

New generation tonometers: Is it time to say goodbye to the Goldmann? C6484

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New generation tonometers: Is it time to say goodbye to the Goldmann?

Priya Dabasia presents the historical evolution of tonometry instrumentation, and provides a basic introduction into newer principles of measurement, discussing the influence that these recent developments will have upon glaucoma screening and management in the future.

Glaucoma is one of the leading causes of blindness in the Western World. The science of glaucoma detection has been a captivating area of study in many research centres worldwide, with newer methodologies continually evolving. Nonetheless, intraocular pressure (IOP) still remains one of the most significant criteria in diagnosis and management, making accurate screening essential. In practice, it is indicated by measuring intraocular tension, in which a force is applied to deform the outer coat of the eye - a process better known as Tonometry. A true measure of IOP can only be attained using manometric methods, which involve inserting a pressure probe directly into the anterior chamber.

Traditional methods of tonometry rely on measuring the force required for applanating or indenting the cornea by a specified amount. Nowadays, most practices use either applanation tonometers based on non-contact 'air puff' systems, or contact instrumentation such as the Goldmann Applanation Tonometer (GAT). GAT has been considered the 'gold standard' for over half a century, but in recent years strong concerns have been raised over its specificity and sensitivity as a screening tool for ocular hypertension (OHT). With rapid advances in tonometry technology, has the reign of the GAT finally come to an end?

When the GAT was first introduced in the 1950's, Hans Goldmann published papers reporting limitations of his prototype, stating that accuracy was heavily dependant on Central Corneal Thickness (CCT). The instrument was designed to measure IOP most precisely when applied to a cornea 520 μ m in thickness, predicting a loss in reliability with any deviation from this figure¹. At the time, this value was thought to represent the average CCT in the population, but results from more recent clinical papers suggest it may be incorrectly thin. A study by Doughty and Zamen (2000) determined a higher mean CCT of 545 μ m². Furthermore, when ocular hypertensive (OHT) groups are considered in isolation, the average corneal thickness has been found to be even greater, with more than a quarter measuring above 600 μ m³.

A thicker cornea is believed to measure a higher IOP than the actual value and vice versa. While it is clear researchers have been aware of the problems inherent in conventional applanation tonometry for some time, the bearing on glaucoma screening has only been highlighted more recently by the Ocular Hypertension Study (OHTS). It is believed to be the most influential Glaucoma clinical trial ever undertaken, involving 1636 participants from 22 centres around the US, over a 5 year period. One of the findings published in 2002 indicated a weak association between CCT and IOP⁴, confirming current ophthalmic literature which suggests that other physical characteristics of the cornea can also influence IOP readings. In response to these new concerns, extensive research has been conducted into the more complex material properties of the cornea, leading to the development of a new measure called Corneal Hysteresis (CH). A new generation of 'dynamic' tonometers have been designed to account for this biomechanical feature and 'correct' the IOP accordingly.

Early Tonometers

Basic tonometry procedures were first introduced in the late 1800's in the form of 'Digital Palpation', where physicians gained an estimation of IOP by applying finger pressure to the closed eyelid. Although the technique can only provide a crude measurement, it may still be used by experienced practitioners in A+E departments in the assessment of patients presenting with painful eyes, or in general practice on uncooperative patients.

The Schiötz tonometer (Figure 1) was one of the first mechanical instruments to emerge on the market in the early 1900's. These early designs were based on the principles of indentation tonometry, in which a concave footplate is rested on the ocular surface, while a plunger is used to indent the cornea. The plunger device is attached to a needle which moves along a scale, providing a measure of indentation depth. This in turn correlates to the final IOP along with an estimate for ocular rigidity when plotted against the Friedenwald Nomogram and applied to conversion tables. The procedure is then repeated with additional weights

measuring 5.5, 7.5, 10 or 15 grams. In essence, the greater the indentation per given weight, the lower the measured IOP. However, the use of Schiøtz is no longer justified in screening as the procedure is highly invasive, and is known to underestimate readings. This error is mainly the result of fluid displacement under the sheer weight of the apparatus, in which basic components alone weigh 11 grams.

