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Self-tonometry as a complement in the investigation of glaucoma patients

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ABSTRACT.

Purpose: **To evaluate the reliability of intraocular pressure (IOP) measured by patients with glaucoma themselves using a new hand-held tonometer and to observe whether the IOP variations have the same pattern on different days while glaucoma treatment is constant.**

Methods: **Eighty-seven patients diagnosed with open-angle glaucoma or ocular hypertension were recruited to the study. Intraocular pressure (IOP) measured using Goldmann applanation tonometry (GAT) was compared with IOP measured using tonometry at baseline and on the second visit. Patients measured their IOP at home using the hand-held tonometers.**

Results: **The mean difference between GAT and iCare® values varies from 0 to 1 mmHg. Seventy-eight per cent of iCare® measurements were within 3 mmHg of the GAT measurements. Approximately 64% of the study eyes had higher IOP in the morning than in the afternoon/evening. Circadian patterns differed between consecutive days in 47% of the study eyes. There were IOP peaks outside office hours in up to 16% of the study eyes.**

Conclusion: **Measurements made using rebound self-tonometry are accurate and could be used to complement the investigation of patients with glaucoma. Intraocular pressure curves provide valuable data usable when adapting glaucoma treatment.**

Key words: circadian rhythm of IOP – circadian patterns between days – rebound tonometry – self-tonometry

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Introduction

Responsible for nearly 8.5 million cases of blindness in the world (Quingley & Broman 2006), glaucoma greatly challenges today's ophthalmologists. Patients need regular eye examinations in which the intraocular pressure (IOP), visual field, and optic nerve head are monitored. Although IOP is no longer considered a criterion for diagnosis, it is a major risk factor for glaucoma and is the only disease parameter that can be influenced, using eye drops, laser treatment and surgery. As lowering IOP usually slows the progression of the disease (Asrani et al. 2000, Heijl et al. 2002, Garway-Heath et al. 2014, Heijl 2014). Intraocular pressure (IOP) measurements are extremely important in evaluating the target pressure and choosing the appropriate treatment.

Intraocular pressure (IOP) is usually measured by healthcare providers using Goldmann applanation tonometry (GAT) during office hours at hospital or in private practice. Although GAT is considered the gold standard, like any other methods, it has its limitations and uncertainties (Burr et al. 2012). Measurements made during office hours capture the IOP at specific moments and therefore do not reflect IOP fluctuations over a 24-hr period (Jonas et al. 2005). Monitoring IOP variations over a longer period of time provides data that in certain cases may help in determining more suitable treatment (Hughes et al. 2003). However, the influence of IOP variation on visual field is still controversial (Bengtsson & Heijl 2005) and most relevant studies present low-quality evidence (Medical Advisory Secretariat 2011). To obtain a 24-hr IOP curve, it has been necessary to have the patient stay in hospital where IOP is measured repeatedly, giving an indication of IOP fluctuations and peaks. However, it is difficult to know whether the pattern observed is the same on consecutive days or varies from day to day (Fogagnolo et al. 2013). Such inpatient measurements are expensive and time-consuming for both the clinic and patients.

As IOP peaks can occur outside office hours (Liu et al. 2003, Mosaed et al. 2005, Barkana et al. 2006), accurate devices that allow patients to measure IOP themselves at home over a few days or on a 24-hr basis could help in adapting glaucoma treatment to individual needs. Attempts have been

made in the past to develop home tonometers (Asrani et al. 2000, Marchini et al. 2002, Meyer et al. 2006). Rebound tonometry as developed by iCare® has been used by healthcare professionals since 2003, and clinical studies have demonstrated high agreement between GAT and iCare® results (Brusini et al. 2006, Davies et al. 2006, Nakamura et al. 2006, Jóhannesson et al. 2008, Burr et al. 2012, Beasley et al. 2013, Moreno-Montanes et al. 2015). In iCare® devices, which do not require the use of anaesthesia, a lightweight probe rebounds from the cornea. The speed of the probe and the duration of contact with the cornea are analysed with an algorithm, high IOP corresponding to fast probe deceleration and short contact time with the cornea. Based on the same principle of rebound tonometry, it is nowadays possible to monitor IOP fluctuations using a hand-held tonometer that patients can borrow and take home. The first version of the device is called iCare® One, and its results have previously been compared with those of GAT in clinical studies, the mean difference between the two methods ranging from 1.0 ± 3.5 to 1.40 ± 2.19 mmHg (Brusini et al. 2006, Nakamura et al. 2006). The improved version of this device is called iCare® Home. A major difficulty in self-tonometry is for the patient to place the tonometer correctly and make a measurement at the apex of the cornea. A previous study has demonstrated that a slight deviation from the apex is of statistical but not clinical significance to the IOP measurements (Kontiola 2000).

