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# **Clinical Decision Making V: Intraocular Pressure and Tonometry**



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The measurement of intraocular pressure (IOP) is perhaps most commonly associated with glaucoma. Glaucoma is the name given to a group of diseases that produce characteristic progressive optic nerve atrophy and associated visual field loss. According to the World Health Organisation, glaucoma is the leading cause of irreversible blindness and currently affects an estimated 61 million people - this number is expected to rise to almost 80 million by 2020.<sup>1,2</sup> On average, around 2.1% of people aged 40 years and over have open angle glaucoma (OAG), but this prevalence varies substantially due to age (increasing by several per cent per decade) and racial background (1.4% in eyes of people of Asian origin and 4.2% of people with African origin).<sup>3</sup>

# Detecting glaucoma

Due to a lack of obvious early symptoms, about 50% of people with glaucoma are actually unaware that they are have the condition.<sup>4,5</sup> Even to trained eve, considerable а irreversible damage to the retinal nerve fibre layer is likely to have occurred before visual field loss is detectable (about 40% loss),6 or before optic nerve cupping becomes visible (55% loss in rats),<sup>7</sup> and thus timely glaucoma diagnosis remains an important but elusive clinical issue for all optometrists.

The College of Optometrists has produced guidelines for examining the patient at risk from primary angle glaucoma (see www.collegeoptometrists.org) and broadly recommends that: when examining a patient who falls within the at-risk groups for primary open angle glaucoma, the optometrist has a duty to carry out the appropriate tests necessary to determine the likelihood of the condition being present. IOP measurement is listed as an "appropriate test", and this article will discuss normal and abnormal variations in IOP, how IOP can be used to identify patients who are at risk of glaucoma, how best to measure IOP using conventional optometric equipment and new technological developments.

### Is there a normal IOP?

The short answer to this question is "no". Goldmann and Schmidt originally reported that the average IOP in 400 eyes measured using the Goldmann applanation tonometer was 15.5±2.5 mmHg.8 Based on these figures, about 95% of people have an IOP that falls within the range of 10mmHg to 21mmHg. However, it is likely that this range applies only to a Caucasian population, as the mean IOP is known to be closer to 13mmHg in some Asian populations.9-11

### Why is 21mmHg an important number?

21mmHg is purely a statistical marker. The "normal" IOP range is defined by statistical calculation as two а standard deviations either side of the mean value of 15.5mmHg, or between approximately 10mmHg and 21mmHg. Although we do know that the risk of glaucoma increases as IOP increases, and as such we might expect that most eyes with glaucoma will have an IOP of more than 21mmHg, this value is not intended to represent the division between healthy and unhealthy eyes. Therefore, it is unwise to screen for glaucoma based on IOP measurements alone.

# Variations in IOP

IOP changes over time. IOP can vary by several mmHg over a short (a few seconds), medium (minutes to hours) and long (weeks to months) periods of

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| Short-term   | Medium-term  | Long-term  |
|--|--|--|
| Breath-holding/Valsalva manoeuvre<br>Straining to reach slit lamp or keep<br>eyes open<br>Lid squeezing<br>Ocular pulse<br>Accommodation and eye<br>movement | Diurnal variation of IOP<br>Changes in posture<br>Repeated IOP measurements<br>(Goldmann or Perkins tonometry<br>only)<br>Recent alcohol consumption or<br>smoking (possibly)<br>Recent vigorous exercise<br>Recent consumption of large<br>volumes of fluid<br>Tight clothing around the neck<br>Prescribed or recreational<br>medication<br>Recent contact lens removal<br>Eye rubbing | Age: Increases in Caucasians<br>(possibly) and patients of African<br>descent, decreases in Japanese<br>Seasonal |

### Table 1

Common factors that affect IOP

time. Some of these variations are patient dependent, some are instrument dependent and some are operator dependent – all need to be taken into consideration when attempting to interpret an IOP measurement. Table 1 lists some of the most common factors that affect IOP, which have been adapted from a review article published by Whitacre and Stein in 1993.<sup>12</sup>

# IOP and the risk of glaucoma

The greater the IOP the greater the risk of glaucoma. Even though the requirement for raised IOP to be part of a glaucoma diagnosis has now been relegated to old textbooks, and screening for glaucoma on the basis of IOP alone is no longer considered to be acceptable clinical practice, an elevated IOP remains among the strongest risk factors for the of glaucoma.13-15 development Additionally, IOP is currently the only risk factor that can be modified and studies have shown conclusively that the risk of glaucomatous damage decreases following the reduction of IOP via medication or surgical means.14,16,17