Goldmann and Perkins Applanation Tonometers

Fifty years on, Goldmann and Schmidt introduced the GAT, the first of the 'static' applanation systems which provide the basis for most modern methods of measurement. 'Applanation' tonometry is derived from the Maklakoff-Fick law, more commonly known as the Imbert-Fick law. It states that for a spherical container assumed to be infinitely thin, perfectly elastic and dry in form, the pressure is equivalent to the force per unit area of applanation⁵. It is obvious the cornea does not fit this model with its rigid, thick structure and tear-moistened outer surface. Nevertheless, Goldmann proposed that by selecting an applanation area of 7.35mm^2 , the relative error induced in measurement could be reduced to 2.5%. Using this circular zone diameter of 3.06mm, the four forces acting on the cornea are believed to balance, as the combined outward resistance to deformation and IOP are cancelled by the force of the probe and combined tear capillary action. In addition, once the density of mercury (13.6g/cm^3) has been taken into account, an easy conversion is permitted in which 1 gram of force equates to 10mmHg of pressure.

The GAT is a slit-lamp mounted device which uses a flat cone comprised of two apposed prism apices to applanate the central zone of the cornea, creating an image of two horizontally separated rings. The force applied is then varied to make the inner edges of the rings touch. The GAT and Perkins tonometers (Figures 2 and 3) are the two main contact applanation instruments used in practice today; both utilise a fixed area-variable force principle for measurement. The latter is essentially a hand-held, portable version of the Goldmann. Alternative fixed force-variable area instruments such as the Maklakoff are commercially available, but are more widely used abroad in countries such as Russia and China.

The use of 'static' single applanation techniques circumvented the major limitations of their predecessor by reducing the induced aqueous outflow on measurement to a negligible volume of 0.50mm^3 .



Figure 1 Schiøtz Tonometer. Photograph kindly supplied by The British Optical Association Museum, © College of Optometrists.



Figure 2 The Goldmann applanation tonometer



Figure 3 The Perkins applanation tonometer

However, the procedure does involve a degree of uncertainty with a strong operator bias, even when conducted repeatedly on the same eye by a trained examiner. Moreover, it cannot be delegated to non-optical staff making it an inefficient screening tool for high street practices.

This led to the development of the third generation of tonometers, based on non-contact applanation systems, in which a force is applied to the central 3mm of the cornea by an 'air puff' generated from an in-built pump. Readings have shown good concordance with GAT within the normal range, with increasing variability above 30mmHg. In the 1970's, Reichert developed the first model, the American Optical (AO-NCT) designed to measure the time taken to fully flatten the cornea. Newer instruments such as the Keeler Pulsair, NT-3000 (Figures 3 and 4) and AT555, are fitted with a transducer to monitor the air pressure on applanation, recording this digitally as the final IOP. Unlike contact tonometry, multiple readings are essential to average out variations in pressure with cardiac pulse, and initial costs of instrumentation can be relatively high. However, these are outweighed by the benefits of ease of use, a minimally invasive procedure and delegation of screening to trained non-optical staff.

Nonetheless, it is important to bear in mind that since basic methodology is still based on 'applanation', it is subject to the same errors induced by variation in corneal physiology as GAT. This is evidenced in a study comparing the inconsistency in IOP readings when measured using the NCT, GAT, Tono-Pen and ocular blood flow tonograph (OBF). Their data showed that all four instruments were significantly influenced by CCT, with the NCT being more affected comparative to GAT⁷. This raised strong concern amongst optometric practitioners as NCT instruments are the most widely used screening tools for OHT in the UK.

Later, publication of the OHTS reinforced the value of CCT in glaucoma screening. It established a strong correlation between reduced CCT and increased severity of nerve fibre loss, identifying thin corneae as an independent risk factor in the development of the disease in a multivariate analysis⁸. Essentially, patients with thinner corneae and higher IOP values are now considered more at risk than those with thicker corneae and OHT. This was supported by a multi-centre clinical trial undertaken in Korea and Australia, in which thinner corneae were significantly associated with increased C/D ratios⁹. Subsequently, researchers began to advocate measuring CCT with IOP readings as part of the full glaucoma work-up, using it to either 'correct' the measured IOP or directly as a powerful predictive factor.

This encouraged many optometrists to invest in tonometers designed to measure both IOP and CCT, with in-built algorithms to 'adjust' the absolute readings



Figure 3 the Keeler Pulsair 3000



Figure 4 The NT-3000 (Nidek)

accordingly, or separate Pachymeters with conversion capabilities. Pachymetry is defined as the measurement of corneal thickness, using predominantly ultrasound based methodology. The apparatus emits ultrasonic beams which reflect from boundaries of differing refractive index, namely the anterior and posterior surfaces of the cornea. The echoes received by the transducer are amplified and Fourier analysed to determine the relative time delay between signal peaks. The final CCT is calculated using known measurements for the speed of sound in corneal media.

