# Modalities of Tonometry and their Accuracy with Respect to Corneal Thickness and Irregularities

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## ABSTRACT

Recent advances in tonometry have led to the development of a number of devices with differing clinical applications. Their role in cases of abnormal corneal thickness and surface irregularities is particularly important, as inaccurate estimation of the true intraocular pressure (IOP) in such cases may lead to suboptimal evaluation.

The purpose of the present review was to evaluate the accuracy of the most widely used devices in cases of corneal thickness and surface irregularities, based on a survey of the published literature.

The analysis was based on a Medline search focusing mainly on papers that have evaluated the devices' accuracy with respect to corneal thickness and irregularities.

Nine device types (Goldmann tonometer, Tono-Pen, Perkins tonometer, Ocular Response Analyzer, non-contact tonometer, pneumatonometer, I-Care rebound tonometer, Pascal dynamic contour tonometer (DCT) and Phosphene tonometer) were described in detail. Moreover, the physical principles and major utility of each tonometer were compared.

Each of the many different commercially available tonometers has specific advantages and disadvantages. New non-invasive technologies are getting closer to a precise estimation of the true IOP. However, among all tonometers, none is highly accurate when both corneal thickness and surface irregularities are present. Fifty years after its development, Goldmann tonometry remains the gold standard to which all other devices are compared.

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**KEY WORDS:** tonometry accuracy; intraocular pressure; corneal thickness; corneal irregularities.

## RESUMEN

Avances recientes en el campo de la tonometría han propiciado el desarrollo de diversos dispositivos con diferentes aplicaciones clínicas. Resulta de particular importancia el papel que juegan en el caso de espesores corneales anormales o en presencia de irregularidades en la superficie de la córnea, puesto que, en esos casos, una medida imprecisa de la presión intraocular (PIO) real puede traer como consecuencia una valoración incorrecta del caso.

El objetivo de esta revisión es evaluar el grado de precisión de los dispositivos más utilizados hoy en día en casos en los que existen irregularidades en la superficie de la córnea o en el espesor corneal. Para ello, se llevó a cabo una búsqueda de datos entre los artículos publicados.

El análisis estuvo basado en una búsqueda bibliográfica realizada dentro de Medline, centrándose principalmente en aquellos artículos científicos que habían estudiado el grado de precisión del dispositivo en función del espesor corneal del paciente y de la presencia o no de irregularidades corneales.

Se describen en detalle nueve tipos de dispositivos: tonómetro de Goldmann, Tono-Pen, tonómetro de Perkins, Ocular Response Analyzer, tonómetro sin contacto, neumotonómetro, tonómetro de rebote I-Care, tonómetro de contorno dinámico Pascal y tonómetro de fosfeno. Además, se presentan de forma comparada los principios físicos en los que está basado cada tonómetro y las situaciones en las que cada uno resulta de mayor utilidad.

Cada uno de los distintos tonómetros disponibles en el mercado presenta ventajas y desventajas respecto al resto. Las nuevas tecnologías no invasivas están logrando estimaciones de la PIO cada vez más cercanas al valor real de la PIO. Sin embargo, de entre todos los tonómetros analizados, no hay ninguno que sea sumamente preciso sea cual sea el espesor corneal y en presencia de irregularidades en la superficie de la córnea. Trascurridos cincuenta años desde su aparición, la tonometría de Goldmann sigue siendo la técnica de referencia, con la que han de compararse el resto de dispositivos.

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**PALABRAS CLAVE:** exactitud tonometría; presión intraocular; espesor corneal; irregularidades corneales.

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## INTRODUCTION

The term "intraocular pressure" (IOP) describes the tension exerted by the aqueous humor in the intraocular tissues as a result of the balance between its production and drainage. Since there is currently no safe invasive method of measuring the IOP intraocularly, it is really "estimated" rather than "measured" in clinical practice. However, because of its widely accepted use in the literature and in practice, we will use the term "measurement" in this review.