There is no level of IOP that is able to separate "glaucoma" from "not glaucoma". An estimated 40% of eyes with OAG have an IOP that never rises above 21mmHg (commonly referred to as "normal tension glaucoma"), while about 90% of people with an IOP within the range of 24mmHg to 32mmHg will not develop signs of glaucomatous damage over a follow-up period of five years (commonly referred to as "ocular hypertension").<sup>16</sup> This information appears to indicate that it is the susceptibility of individual eyes to a particular IOP that is linked to glaucoma, not the absolute IOP itself.<sup>18</sup>

While there is no minimum threshold level of IOP that guarantees that a patient will be free of glaucoma, there is an upper level that should be considered a cause for concern even in the absence of other glaucomatous signs. As a general rule, all patients who have an IOP of 30mmHg or above should be referred for treatment, plus all patients with an IOP in the mid 20's if other significant risk factors (discussed below) are present.<sup>19</sup>

# **Asymmetrical IOP**

The IOP in both eyes should be similar. Allowing for momentary fluctuations in IOP and measurement variability, the IOP in both eyes should be similar. If a difference of more than 4mmHg exists between the eyes, this should be considered as being suspicious and supplementary investigations such as visual fields assessment should be conducted.

# **Diurnal variation in IOP**

Undetected pressure spikes may be present. In healthy eyes, the IOP will vary by an average of 3mmHg over a 24-hour period but larger fluctuations in IOP have been implicated in the progression of glaucoma.<sup>20</sup> For this reason, it can be valuable to repeat a borderline IOP measurement on another day and/or at another time.

# **Other general risk factors**

Other risk factors may increase the risk of IOP-related damage. Patients may have an increased susceptibility to IOP-induced glaucomatous damage if they have any of the ocular or systemic risk factors or signs listed in Table 2.

### Tonometry

Tonometry is the name given to the

| Ocular Risk Factors   | Systemic Risk Factors                           |
|---|---|
| Thinner than average central corneal thickness (CCT)              | Increasing age                                  |
| Large or asymmetric cup to disc (C/D) ratio                       | Being of African descent                        |
| History of disc haemorrhages                                      | Family history of glaucoma, especially siblings |
| A large pattern standard deviation during visual<br>field testing | Some medications, especially corticosteroid use |

### Table 2

Ocular and systemic risk factors for glaucoma, in addition to IOP\* \*This list is not exhaustive and may change as new research becomes available



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### Figure 1

The forces involved in Goldmann tonometry; red arrows are forces acting to resist applanation and green arrows are forces acting to induce applanation

measurement of IOP. Several different types of tonometers are found in clinical practices throughout the UK, with the most common falling into two groups – contact (Goldmann and Perkins) and non-contact.

### **Contact Tonometry**

Goldmann applanation tonometry (GAT) was introduced approximately 50 years ago, and since that time it has been elevated to the status of the "gold standard" instrument for the clinical measurement of IOP.<sup>®</sup> For the purposes of this discussion, the Perkins tonometer will be considered equivalent to GAT.

GAT operates via the Imbert–Fick principle – this principle states that the IOP can be estimated indirectly via measuring the force required to applanate or "flatten" a given area of the cornea. Strictly speaking, the Imbert-Fick principle should only be used to determine the pressure within any spherical object whilst it also assumes that the surface of that object is dry, elastic and infinitely thin. However, in reality, the cornea meets none of these conditions as it is actually elliptical, covered by a wet tear film, exhibits viscoelastic rather than elastic behaviour and has an average thickness of 540µm. In order to compensate for the mismatch between theory and reality, the Goldmann tonometer was calibrated in experiments against directly measured intracameral readings of IOP, where a needle was placed in the anterior chamber of the eve. Goldmann and Schmidt then selected an applanation diameter for their tonometer which most closely matched the intracameral IOP;<sup>8</sup> it was at this point that they believed that the resistance of the cornea and the attractive capillary forces of the tear film were equal and opposite (shown as red and green arrows in Figure 1, respectively) and thus were able to cancel each other out and provide an accurate IOP reading.

However, due to the fact that the Goldmann tonometer was calibrated against measurements obtained in real eyes, its accuracy depends on the similarity of corneas of each patient to those used in the original calibration sample. Goldmann and Schmidt knew that the results of their tonometer would be invalid if it was used in eyes that differed significantly from the eyes that were used to calibrate the instrument, or under non-standard conditions (such as in corneas with oedema or scarring),<sup>8</sup> but what they did not appear to realise was that corneal properties varied widely from person to person, thus making their tonometer susceptible to measurement errors.