The most widely recognised instruments have been outlined as follows:

The Accutome Pachpen

The Pachpen is a lightweight (3oz), handheld device with an in-built A-Scan ultrasonic Pachymeter, and 2.5mm non-detachable probe. The probe head is slightly concave in shape to compliment the corneal radius on contact. Each successful reading is indicated by an auditory signal and once all 9 readings have been attained, 3 further beeps alert the examiner that assessment is complete. The measurements are displayed on an LCD screen, with an option to erase anomalous readings from the results pool. A measure of the mean IOP is then inputted and used to generate a truer CCT-corrected reading, by means of an integral algorithm developed by Doughty and Zamen.

Accupach V

The Accupach V is a portable pachymeter with IOP conversion facilities for CCT, which like the Pachpen has been designed with digital waveform analysis.

Palmscan P2000

The Palmscan P2000 - another ultrasonic biometer which can be set to measure both central and peripheral corneal thickness with a similar IOP adjustment capacity.

The Reichert TONO-PEN

The Tono-Pen (Figure 5) is an applanation tonometer based on the earlier Mackay-Marg design. The contact 'tip' incorporates a stainless steel transducer which uses microstrain gauge technology to convert pressure into an electrical signal. The signal is analysed and displayed as the final IOP on a quartz crystal screen as an average of 4 readings, along with a statistical coefficient. In the normal population, Tono-Pen has been found to be consistent and accurate comparative to GAT in the mid-IOP range of 11-20mmHg. Results are less accurate in the 4-10mmHg and 21-30mmHg intervals, and considered unreliable over 30mmHg where it can significantly underestimate the pressure¹⁰.

Although the Tono-Pen does not actually measure CCT, it has been included in this section as clinical trials have shown that in certain cases, readings are less affected by variations in corneal thickness. In a prospective single-centre study of the Tono-Pen by Mok et al (1999), no clinical significant difference was found between IOP readings measured from the central or peripheral cornea¹¹. In fact, clinical assessments have shown it provides a truer reading comparative to GAT when applied to the peripheral cornea of eyes which have undergone refractive surgery¹². A similar observation has been made in an analysis of post-keratoplasty eyes in which Tono-Pen has proved as accurate as the Mackay-

Marg tonometer in IOP screening¹³. This is thought to be attributed to the smaller corneal contact diameter of 1.5mm compared to the GAT cone head, which is otherwise subjected to interference by sutures and other surface irregularities. It is precisely in these patients where correct IOP measurement is crucial as corneal changes already make visual field assessment or optic disc evaluation difficult.



Figure 5 The Reichert TONO-PEN AVIA (a) The TONO-PEN XL (b). The metal transducer contact tip (c). The OCULO-FILM[®]+ latex tip covers protect TONO-PEN brand tonometers from dust and fluids, and help protect patients from the risks of cross contamination. The tip covers also feature a textures surface skin to reduce sticking to itself and the metal transducer tip during application.

When altering the measured IOP for CCT, many researchers advise a nominal reduction in IOP for every 100µm decline below 520µm, but these values can range widely between 2.0 and 7.5mmHg¹⁴. Alternatively, linear corrective nomograms can be applied, similar to those integrated in many of the instruments detailed above, but this is also considered an imprecise science in light of recent studies suggesting that 'correction' may be in the wrong direction. This is illustrated by a US study

examining IOP and CCT measurements of eyes with corneal dystrophies. The authors concluded that in eyes with Fuchs' Endothelial Dystrophy, GAT measurements were low while CCT values were generally higher than average, contradicting traditional models of thought¹⁵. It is apparent that CCT alone cannot account for this variability, and the accuracy of GAT must be dependant on other physical dimensions of the cornea such as rigidity, curvature or hydration.

It is only more recently that further research has been conducted on these additional corneal properties. Liu and Roberts (2005) applied engineering models to show that the impact of other corneal biomechanical properties is often greater than CCT alone. IOP measurement was minimally affected by corneal curvature, moderately altered by CCT, and largely influenced by material properties, which in some cases introduced an error of greater than 10mmHg¹⁶.