The main purpose of this study was to evaluate the feasibility of having patients with glaucoma, to make measurements using hand-held tonometers and to compare these readings with those made using Goldmann applanation tonometry. The second purpose was to study the circadian rhythm of IOP and evaluate whether IOP variations display the same pattern on different days while glaucoma treatment remains constant.

Patients

This is a prospective, non-randomized clinical study carried out from 2013 through 2015. During this period, as part of the glaucoma investigation, 87 consecutive subjects were enrolled in either the iCare® One (35 subjects) or iCare® Home (52 subjects) study.

The patients participating in these studies were diagnosed with open-angle glaucoma or ocular hypertension. The studies adhered to the tenets of the Declaration of Helsinki and were approved by the Central Ethical Review Board. Informed consent was obtained from each patient before inclusion. Six patients, three from the iCare® One and three from the iCare® Home studies, were excluded due to early withdrawal or problems in handling the tonometer.

For accuracy analysis, 81 patients were included, 49 men and 32 women aged 26–82 years with a mean age of 64 ± 13 years. Of these patients, 76 used eye drops and 27 had previously been treated with selective laser therapy or glaucoma surgery. The patients remained on the same treatment protocol and took eye drops as prescribed during the study period. Only four patients were untreated.

When analysing the IOP patterns, 14 patients were excluded due to non-compliance with the measurement schedule. We analysed the records of 67 of 87 (77%) patients, 41 men and 26 women, including those of eight-one-eyed patients.

Methods

Each patient visited the clinic twice. During the initial visit, which lasted approximately 30 min, the patients learned how to use the iCare® (Vantaa, Finland) tonometer, a hand-held rebound device.

The iCare® One and iCare® Home devices apply the same IOP measurement principle. iCare® One is the first version of the hand-held tonometer and cannot detect which eye is being measured. Patients used iCare® One on the right eye for 3 days and then on the left eye for the following 3 days. As an improved version, iCare® Home can identify and record which eye is being measured. With this device, IOP was measured on both eyes at the same time-points on three consecutive days. The iCare® One device indicates a valid IOP measurement on a scale ranging from 5 to 50, whereas iCare® Home indicates only whether a valid reading has been obtained, by the illumination of a green indicator light.

The patients had the opportunity to practice until they obtained acceptable measurements. On both visits, the patient measured the IOP using the iCare® tonometer and a study nurse measured the IOP according to GAT. To evaluate the comparability of the iCare® tonometers, these IOP values were compared for each visit.

Between the two visits to the clinic (later referred to as visits 1 and 2), patients measured their IOP at home on three different days (later referred to as days 1, 2 and 3) according to the following schedule: 4 am, 8 am, 12 pm, 4 pm and 8 pm. They were instructed to take their medication at the prescribed times. The measurements were read at the clinic by connecting the iCare® device to the ICARE® LINK software. The registered data consisted of the date, time of day and IOP value in each eye.

To analyse the pattern of IOP variation, we compared the measurements made on 2 days. The pattern was defined as the highest IOP value in the morning (i.e. at 4 am, 8 am or 12 pm) and in the afternoon/evening (i.e. at 4 pm or 8 pm). The results gave an ascending or descending pattern.

The IOP values recorded with iCare® outside office hours were compared with those recorded during office hours. An outside-office-hour peak was defined as a value measured outside office hours that is 4 mmHg higher than the highest value measured during office hours.

Statistical analysis was carried out using Windows Excel. Bland–Altman analysis was performed to assess the agreement between GAT and iCare® values.

Results

The demographics of the study participants are presented in Table 1. Of the 87 enrolled patients, six were excluded from the analysis of tonometer accuracy

Table 1. Patients characteristics.

n	81
Age (years)	64 ± 13
Gender	
Male	49
Female	32
One-eyed	10
Glaucoma treatment	
Topical eye drops	76
Laser (SLT)	27
Surgery	12
None	4

due to early withdrawal (four) or problems in handling the iCare® tonometer (two). In the analysis of IOP variations, 14 patients were excluded due to non-compliance with the schedule.

The mean IOP values obtained on visits 1 and 2 using GAT and iCare® tonometers are listed in Table 2. The difference between the GAT and iCare® measurements for the right eye was 1 ± 3 mmHg on visits 1 and 2 (p = 0.588); for the left eye, the difference was 0 ± 3 mmHg on visit 1 and 1 ± 4 mmHg on visit 2 (p = 0.467). Of 307 measurements made using iCare® tonometers, 78% were within 3 mmHg, 64% within 2 mmHg and 39% within 1 mmHg of GAT values.

Bland–Altman plots of the correlation between the GAT and iCare® measurements indicate good agreement. There is no trend of increase or decrease within the current measurement range (Figs 1 and 2). iCare® measurements underestimate IOP compared with GAT measurements for values under 18 mmHg for visit 1 (p = 0.031) and under 20 mmHg for visit 2 (p = 0.065) and overestimate IOP above these values (Figs 1 and 2).