#### Non-contact Tonometry

Non-contact tonometry (NCT) was introduced by Grohlman in 1972 as an alternative to Goldmann-type tonometers.<sup>21</sup> Like Goldmann tonometry, it measures the force required to applanate the cornea, though instead achieves applanation via the rapid application of a columnated air-pulse to the cornea.

Due to the fact that NCT was calibrated to give readings that were consistent with Goldmann readings, and are also obtained via a form of applanation, it too is sensitive to most of the corneal factors that affect Goldmann tonometry. Recent research suggests that NCT is actually more sensitive to variations in corneal properties, particularly in thicker corneas. This may be because NCT encounters more corneal resistance since it applanates a larger area, and because it is a more rapid process that is likely to increase viscoelastic resistance compared to the slower Goldmann process.<sup>22</sup>

The results of most modern NCT devices are considered to be roughly equivalent to the results provided by Goldmann tonometer except at high levels of IOP, where NCT tends to overestimate the IOP.<sup>23</sup> Additionally, NCT measurements are taken over a very short period of time - they are sensitive to the ocular pulse and this makes NCT results more variable than Goldmann readings, though the reliability improves dramatically if an average of three readings are



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taken for each eye. For these reasons, it is suggested that borderline or high NCT readings are verified with a Goldmann tonometer.

### The importance of Tonometer Calibration

Tonometers need to be checked regularly to ensure that they are calibrated. The accuracy of tonometers decreases over time. In a recent survey conducted, almost 70% of respondents checked the calibration of their Goldmann tonometers at less than the recommended monthly frequency,24 and an estimated 40-50% are inaccurate by more than ±2.5mmHg at any given time.25 Goldmann and Perkins tonometers should be checked monthly and returned to the supplier for re-calibration if found to be inaccurate by 2.5mmHg or more; for non-contact tonometers it is advised that practitioners contact their supplier for the recommended service interval.

# The problem of corneal thickness for tonometers

Following the introduction of accurate corneal pachymetry (corneal thickness measurement) some years after the introduction of the Goldmann tonometer, it was realised that there was a much greater variability in corneal properties throughout the population than had originally been anticipated. Though averaging  $540\mu$ m in most people, corneal thickness can vary by  $60\mu$ m either side of this value in perfectly healthy eyes, and even more in extreme cases.<sup>26</sup>

The impact of this inter-patient variability in central corneal thickness (CCT) on IOP measurement was unknown until 1975, when Ehlers et al. performed a study where they compared the Goldmann IOP to the intracameral IOP in 29 patients who were about to undergo cataract surgery.27 They found that Goldmann IOP was underestimated in eyes with thin corneas and overestimated in eyes with thick corneas, with the effect amounting to approximately ±5mmHg over the range of corneal thicknesses that are likely to be encountered in routine clinical practice. A similar conclusion has been reached in many similar studies since that time, albeit that the effect has not always been reported to be as large or as consistent.<sup>26</sup> This effect also appears to be present in all other tonometers that rely on corneal manipulation to estimate IOP, including non-contact and Perkins tonometry, as well as the TonoPen.<sup>22</sup>

The potential influence of corneal thickness-induced errors in IOP glaucoma measurements on management were highlighted by Copt et al., who estimated that 31% of eyes diagnosed with normal tension glaucoma have statistically elevated IOP when corrected for the effects of CCT, while 55% of eyes classified as having ocular hypertension have a statistically normal IOP.28 A further study by Shih et al. of 188 subjects with glaucoma or ocular hypertension indicates that 43% of eyes require an adjustment in IOP of at least ±3mmHg following CCT measurement, with 19% of the subjects requiring a change in glaucoma therapy following corneal thickness correction.<sup>29</sup> This means that there are some patients with glaucoma who may be under-treated (or not detected at all by glaucoma screening programs based on IOP), and others who are being monitored unnecessarily for glaucoma.