On an anatomical level, when examining structural variations of the normal cornea, researchers have observed significant differences in hydration, elasticity, rigidity and linking of stromal lamellae. These physical characteristics may change with age through the development of ocular disease such as dystrophies of the cornea, or metabolic diabetes-type conditions. They can also be altered synthetically by refractive laser surgical procedures, or through the instillation of certain topical medications including IOP reducing agents used in the treatment of glaucoma.

So can these physical properties be identified and measured, and more importantly how can they be used to correct the measured IOP and produce a truer reading? The search for answers has led to a new generation of instruments, carefully designed to overcome all the issues that have undermined traditional methodologies. They include the ORA (Ocular Response Analyser) by Reichert, the Pascal DCT (Dynamic Contour Tonometer) and to a certain extent the I Care by Tiolat.

Reichert's Ocular Response Analyser

The ORA is a 'dynamic' non-contact tonometer which uses 'air-puff' applanation principles not dissimilar to conventional models in which a rapid, collimated jet of air of increasing intensity is directed towards the central cornea. The full cycle is monitored by a complex system of electro-optical components, comprising of an emitting and photoreceptor diode. In static tonometry, once the cornea has been fully flattened reflecting maximum IR rays into the receptor diode, the air puff is stopped allowing the cornea to retain its original curvature. The pressure required for full applanation is monitored and recorded as the final IOP. In comparison, during the ORA sequence, the cornea undergoes 'bi-directional' applanation as the precisely metered air pulse increases

at a higher force, deforming the cornea beyond into concavity (Figure 6). Once full deformation has been achieved, the air puff stops reducing the pressure applied, enabling the cornea to resist the outward force and once again returns to its natural convex configuration. In the process, it passes through a second applanation event. The air pressure at each of the applanation phases is monitored. Due to the viscoelastic behaviour of the cornea, the time delay between applanations creates a disparity in pressures readings, where the outward event occurs at a lower pressure to the inward.

Results consisting of these characteristic curves are instantly displayed on a graphical plot, which require interpretation by a trained operator (Figure 7). The ORA is also incorporated with a 20MHz ultrasonic pachymeter to measure corneal thickness as required.

Reichert recommends taking more than one reading as consistently 'strong' signal curves indicate a high degree of reliability. Although there is no absolute figure, the software permits four graphical plots to be displayed at any one time. It is however important to note that consistently low amplitude signals may be indicative of corneal pathology such as Keratoconus¹⁷.



Figure 6 Reichert's Ocular Response Analyser (ORA)
Reproduced with permission from Reichert.

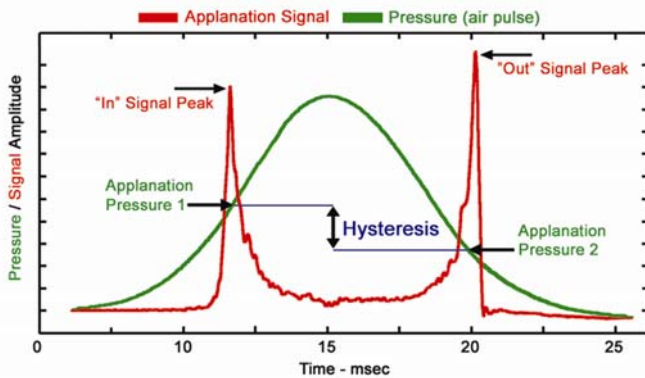


Figure 7 Green curve - represents the pressure of air applied to the cornea during the bi-directional applanation event. Red curve - indicates the strength of signal reflected from the cornea into the receiving diode. The two distinctive peaks correspond to each applanation. The difference between these two pressure values is Corneal Hysteresis (CH). Reproduced with permission from Reichert.

Analysis and manipulation of the raw data generates two indices of corneal physical properties, and two measures of IOP:

- ◆ CH (Corneal Hysteresis) - a unique measure of biomechanics (mmHg) shown to correlate weakly with CCT. It is the difference in pressure readings at the two points of applanation.
- ◆ CRF (Corneal Resistance Factor) - an indicator of the overall resistance of the cornea. Unlike CH, it has a stronger link with CCT and a weaker association to corneal-corrected IOP, as it is influenced by thickness and corneal topography, as well as biomechanical properties.
- ◆ IOPg - Goldmann correlated IOP determined by the mean pressure at the two applanation events, provided more as a historical comparative reference.
- ◆ IOPcc - True IOP altered for corneal biomechanical influences.