The importance of measuring IOP comes primarily from the concept that it is the most significant risk factor for the development and progression of glaucoma,[1-5] the most important cause of irreversible blindness worldwide.[6] Nevertheless, precise IOP measurement is subject to some confounding variables, such as circadian variation[7-9] and the influence of corneal biomechanical properties.[10-13] Furthermore, as refractive procedures become more popular and increases the indication of different modalities of keratoplasty, there is a growing interest on whether changes in corneal structure may influence IOP measurements and how it could affect the management of these patients once they are referred to a glaucoma practice.

Most commercially available tonometers estimate IOP based on corneal applanation or indentation. These devices consider that the force exerted on the external corneal surface reflects the pressure at the level of the endothelium and, therefore, the pressure in the anterior chamber and vitreous cavity (see equation 1). Where (F) is the force applied to the outer corneal surface area (A), (Pcp) is the pressure related to the corneal properties, and (tIOP) is the true IOP.

(equation 1) $$F / A = Pcp + tIOP$$

In that case, for a given ideal standard infinitely thin and spherical corneal area, the external pressure would equal the true IOP. This assumption presupposes that all individuals have identical corneal thickness and viscoelasticity. However, differences in these properties exist across individuals depending on their age, race, corneal abnormalities, or even between fellow eyes.[11-13] Thus, the accuracy of IOP measurement depends on the corneal thickness, curvature and biomechanical properties.

In this review, we will describe the most commonly used tonometers, their applicability, advantages, disadvantages, and the differences among them in terms of accuracy of measurement. To that end, we have divided them into two groups: applanation and non-applanation tonometers.

## Applanation Tonometers

### Goldmann Tonometer (Haag Streit, Koeniz, Switzerland)

Goldmann applanation tonometry (GAT), developed in the 1950s, is based on the Imbert-Fick law, which states that "the pressure in a sphere filled with fluid and surrounded by an infinitely thin and flexible membrane is measured by the counter-pressure which just flattens the membrane to a plane."[14] However, such a hypothetical membrane does not fit the corneal model. Hence, Goldmann and Schmidt[14] suggested that this device would be more precise in patients having an average central corneal thickness (CCT) of between 500 and 525 µm.

Particular attention was paid to CCT after the Ocular Hypertension Treatment Study (OHTS) found that eyes with thinner CCT are at increased risk of developing glaucoma.[2] One hypothesis was that thinner corneas may lead to underestimation of the real IOP; that is, the pressure that is causing glaucoma damage is actually higher than that measured by GAT. Despite that, GAT is still the most commonly used tonometer in clinical practice worldwide and thus remains the "gold standard" for tonometry.

The clinician should be particularly careful regarding value reliability when measuring IOP in eyes with significantly thinner (<525 µm) or thicker (>555 µm) corneas. In eyes with decreased CCT, GAT tends to underestimate IOP, while in eyes with increased CCT, this measuring technique tends to overestimate IOP. While controversial, the same seems to be valid for corneas that are flatter or steeper than usual.[15,16]

The suggested inaccuracy of GAT measurements has raised an extensive debate in the literature, particularly in cases of irregular corneas (keratoconus) and following surgical procedures (penetrating keratoplasty and refractive surgery). In keratoconus, high astigmatism, and stromal scarring, GAT may show greater variability and lower accuracy.[17-19] Brooks et al.[18] found that GAT measurements yielded significantly lower values at the apex of the cone when compared to flatter or thicker areas of the cornea, which resulted in an overall underestimation of the true IOP. In keratoconus patients, GAT IOP seems to be 5.3±2.2 mmHg lower than that yielded by non-applanation tonometry, which seemed to provide measurements closer to the true IOP.[20]