### What Else Can Central Corneal Thickness (CCT) Tell Us?

CCT is a risk factor for glaucoma. Recent studies indicate that eyes with a below average CCT may be more prone to develop glaucoma,13 and to have more serious glaucomatous damage at diagnosis.<sup>30</sup> As mentioned above, one possible explanation for this increased risk of glaucoma in eyes with thinner corneas is the failure of tonometry to detect an elevated IOP due to measurement errors. However, even if CCT-related errors in IOP measurement are taken into account, eyes with thinner corneas are still more susceptible to glaucomatous damage. As such, CCT is now considered to be a risk factor for glaucoma in its own right, with eyes with a CCT of 555µm or less being 3.4 times more likely to develop glaucoma compared to eyes with a CCT of more than  $588\mu$ m.<sup>13</sup> This may be because eyes with thinner CCT have a thinner retinal nerve fibre layer than eyes with thicker CCT,<sup>31</sup> or that these eyes may also have changes in the posterior sclera and/or lamina cribrosa that makes a them more sensitive to the effects of IOP.32

Eyes with thick corneas also exhibit unusual properties with respect to glaucoma, as they appear to be



#### Figure 2

Behaviour of CCT (blue) and Goldmann-measured IOP (green) measured over the course of a day between eye opening and sleep. Adapted from Hamilton et al <sup>37</sup>



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somewhat protected against the effect of high IOP.<sup>33</sup> Researchers have also noted that eyes with thick corneas are less responsive to IOP-lowering medications, again in a way that cannot be accounted for by corneal thicknessrelated errors in IOP measurement.<sup>34</sup>

# Measurement of CCT

Optometrists may benefit from CCT measurement. Due to the risk of CCTinduced measurement errors in tonometry, the increased risk of glaucoma associated with thin corneas, and the effect of CCT on the effectiveness IOP of lowering prominent medications. several Ophthalmological associations (including the Royal College of Ophthalmologists in the UK and the Association American of Ophthalmologists in the USA) are now recommending that CCT is routinely measured in eyes with a raised IOP, in glaucoma suspects and in all glaucomatous patients at diagnosis. Given that pachymetry is quick, simple and can be conducted at minimal risk to the patient, Optometrists may also benefit from the additional information that can be gained by measuring CCT.

### How is CCT measured?

CCT is measured using ultrasonic pachymetry by applying a small probe directly to the corneal surface following the instillation of a topical anaesthetic. The most reliable measurements can be obtained by adhering to the following guidelines:

The cornea thickens away from the centre so take care to apply the probe over the centre of the pupil. It must be held at a 90° angle to the corneal apex.
Record the average of three readings and the time of day.

**3.** Do not take measurements within 2 hours of awakening as overnight corneal oedema may still be present and will interfere with the readings.

**4.** Be aware of factors that may affect CCT such as recent contact lens wear, corneal refractive surgery or corneal abnormalities such as keratoconus or Fuchs' endothelial dystrophy.



Figure 3 The Ocular Response Analyser (ORA) and computer

# Should IOP measurements be corrected for CCT?

Correction of IOP based on CCT alone is inaccurate. The discovery of the relationship between CCT and the accuracy of IOP measurement has lead to the development of corneal correction factors. Though there are several different correction factors available, the premise for using them is the same – CCT is measured for each patient, a correction factor (in mmHg) is deduced from the CCT, and this value is then added or subtracted from the IOP reading in order to produce an adjusted IOP measurement that should theoretically be closer to the true IOP. These correction factors are becoming increasingly available to Optometrists via a variety of sources; they may be electronically incorporated into software, or appear as a summary table on a card that can quickly convert a CCT measurement into an IOP reading. However, it is generally not appropriate to correct an IOP based on CCT because:

**1.** While most researchers agree that IOP is underestimated in eyes with

thin corneas and overestimated in eyes with thick corneas, they have not been able to confirm a specific numerical relationship between the two, and thus there is no universally accepted correction factor.

**2.** Other corneal factors are almost certainly as important as CCT to the accuracy of IOP measurement, and thus a correction factor based solely on CCT cannot be accurate.

However, this does not mean that we should stop measuring CCT. While there is no clear point dividing normal CCT from abnormal CCT, and there is no correction factor known to be suitable for all patients, large differences from the average CCT values are clinically important because it may affect the management of our patients via the link to the risk of glaucoma.

### Why CCT measurement isn't enough

As discussed above, the accuracy of IOP measurement depends on the properties of the cornea through which it is measured; CCT is a well-





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established influence but is not the only one, and many other corneal factors that have been shown to influence the accuracy of IOP measurement.