At present, by measuring CH, the ORA is the only instrument able to quantify the 'damping' effect within corneal tissues. A greater difference in IOP between the two applanations generates a higher CH, indicative of a relatively 'stiffer' cornea. To provide an indication of normal values for biomechanical properties, a recent study performed on 30 normal eyes, measured a mean CH of 10.2mmHg +/- 1.4SD and CRF of 10.2mmHg +/- 1.2SD¹⁸. Correcting the IOP for CH has been shown to by and large generate higher true IOP measurements with a wider range comparative to conventional 'static' applanation systems, namely the GAT. While it is primarily recognised in its role to improve the accuracy of IOP screening, it is interesting to note that it does have other potential clinical use.

Firstly, it can be used in the identification of suitable candidates for corneal refractive surgery, to improve the prediction and control of successful outcomes. It has

proved a more effective tool in assessing the risks of post-surgical complications such as corneal ectasia than current methods using CCT and corneal topography. It also promises to be a potential to aid in the screening and diagnosis of corneal disease. Eyes with compromised cornea such as Fuchs' endothelial dystrophy and Keratoconus tend to have lower mean CH measurements in the 8.0 - 9.0mmHg range, comparative to the normal sample of 10.0 - 11.0mmHg¹⁹. In fact, researchers hypothesise that even in the absence of pathological signs, eyes with lower than average CH may be at higher risk of developing conditions in later life. Lastly, and most significantly, CH may be used as a direct screening tool in glaucoma detection. Researchers investigating the aetiology of normal tension glaucoma (NTG) have measured lower than average hysteresis values with a wider spread in results, with figures not too dissimilar to eyes with corneal dystrophies at 8.74mmHg (2005). One possible explanation of these findings is that biomechanical properties of the cornea may reflect histological characteristics of the lamina cribrosa, indicating the susceptibility of nerve fibres to damage at this anatomical level through lack of adequate structural support.

The ORA is easy to use, can be delegated to trained optical assistants and free of operator bias, but there is still one potential source of error in the screening of IOP. Measurements are taken over a very short time period of 20 milliseconds, and are hence subject to short-term fluctuations such as cardiac pulse. Further trials are still required to determine an absolute number of measurements which may average out this variability.

PASCAL Dynamic Contour Tonometer

The Pascal DCT by Zeimer Ophthalmic systems (Figure 8) is a contact tonometer, which maintains corneal touch over the course of the cardiac cycle, thereby overcoming the ocular haemodynamic influenced limitations of the ORA. It has been named after the 17th century physicist Blaise Pascal who developed the universal law of pressure stating 'pressure is equivalent to the force per unit area'.

The instrumentation is not dissimilar in appearance to the GAT, attaching to a slit-lamp by the standard metal footplate. The corneal 'tip' is mounted on a cantilever arm and main instrument body, collectively applying only one gram of force to the cornea during measurements. It has an integrated solid-state piezoelectric pressure sensor which permits a direct IOP measurement free of systematic observer-dependant errors inherent in applanation tonometry in the conversion of force to pressure. The contact surface is contoured to compliment the average corneal profile, minimising distortion and 'bending', to direct all the outward forces to the sensor. This process of contour matching is independent of both the applied force and contact area,

thereby accommodating for all variations in corneal physical dimension in the population.