There was no significant difference between IOP measurements made by patients older and younger than 70 years. *T*-tests showed p = 0.229 for the right eye and p = 0.775 for the left eye on visit 1, and p = 0.304 for the right eye and p = 0.509 for the left eye on visit 2.

Eighty-one of 126 eyes (64%) had higher IOP in the morning (i.e. 4 am–12 pm) than in the afternoon/evening (i.e. 4–8 pm) on day 2, whereas 45 eyes (36%) displayed the opposite pattern. On day 3, 82 eyes (65%) had higher IOP in the morning versus 44 eyes (35%) in the afternoon/evening. Sixty-seven eyes (53%) had the same pattern on consecutive days, whereas 59 eyes (47%) had patterns that differed between days 2 and 3.

The IOP measured on day 2 (4 am–8 pm) using the iCare® tonometers ranged from a minimum of 11 ± 5 mmHg to a maximum of 19 ± 7 mmHg, a mean difference of 8 mmHg. Similarly, on day 3, the IOP ranged from 11 ± 5 mmHg to 19 ± 7 mmHg, a mean difference of 8 mmHg.

There were IOP peaks outside office hours in 11 study eyes (9%) on day 2 and in 20 eyes (16%) on day 3.

Table 2. IOP measurements made using GAT and iCare® tonometers.

	Eye	Visit 1	p-value	Visit 2	p-value
GAT	Right	15 ± 5 mmHg	0.524	15 ± 5 mmHg	0.410
iCare®		15 ± 5 mmHg		14 ± 6 mmHg	
GAT	Left	14 ± 5 mmHg	0.783	15 ± 5 mmHg	0.511
iCare®		15 ± 6 mmHg		15 ± 6 mmHg	

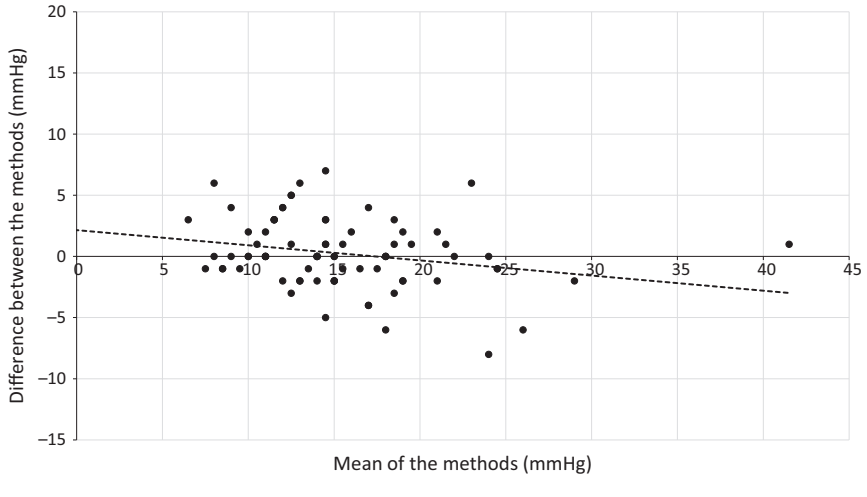

Fig. 1. Goldmann versus iCare® at visit 1. Bland–Altman plot of agreement between intraocular pressure (IOP) measured using Goldmann applanation and iCare® self-tonometry at visit 1. Correlation $R^2 = 0.060$, $y = -0.124x + 2.154$, slope (p = 0.031), intercept (p = 0.021).

Discussion

Our study primarily aimed to evaluate the reliability of measurements made by patients themselves using iCare® tonometers and to compare these with GAT measurements.

Of the eight-one-eyed patients enrolled, only two were excluded because they could not position the tonometer properly to obtain useful measurements, suggesting that most one-eyed patients can handle the device.

Goldmann applanation tonometry is considered 'the gold standard' and is the method used by most ophthalmologists. In our study, we found that the mean differences between GAT and iCare® values range from 0 to 1 mmHg. These differences are in accordance with those of Moreno-Montanes et al. (2015), who found the mean difference between GAT and iCare® One measurements to be 0.60 mmHg. Earlier studies (Burr et al. 2012) comparing GAT and iCare® Pro measurements found differences of 2.02 ± 0.50 mmHg (Jóhannesson et al. 2008), 1.40 ± 0.44 mmHg (Martinez-de-la-Casa et al. 2006), 1.40 ± 0.64 mmHg (Nakamura et al. 2006), and 0.50 ± 0.50 mmHg (Davies et al. 2006). In addition, more than 78% of the measurements made using iCare® One and iCare® Home tonometers are within 3 mmHg of the GAT measurements. The differences between GAT and iCare® measurements between the right and left eyes and between visits 1 and 2 were not statistically different, confirming the comparability of the measurements made by the patients themselves. In our study, the IOP values obtained by a few patients using iCare® self-tonometers differed greatly from the GAT values (Figs 1 and 2). In future clinical practice, we intend to provide further training for these patients to improve their measurement performance. In some cases, it might be necessary to train the patient's relatives and ask them to make the measurements.