# Corneal biomechanical behaviour

An recent article in Optometry Today (The biomechanics of keratorefractive surgery September 5 2008) described the concept of corneal biomechanics in some detail, so the present article will refrain from further discussion except to say that corneas can vary from very pliable to very inflexible, meaning that corneas with identical thickness can behave entirely differently during tonometry depending on whether they have a soft or rigid biomechanical nature. In the average healthy population, the natural variation in corneal biomechanical behaviour is sufficient to cause an error in IOP measurement that is almost the same size as the CCT-related errors.<sup>35</sup> This could create serious complications if CCT-based correction factors are used in eyes that have soft thick corneas because the "corrected" IOP may be even further away from the true IOP

than the raw Goldmann reading. Unfortunately, biomechanical behaviour does not change the clinical appearance of a cornea and it cannot be measured using conventional optometric equipment.

# **Corneal hydration**

The hydration of all human corneas varies over a 24-hour period; this manifests as a characteristic more commonly known as the diurnal variation of corneal thickness, which averages about 3.5%.<sup>36</sup>

Figure 2 shows how corneal thickness and IOP behave during waking hours. For the first two hours, the IOP measurement follows the same pattern as the CCT measurement, which indicates that the small corneal oedema present on awakening causes an overestimation error in IOP.37 This overestimation was also confirmed in eyes with artificially induced corneal oedema through contact lens wear, and thus appears not to be a coincidental finding that might be related to posture or other sleep-related phenomena.38,39

The overestimation of IOP by

tonometry due to corneal oedema is a relatively new finding, and many textbooks still indicate that corneal will result oedema in an underestimation in IOP.40 The latter remains true but occurs only in highly swollen corneas, mostly because it is quite easy for a tonometer to "squash" the soft swollen epithelium into an applanated shape; in these circumstances, the tonometer reading will be unrelated to the IOP.

The clinical advice is that IOP measurement should not be performed until overnight oedema has had sufficient time to clear - this is currently two hours in young healthy subjects but it is possible that this may need to be longer in older individuals due to the decrease in corneal endothelial function that occurs with aging. Tonometry generally should not be attempted when the cornea is highly swollen.

### **Corneal curvature**

Theoretically, corneal curvature is capable of affecting the accuracy of GAT, but research results have been inconclusive.<sup>27,41.43</sup> The general consensus appears to be that the IOP



### Figure 4

The output of the ORA. Applanation pressure 1 (P1) and 2 (P2) are the pressure readings (pressure is shown in green) recorded at the "in" and "out" applanation events (shown as red peaks). The difference between P1 and P2 pressure readings is known as corneal hysteresis (CH) and is measured in mmHg



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will be underestimated slightly in flat corneas and overestimated slightly in steep corneas, but the effect is probably confined to the extreme limits of "normal" corneal curvature and thus is generally not a significant factor in the average clinical setting.

### **Refractive surgery**

IOP measurements are usually significantly reduced by several mmHg in eyes that have had LASIK, LASEK or PRK, but by an amount that cannot be fully explained or predicted by the decrease in corneal thickness, the amount of refractive error corrected or the change in corneal curvature.<sup>32</sup> Therefore, care must be taken when interpreting an IOP measurement performed by GAT in an eye that has had corneal refractive surgery. It would be wise to look more closely for other signs of glaucomatous damage rather than rely on traditional IOP measurements in these patients, or consider using an alternative tonometer (see below for more details).

# Peripheral corneal thickness

Until recently, almost all of the research that has looked at the effect of corneal thickness on IOP measurement has considered the thickness in the centre of the cornea only (CCT). However, both GAT and NCT applanate an area that is over 3mm in diameter, and it has been known for many years that the cornea increases in thickness towards the periphery.44 It has recently been shown that the increase in corneal thickness towards the periphery, specifically 2.5mm to the temporal side of the corneal centre, can interfere with NCT readings.45 In this study, the increase in temporal corneal thickness was associated with an overestimation error in IOP, in addition to any error already induced by the CCT, and importantly, this interference from the peripheral corneal thickness was almost the same size as the effect of CCT.<sup>45</sup> To complicate matters further, the increase in thickness that occurs in the periphery cannot be estimated by the measurement of CCT and thus must be measured independently.<sup>45</sup> However, preliminary data conducted by the same researchers suggests that conventional ultrasound pachymetry may not be adequate to perform thickness measurements of the midperipheral cornea reliably, and that a wide-field pachymetry device such as the Orbscan IIz or Pentacam would be more appropriate.

Research is currently underway to determine whether peripheral corneal thickness has a similar effect on Goldmann tonometry, so in the meantime, the clinical advice is to keep this factor in mind but await further information before attempting to incorporate it into routine corneal thickness measurement.