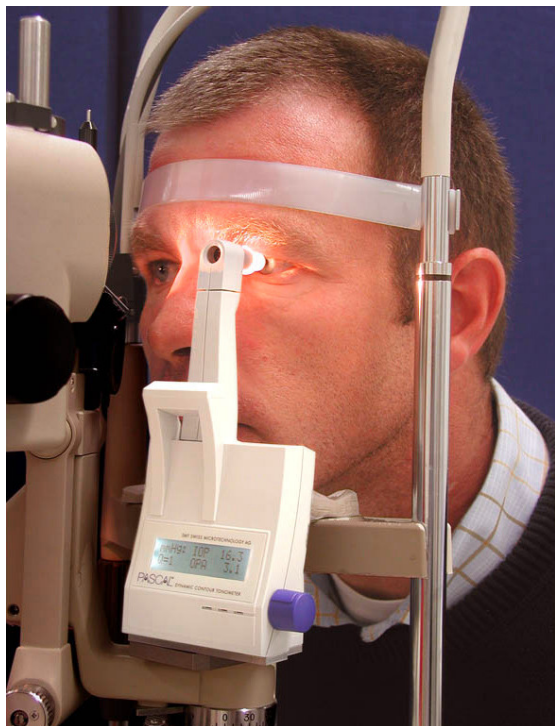


Figure 8: The Pascal Dynamic Contour Tonometer

On measurement, an auditory signal informs the examiner of 'good' contact with the anaesthetised cornea, although this can also be observed visually through the slit-lamp as a concentric, regular, constant area of contact just within the total lens diameter. An average contact time of 5 seconds is usually required for a satisfactory measurement, although some readings can take up to 8 seconds. During this time, up to 100 measurements are taken per second, and the average minimum reading is displayed on the digital LCD screen, with a Q value indicating reliability. The tips are available with disposable covers to eliminate the risk of transferring pathological microbes. The Pascal can also self-calibrate, thereby avoiding any potential operator-induced errors associated with instruments such as the GAT.

A measure of ocular pulse amplitude (OPA) is also displayed with each IOP reading, enabling quantification of fluctuations in pressure with cardiac pulse. It is determined by the difference between maximum and minimum pressures of the pulsatile IOP wave, and can vary widely between 3 and 9mmHg. OPA may play a significant role as a supplementary test in the differentiation of glaucoma sub-types, as lower measurements have been linked with normal tension glaucoma (NTG). Since OPA is dependant on ocular perfusion as well as IOP, it provides an estimation of

ocular blood flow to the optic nerve head, thereby accounting for nerve damage in the absence of ocular hypertension.

The Pascal DCT requires little basic training, producing consistent results with no noticeable learning effects, but comparative to the ORA, the procedure is more invasive and cannot therefore be undertaken by non-optical staff. Potential sources of error during measurement can be reduced by following the recommended procedures. Firstly, care must be taken to ensure the sensed tip is accurately centered on the eye. Secondly, the quality of data can be dependant on surface tear volume. Excessive liquid between the sensor tip and cornea acts as a physical barrier, preventing sufficient contact hence generating lower than true IOP readings. Conversely, poor lacrimation or dry eyes produce higher measurements as the lack of a liquid cushion induces corneal adherence. The resultant distortion forces acting on the cornea can almost double the IOP, while also causing erosion of the surface epithelium. Zeimer recommends the use of low viscosity artificial tears if instillation of more anaesthetic is still insufficient.

Pascal DCT has been shown to correlate well with IOP measurements made using manometric pressure sensor devices in cadaver eyes. This is supported by a similar clinical trial undertaken in Germany of 11 living eyes just prior to cataract surgery, in which DCT readings were within 1mmHg of intra-cameral measurements²⁰. Furthermore, in comparative studies, Pascal results show smaller inter and intra patient variability, despite the fact that the examiners involved had over five years of experience in using the GAT. Since manometric instrumentation alone is believed to measure the precise IOP directly, this is strong evidence to support the claim by Zeimer, that the Pascal DCT is the only tonometer currently available with the ability to measure the 'true' pressure of the eye. It is also important to note that as with ORA research, DCT readings tend to be consistently higher than the GAT.

Many clinical papers investigating the validity of DCT support the idea that measurements are not significantly affected by changes in CCT, keratometry or corneal biomechanics. When compared to GAT in the measurement of IOP in glaucomatous eyes as part of the AGIS (Advanced Glaucoma Intervention Study), DCT consistently recorded higher pressures in the eye with greater visual field loss, regardless of similar CCT and CH measures, while GAT readings were not significantly different.

The iCare tonometer by Tiolat

Antti Kontiola began developing the iCare tonometer (Figure 9) in the early 1990's, but the final model was only completed after a decade of work, finally gaining

approval for medical human usage in 2003. The instrument is handheld, lightweight, portable and very non-invasive with no need for anaesthesia making it ideal for use on young children or generally non-complaint patients. It is based on the principles of rebound tonometry, in which a disposable, ultralight probe held in position by an electromagnetic field, collides with the central cornea at low speed over a short time period of a few milliseconds. The force applied is so minimal that it does not even elicit the blink reflex. IOP is indicated by the relative deceleration and motion of the probe on corneal contact. A total of 6 readings are required per eye, and results are instantly displayed on an LCD screen showing a running average with each consecutive reading. An auditory signal alerts the examiner once all the results have been taken. The highest and lowest readings are automatically omitted as the mean of the remaining 4 results are displayed as the final IOP.



