 18 to 86 y). In 286/292 eyes (97.9%), an Icare reading with no error bar (P) was achieved within 3 attempts at IOP measurement. In these subjects, the mean number of measurements required to reach a no error bar reading was 1.36 (SD 0.6). In all eyes, an acceptable mean reading showing either P or P− was obtained within 3 attempts.

Mean IOP measured using GAT was 18.2 mm Hg (SD 8.7 mm Hg) and using Icare tonometry 17.6 mm Hg (SD 8.7 mm Hg) (Table 1). There was a high degree of correlation between the 2 methods with an intraclass correlation coefficient of r = 0.95 for right eyes and r = 0.93 for left eyes. The mean CCT was 537.5 μm (SD 43.9).

The mean of the difference (Icare − GAT) in IOP measurements was +0.4 mm Hg in right eyes [SD 3.0, 95% confidence interval (CI) − 5.5 to +6.3] and +0.8 mm Hg in left eyes (SD 3.0, CI − 4.7 to +6.2).

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<tr>
<th>Table 1. IOP Measured by GAT and Icare Tonometer, and CCT</th>
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<td><strong>IOP (mm Hg)</strong></td>
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<td>CCT (μm)</td>
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SD indicates standard deviation.
and was not significantly different between eyes \( (t = 1.68; \ P = 0.095) \) (Figs. 1A, B). This difference varied as GAT IOP increased. There was a significant difference between mean Icare/C0 GAT for GAT IOPs < 21 mm Hg compared with those when GAT IOP was ≥ 21 mm Hg (Table 2).

The Icare—GAT difference did not change significantly throughout the study, suggesting no significant learning effect associated with the Icare. Compared with the first third of subjects, the last third showed a similar mean Icare—GAT for GAT IOPs < 21 mm Hg compared with those when GAT IOP was ≥ 21 mm Hg (Table 2).

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The 95% limits of agreement for the Icare versus GAT were approximately between 5.0 and +6.0 mm Hg (90% CI of ±4.8 mm Hg) which is comparable with those reported for repeat measurements with GAT. A repeat test with GAT was shown to have a 90% CI of ±4.5 mm Hg for a single reading and ±3 mm Hg for the average of 2 readings.\(^6\)

### DISCUSSION

The Icare tonometer has been marketed as a highly reliable and accurate portable tonometer, which uses a novel mechanism to obtain an IOP measurement. However, there have not been many studies to critically appraise its reliability in the clinical setting. Our aim was to compare the IOP measurements obtained by the Icare tonometer with those acquired using the gold standard, GAT. There is widespread consensus that accurate and reliable IOP measurement is extremely important in the management of patients with glaucoma and has significant prognostic implications. Portable and easy to use devices would also be of value as screening tools or in situations where the use of GAT is impractical.

Our results demonstrate that the Icare tonometer is in close agreement with the GAT, in the majority of patients. Furthermore, the Icare was consistently able to identify cases in which the IOP was well outside what is considered normal. However, it does appear that the Icare overestimates the GAT in the lower IOP ranges and underestimates in the higher ranges. Despite this, these discrepancies are small and may not be clinically significant, especially if the instrument is used for screening purposes.

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Our results using the Icare are more favorable compared to studies comparing other portable tonometers with the GAT. Studies looking at the TGDC-01 portable tonometer have found this device to have significant fluctuations and variability compared with the GAT. \(^\text{7-10}\) In comparing the Tonopen with GAT, some studies reported significant differences between the 2 devices,\(^\text{11-13}\) whereas others failed to show significant differences.\(^\text{14,15}\)

There are few studies comparing the Icare impact tonometer with the GAT. Kontiola\(^\text{2}\) compared a predecessor of the Icare with GAT in pig’s eyes that were pressurized at different levels. They concluded that the impact tonometer underestimated the IOP measured by the GAT by 4.8 mm Hg. Another small study of subjects with normal IOPs concluded that the Icare overestimates the GAT, although with an absolute bias of < 3 mm Hg in approximately 80%.\(^\text{16}\) A study of 103 subjects compared the Icare with the GAT and found no significant difference between the 2 modalities.\(^\text{15}\) Recently Martinez-de-la-Casa et al\(^\text{17}\) reported a good correlation between IOP readings obtained by the Icare and the GAT \((r = 0.865)\). Unlike our findings, this study found that the Icare readings were consistently higher than GAT measurements, throughout the IOP ranges. The number of eyes tested in this study, however, were approximately half that of our study.

A more recent study looking at the Icare and GAT readings in 42 healthy subjects concluded that IOP measurements using the Icare were not significantly different to the GAT. However, intersessional repeatability of IOP was poorer with the Icare compared with GAT.\(^\text{18}\) Nakamura et al\(^\text{19}\) compared IOP measurements using the Icare with GAT, Tonopen XL, and noncontact tonometer, and the influence of CCT in 45 (12 control and 33 glaucomatous or ocular hypertensive) subjects. They reported a mean difference (95% limits of agreement) in IOP readings between Icare and GAT of 1.40 ± 4.29 mm Hg. Similar to our results as the CCT got thicker, Icare was found to overestimate GAT.

A large study of 178 open-angle glaucoma patients by Brusini et al,\(^\text{20}\) again demonstrated good agreement between GAT and Icare IOP measurements. The CCT was once more found to impact on the Icare IOP reading, although its influence was more striking than was observed in our study. Increasing CCT resulted in an overestimation of the IOP measurement, with a change of 10 μm in CCT yielding a deviation of 0.7 mm Hg in the Icare readings.

We feel that the findings with regard to the influence of CCT on IOP measurements obtained by the Icare are unlikely to be of significance in most clinical situations, especially if the Icare is used as a screening instrument. In our study, the Icare overread the Goldmann by 1 mm Hg for every 100-μm increase in CCT measurements. Possibly, this may be of significance in conditions in which there is marked corneal thickening (eg, Corneal edema). Martinez-de-la-Casa et al\(^\text{17}\) found that in terms of pachymetry, the 2 tonometers behaved in a similar manner.\(^\text{17}\)

In our experience to obtain more accurate readings (ie, no error bars) or readings more consistent with the GAT, extra attention was needed to ensure the probe was held perpendicular to the cornea and the 6 measurements taken as quickly as possible, with minimal movement of either the operator or the patients’ eyes. It was necessary for the operator to stand directly in front of the subject to ensure that the probe is not tilted either in the horizontal or vertical plane. We felt that failure in ensuring optimal positioning often resulted in readings with either error bars or readings, which differed considerably from repeat measurements, or GAT recordings. However, our results indicated that there was no apparent learning effect when the first third of patients were compared with the last third.

In conclusion, the Icare seems to record accurate readings in most situations when compared with GAT. It is easy to use, requires little training, does not require the use of topical anesthetic, and is very well tolerated by patients. It may be of particular benefit in community screening programs, inpatient settings, and emergency departments in which the routine and accurate use of the GAT may be unrealistic. The Icare may also be useful in obtaining IOP measurement in children or patients in which Goldmann applanation is technically challenging (eg, blepharospasm). Although the Icare may be advantageous in many situations, it is unable to be used with the patient in supine position. In addition, further studies are required to assess its reliability over time.

**REFERENCES**

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