### New tonometry methods

Given that the cornea has such a strong ability to influence IOP measurements using traditional tonometers, several new tonometers have been introduced into the marketplace, which have attempted to address the interference of corneal behaviour in two distinctly different ways:

**1**. To measure corneal behaviour directly and then compensate for it (e.g. the Ocular Response Analyzer - ORA).

2. To obtain a measurement of IOP

| Parameter        | Definition   |
|------------------|--|
| IOP <sub>6</sub> | Goldmann correlated IOP<br>This measurement is directly comparable with any conventional contact or non-contact<br>tonometer   |
| IOP∞             | <b>Corneal compensated IOP</b><br>An IOP measurement that is less influenced by corneal properties such as elasticity<br>and thickness   |
| СН               | <b>Corneal hysteresis</b><br>This is calculated as the difference between Applanation pressures 1 and 2, as shown in Figure 4.<br>It is an indicator of a particular aspect of corneal behaviour called viscous damping, and this number is used in further analysis |
| CRF              | <b>Corneal resistance factor</b><br>A measurement of the total viscoelastic response of the cornea, which includes elasticity<br>and thickness   |

Table 3

Measurements produced by the Ocular Response Analyzer (ORA)

without causing significant corneal applanation, thus avoiding most of the corneal influence (eg the Pascal dynamic contour tonometer - PDCT).

### Ocular Response Analyzer (ORA)

The ORA (Figure 3) is a modified NCT that uses specialised computer software to obtain additional information describing the applanation process. The measurements are performed as for NCT (average of three readings per eye) and similarly, applanation is detected via an infrared (IR) emitter and detector such that in a nonapplanated cornea, very little IR light is able to reach the detector because the rounded cornea disperses it and the resulting light signal intensity is low. When the increasing force of the air pulse is sufficient to cause applanation however, the corneal surface temporarily becomes a flat reflecting surface that directs the maximum amount of IR light into the detector, which causes a peak in the light intensity. In a conventional NCT, the air-puff is terminated and a pressure reading is recorded once applanation has been detected. However, the ORA continues to record the pressure over a longer period of time. There is a slight delay in switching off the air pulse, which



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means that the force of the air pulse temporarily increases beyond the level required for applanation, and so the cornea indents momentarily which is seen as a reduction in the light signal reaching the detector As the force of the air pulse decreases, the cornea passes through a second applanation point before returning to its normal shape. The difference between the two-applanation points produces a unique value called corneal hysteresis (CH), which is representative of the corneal biomechanical properties (Figure 4).

In addition to the waveform shown in Figure 4, the current version of the ORA also produces four different numbers: two different types of IOP measurements and two measurements representing corneal biomechanical behaviour. A summary of these can be found in Table 3.

The two IOP measurements  $IOP_G$ and  $IOP_{GC}$  are of most interest to clinicians.  $IOP_G$  is important because it allows a direct comparison with conventional tonometry (particularly useful when comparing new readings to those taken with a previous tonometer), while  $IOP_{GC}$  is important because it is believed to provide an IOP measurement has been corrected for the interference of corneal properties, including thickness.

Via its analysis of corneal properties, the ORA may also provide a way of distinguishing between true ocular hypertension and eyes with artificially elevated IOP due to measurement errors. Additionally, early findings indicate that CH and CRF may be able to detect structural changes due to glaucoma.<sup>46</sup>

### Pascal Dynamic Contour Tonometer

The Pascal Dynamic Contour Tonometer (PDCT) (Figure 5) is a slitlamp mounted device designed to measure IOP without interference from corneal properties. Though it may look like a Goldmann tonometer in some ways, it is significantly different because:

**1.** The tip of the probe is concave rather than flat (Figure 6). This design feature is intended to follow the



Figure 5 The Pascal Dynamic Contour Tonometer mounted on a conventional slit lamp

corneal contour and neutralise the corneal forces rather than forcing applanation, which then reduces/eliminates the influence of corneal properties on IOP measurement.

**2.** The IOP is measured by an electronic pressure sensor embedded in the probe tip.

**3.** Readings are displayed digitally so it is more objective than GAT.

**4.** The IOP is monitored continuously over a period of several seconds, providing a measurement of the ocular pulse amplitude (OPA).

The PDCT provides a measurement of IOP but also two additional parameters called the Q-value and the ocular pulse amplitude (OPA). These are summarised in Table 4.

The OPA is thought to be related to the overall biomechanical characteristics of the eye and through this it may also be related to the risk of glaucoma. The process of IOP measurement is similar to Goldmann tonometry except that no fluorescein is required to perform the measurements. The pressure sensor is visually aligned with the centre of the pupil and the probe tip is rested on the cornea for several seconds to record an IOP measurement. As with conventional tonometry, record the average of three IOP readings and record the time of day. Due to the fact that GAT is sensitive to corneal properties but the PDCT is not, the IOP readings from the two instruments are not directly comparable.