Figure 9 The iCare apparatus from Tiolat.

Clinical comparative studies with GAT have shown that as with the ORA and Pascal DCT, the iCare also generates higher readings. A study of 46 university students determined an average overestimation of 1.34mmHg²¹. In general, iCare measurements are considered accurate within the normal range, but alternative investigative techniques are recommended in ocular hypertensive patients. Authors have also advised awareness to

practitioners of the high degree of inter-individual variability in results.

Discussion

Every year, thousands of people in the UK are diagnosed with ocular hypertension (OHT), defined as a pressure of 22mmHg+ although individual scales can vary up to 24mmHg. These patients are closely monitored as some may eventually develop glaucoma, while others continue their whole lives with no loss in visual function. The OHTS report demonstrated a 50 percent reduction in the development of glaucoma when OHT patients considered at moderate to high risk of progression were treated with IOP reducing topical medications. Successful management of OHT is heavily dependant on the accurate assessment of IOP, which in turn permits earlier referral to ophthalmologists.

Although IOP is one of many predicting factors used in general practice in the diagnosis of glaucoma, elevated readings prompt the examiner to perform additional investigations such as full threshold visual field assessment or more detailed analysis of the optic disc. Moreover, it is the only modifiable factor when considering treatment options. Some researchers have suggested that in the diagnosis of sight threatening diseases, an error of +/- 3mmHg is unacceptable. So how do these recent developments in tonometry influence the detection of glaucoma?

Dynamic Tonometry and Glaucoma

By accounting for biomechanical properties of the cornea, all the dynamic tonometers considered in this article have been shown to generate higher true IOP readings often with a wider range than conventional tonometry. In a clinical study of 24 NTG eyes (2006), cornea-compensated IOP readings were an average of 2.25mmHg higher than the respective IOPg measurements taken by the ORA²². This suggests that potential glaucoma patients are being missed using limited static tonometers as they measure falsely low IOP readings which may fall within what is considered the 'normal' range.

Furthermore, it questions the validity of NTG - is it possible that all glaucoma patients have high IOP readings, but this is simply going unrecognised due to inaccuracies in current methods of measurement? Studies are ongoing in many research institutes worldwide to evaluate this preliminary hypothesis. Alternatively, some investigators now claim that the use of dynamic tonometry will shift the 'normal' scale to a higher IOP. In the case of GAT, the normative range is considered 10-21mmHg, while dynamic tonometers calibrated to manometric values may be 12-23mmHg.

Dynamic Tonometry and Laser Surgery

Researchers evaluating changes in corneal properties with refractive laser surgery have shown a universal post-surgical reduction in CH. This is positive evidence that creation of a flap in LASIK and ablation of underlying corneal tissue weakens the overall corneal structure affecting both hydration and viscoelasticity, as well as reducing the CCT. GAT post-surgical measurements have been found to reduce by an average of 2-6mmHg, compared to only 1mmHg in ORA readings, even though CCT was in some cases reduced by up to 171 μ m²³. Similar trends have been observed using the Pascal DCT in which post LASIK IOP measurements remained relatively unchanged while GAT readings, unable to account for this overall 'softening' of the cornea, showed a greater decline.

In screening for OHT, compensation for variability in corneal physical properties is vital not only in patients who have undergone corneal surgery, but also in those at risk of changes in corneal structure such as with corneal dystrophies or injuries.

Conclusion

At present, the ORA is the only instrument which attempts to measure corneal biomechanical properties in the form of CH, a criterion which may be used in the screening for laser surgery candidates, corneal disease and glaucoma. Dynamic tonometry has great potential in the diagnosis and management of glaucoma, particularly in light of the continuing growth in popularity of laser refractive surgery, increasing life expectancy and the rising number of baby boomers reaching the age for higher risk of development.

The key to accurate screening for OHT in the future may be provided by a battery of tests including measurement of corneal compensated IOP, corneal hysteresis, central corneal thickness and ocular pulse amplitude. This makes it all the more inevitable that one day 'static' tonometers such as the GAT will be completely replaced by their 'dynamic' counterparts, joining the ranks of the Schiötz as mere historical references.

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