Bland–Altman plots (Figs 1 and 2) reveal that iCare® tonometers tended to underestimate IOP values under 18 mmHg on visit 1 and under 20 mmHg on visit 2 and to overestimate IOP values above these values, both relative to GAT measurements. This should be taken into account

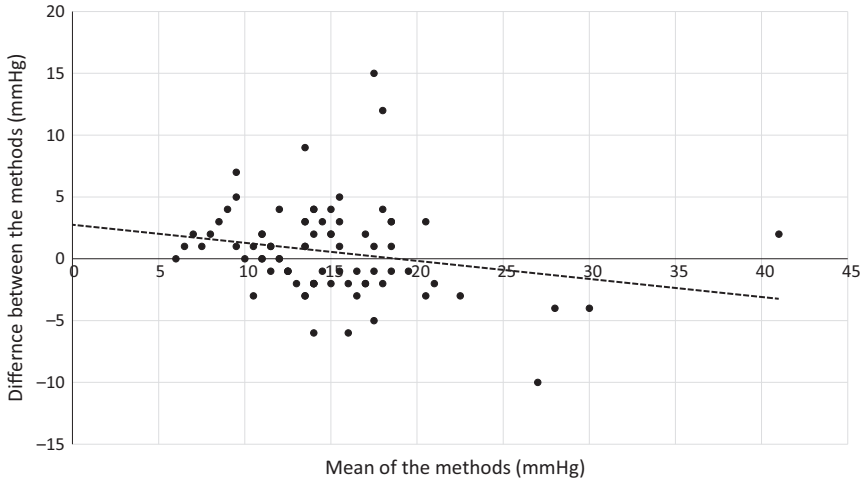

Fig. 2. Goldmann versus iCare® at visit 2. Bland–Altman plot of agreement between intraocular pressure (IOP) measured using Goldmann applanation and iCare® self-tonometry at visit 2. Correlation $R^2 = 0.044$, $y = -0.146x + 2.7472$, slope (p = 0.065), intercept (p = 0.030).

when clinically applying IOP values measured using iCare® devices.

Our study demonstrated that user age does not influence the comparability of the measurements, which is very important as most patients with glaucoma tend to be rather old.

The second aim of our study was to observe the circadian rhythm of IOP and to evaluate fluctuation patterns on different days while glaucoma treatment remained constant.

In accordance with the results of other studies, our results indicate that IOP fluctuations form different patterns. Almost two-thirds of the study eyes have higher IOP in the morning than in the afternoon/evening. Nearly, half of the study eyes (47%) have IOP patterns that differ on consecutive days. The fact that the IOP pattern varies makes it advisable to monitor daily IOP variations in some cases, and home tonometry could be a suitable means for doing this.

Furthermore, similar to the previously mentioned results (Hughes et al. 2003, De Moraes et al. 2011, Fogagnolo et al. 2013), we found IOP peaks outside office hours in 9% of the study eyes measured on day 2 and in 16% on day 3. The high incidence of IOP peaks outside office hours implies once again that, in some glaucoma investigations, it would be useful to measure IOP several times per day to estimate the daily variation. Self-tonometry could be a complement in the investigation of patients with glaucoma showing visual field progression despite acceptable IOP measured during office hours.

The overall comments from the patients were positive. They found the device easy to use and wished that the method could be part of future glaucoma monitoring.

iCare® One allowed patients to instantly read the results as an interval value and patients were very positive to this possibility, which might improve treatment compliance. However, this is not possible with iCare® Home because the results can only be read using special software (iCare® link) installed in a computer, as the manufacturer is concerned about possible risks associated with self-medication. Only a few patients who used iCare® Home expressed disappointment about not being able to see the results of the measurements right away. It would be desirable in the future to have an iCare® self-tonometer version that allows healthcare providers to choose between two modes: with or without visible readings.

iCare® self-tonometer seems to be very promising as a complement in glaucoma care, especially for obtaining IOP values outside office hours. The home IOP monitoring provides valuable information for the glaucoma care and could probably improve compliance. The instrument is easy to use, and the results are reliable after a short period of instruction and practice. The advantage of using self-tonometry is that patients or their relatives can make the measurements at home, saving time for both the patients themselves and the glaucoma care providers. If the devices were less expensive, home tonometry could probably play an important role in patients' everyday life, comparable to instruments for measuring blood pressure and blood sugar level. Further research could usefully investigate the cost-effectiveness of self-tonometry.

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