Many studies have assessed the accuracy of the PDCT since its release in 2005 including several that have compared direct measurement of IOP via intracameral tonometry to the PDCT measurements. It has been found to measure IOP accurately in eyes after corneal refractive surgery, with highly swollen corneas and in eyes with corneal disease such as keratoconus.47,48 However, there are early indications that the PDCT measurements of IOP would be better described as "less" influenced by corneal properties than GAT, rather than completely free of the corneal-related factors, as studies have shown that corneal hydration and CCT may have a small effect.<sup>49,50</sup>

Assuming that future assessment of this instrument follows current trends, the Pascal DCT is on track to become the new gold standard device for the measurement of IOP. However, IOP measurements should still be confirmed with Goldmann tonometry



⇒ Figure 6 The measurement probe of the Pascal Dynamic Contour Tonometer. Note that the probe tip is concave



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| Parameter | Definition   |
|-----------|--|
| IOP       | Intraocular pressure<br>An IOP measurement that is said to be free of corneal influence. This reading is not<br>directly comparable with GAT.                        |
| Q-value   | Quality value<br>This is a measure of the quality of the measurement. A Q value of 1, 2 and 3 are<br>acceptable, but 4 or 5 requires the measurement to be repeated. |
| OPA       | <b>Ocular pulse amplitude</b><br>The IOP increase due to the change in choroidal volume during the cardiac cycle.  |

# 38 **CE1**

Numbers produced by the PDCT

Table 4

prior to referral until further information becomes available.

# Maximising traditional tonometry

Though future developments in tonometry are promising, new technology is typically more expensive than conventional instruments and thus many Optometrists will be likely to continue to use traditional contact and non-contact tonometry for many years to come. Therefore, it is prudent to conduct IOP measurements in light of the issues discussed in this article in order to reach the best clinical decision possible with the available evidence – a summary of the key "take home" messages appears below.

### **Understand IOP**

•There is no such thing as a "normal IOP".

•Be aware of the short and long-term factors that can cause IOP to change, including the diurnal variation of IOP. Always record the time of day that measurements are taken.

•Do not measure IOP during the first two hours of awakening as your result could be influenced by residual overnight corneal oedema.

### Make sure the IOP is what you think it is

•Confirm on a second day, at a different time, and with a Goldmann tonometer UNLESS signs of corneal oedema are present (indicating that an extreme IOP is/has been recently present).

•Remain aware that accuracy of IOP is limited by tonometer design. Consider the effect of the cornea on IOP measurements; measure CCT but interpret results in view of recent research findings.

•Tonometer calibration must be checked regularly.

•Use standardised consistent methods for contact and non-contact tonometry, including recording the average of three readings per eye.

### Consider the big picture

•Remember that IOP is not the only risk factor for glaucoma, but consider the overall picture when making clinical decisions about IOP.

# Should I refer based on IOP alone?

Referral guidelines for suspected glaucoma vary depending on a number of factors including your local health authority guidelines, the preferences of your local Ophthalmologists and whether you are involved with comanagement of glaucoma. New referrals can be accepted based on a raised IOP in the absence of other glaucomatous signs, but generally require that the Optometrist has obtained an elevated reading on 2 separate days with a Goldmann tonometer.

It is necessary to refer patients with highly elevated IOP readings (30+mmHg), but it can also be desirable to refer a patient with an IOP in the mid-20's if they have other significant risk factors for glaucoma. Whether or not treatment will be instituted based solely on IOP is at the discretion of the Ophthalmologist, but they may consider the following factors.<sup>16</sup>

**1.** Risk of glaucoma is generally low in the population

**2.** Burden of long term treatment including possible adverse effects, cost and inconvenience

**3.** The individual's specific risk of developing OAG and/or current state of progression

**4.** The individual's specific likelihood of benefiting from treatment

**5.** Health status, co-existing vision problems and life expectancy

In an attempt to clarify the roles of individuals involved with glaucoma diagnosis and management, including Optometrists, GP's and Ophthalmologist, the National Institute for Health and Clinical Excellence (NICE) is due to release guidelines in April 2009 and these will be made available on their website http://www.nice.org.uk/.

# Conclusion

IOP is a very strong risk factor for glaucoma and thus IOP measurement remains a key component of routine eye examinations conducted bv Optometrists. Appropriate measurement and interpretation of the results requires a good understanding of the ever-changing nature of IOP, the influence of the cornea on IOP measurement and the limitations of the instruments themselves. Research is very active in this field it is important to be on the lookout for new technology and information as it becomes available.

# About the Author

Dr Kirsten Hamilton is a lecturer at the School of Optometry and Vision Sciences at Cardiff University. Her research interests are concentrated on the relationships between the physical characteristics of ocular tissues, IOP measurement and glaucoma.

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### References

See www.optometry.co.uk/references



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# **Module questions**

Please note, there is only one correct answer. Enter online or by the form provided

An answer return form is included in this issue. It should be completed and returned to CET initiatives (c-10134) OT, Ten Alps plc, 9 Savoy Street, London WC2E 7HR by December 2 2008

- Which of the following is not an ocular risk factor for open angle 1) alaucoma?
- Raised IOP a)
- b) A cornea that is thinner than average
- Decreasing age C)
- A large of asymmetric cup to disc (C/D) ratio d)
- 2. Which of the following is false about the relationship between IOP and open angle glaucoma?
- A raised IOP is associated with an increased risk of glaucoma a)
- About 10% of patients with glaucoma have an IOP of 21mmHg or less b)
- 90% of eyes with ocular hypertension with an IOP of 24-32mmHg will not C) develop glaucoma within a 5 year follow-up period
- Patients with certain ocular or systemic risk factors are more sensitive to d) the level of IOP
- Which of the following is **false** about IOP? 3.
- IOP is usually similar in both eyes of the same patient a)
- An IOP of 20mmHg in the morning and 11mmHg in the evening would be b) considered an example of an average diurnal variation of IOP
- The 21mmHg "upper limit of normal IOP" is only a statistical marker C) d) There is no "normal" IOP that could be applied across all age ranges
- 4 Which of the following can cause IOP to change by several mmHg?
- **Diurnal variation of IOP** a)
- **Repeating IOP measurements numerous times** b)
- C) Lid squeezing
- All of the above d)
- 5 How often should Goldmann tonometer calibration be checked?
- Every week a)
- Every month b)
- C) Every 6 months
- d) Once a vear

#### It is useful to measure central corneal thickness (CCT) because 6.

- Eyes with thin corneas are at an increased risk of developing glaucoma a)
- Tonometers generally overestimate the IOP in eyes with thick corneas and b) underestimate the IOP in eyes with thin corneas
- CCT may affect the response to IOP-lowering medication C)
- All of the above d)

- 7. Central corneal thickness (CCT) measurement is most accurate when:
- It is measured within 2 hours of awakening a)
- b) Only one measurement is taken
- The measurement probe is positioned at a 90° angle to the corneal apex C)
- The measurement is taken at a position away from the pupil centre d)
- 8. Although central corneal thickness (CCT) can affect the accuracy of IOP measurement, IOPs should not be corrected for CCT because:
- There is no "correction factor" that is accurate in all situations a)
- It is impossible to measure CCT accurately b)
- Corneal characteristics such as biomechanical behaviour can influence C) **IOP** readings
- Both a and c d)

#### Which of the following is false about the Ocular Response Analyzer? Q

- It produces an IOP measurement called IOPG, which is similar to Goldmann a) tonometry readings
- It produces an IOP measurement called IOPCC, which is corrected for the b) effects of corneal behaviour
- It produces a measurement called OPA, which is the ocular pulse amplitude C)
- It produces a measurement called CH, which is calculated as the difference d) in pressure between 2 applanations that occur during non-contact tonometry
- Which of the following is true about the Pascal Dynamic Contour Tonometer? 10.
- It is a modified non-contact tonometer a)
- The probe tip is concave to minimise the effect of corneal properties b)
- It does not require the use of an anaesthetic C)
- d) It operates via the Imbert-Fick principle
- 11. Elevated IOP readings should not be confirmed by which of the following?
- Repeating IOP measurement with a Goldmann tonometer a)
- Repeating IOP measurement at a different time b)
- Taking the average of three readings with a non-contact tonometer C)
- Repeating IOP measurement on a different day d)

#### 12. Which of the following statements about tonometry is false?

- Goldmann and non-contact tonometry both cause corneal applanation a)
- Non-contact tonometry may be more sensitive to corneal properties than b) Goldmann tonometry
- Non-contact tonometry tends to underestimate the IOP if it is raised C)
- d) Non-contact tonometry requires an average of three readings

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