Ismail et al.[19] reported that in eyes that had undergone penetrating keratoplasty, GAT measurements may be less precise than non-applanation tonometry. Meyenberg et al.[21] suggested that GAT could slightly underestimate IOP in postkeratoplasty eyes (3.1±2.5 mm), a fact which was confirmed in cases in which the procedure preserves the deeper corneal layers.[22]

Regarding the effect of refractive surgery on GAT IOP measurements, there seems to be an agreement on the apparent IOP-lowering effect of the different modalities of surgery.[23-27] Kirwan et al.[26] found that the mean GAT IOP decreased 3.7±2.3 mmHg following LASIK, and a similar decrease was observed following LASEK. Moreover, photorefractive keratectomy (PRK) seems to induce a smaller GAT IOP underestimation than LASIK.[27] It should be emphasized that the IOP might not truly decrease following these procedures, but rather it is underestimated as a result of changes in the corneal structure (e.g., decreased thickness, presence of fluid or scarring tissue).

Attempts have been made to establish specific formulas to calculate the influence of CCT on IOP measurement, but there is no consensus about its use in practice.[28] The simple concept that IOP is being over- or underestimated depending on these variables should suffice when estimating the subject's IOP in clinical setting.

Since GAT is taken nowadays as the gold standard, all further comparisons of the different types of tonometers will be based on GAT in this review.

### Tono-Pen XL (Mentor O&O Inc., Norwell, MA, U.S.A.)

This is a light-weight contact electronic applanation tonometer, which is portable and easy to calibrate and operate. Its digital readout minimizes user bias, and due to its small contact area (2.36 $mm^2$ compared to 7.35 $mm^2$ in GAT), it is recommended for IOP measurements in irregular corneas.[29,30] It is also useful when there is poor patient cooperation, allowing measurements in both supine and sitting positions. A minimum of four measurements is necessary before the device can yield an average value. It also provides a coefficient of variation (COV) which ideally should be less then 5% for a measurement to be considered accurate according to manufacturer information.

However, studies have shown the Tono-Pen to over- or underestimate IOP without a consistent pattern. Salvetat et al.[30] found that Tono-Pen tended to underestimate GAT in 0.5±4.5 mmHg. The authors also reported that compared with GAT, the Tono-Pen showed a tendency to underestimate IOP in eyes with lower IOP (<24 mmHg), and overestimate IOP in those eyes with higher IOP (>24 mmHg). In eyes with increased CCT (>584 µm), the Tono-Pen tended to produce, consistently, higher IOP readings than GAT. Similarly, Broman et al.[31] suggested that the

Tono-Pen would overall underestimate the true IOP based on the assumption that this would be closer to the average IOP measured by three different tonometers. With regard to irregular corneas, Mollan et al.[32] evaluated the performance of four different tonometers in eyes with keratoconus and found that Tono-Pen overestimated GAT in 3.6±10.1 mmHg. Moreover, in this group of patients, the Tono-Pen gave overestimated IOP values for lower IOPs and underestimated ones for higher IOPs (always compared to GAT readings), whereas it seems to be less dependent on CCT in keratoconus than GAT. In postkeratoplasty eyes, GAT and Tono-Pen showed a good agreement (mean difference 0.14 mmHg) and Tono-Pen IOP was largely independent of corneal thickness.[33] In summary, Tono-Pen measurements should be interpreted cautiously especially in eyes with increased CCT, whereas it might prove helpful in irregular corneas due to its smaller contact area.

**Perkins Handheld Tonometer (Medtronic Solan, Jacksonville, FL, USA)**

The Perkins applanation tonometer is a portable version of the GAT, also requiring topical instillation of fluorescein. Portable, handheld tonometers have the advantage of being easily transported from site to site for screening examinations and for those patients for whom the use of a chin rest proves difficult. They are especially useful for the determination of the daily curve of IOP (supine position). There is a close agreement between the Perkins tonometer and GAT,[34,35] with a mean difference of 1.0 mmHg between the two tonometers.[34] Also, since breath-holding (required for GAT measurements, taken in sitting position) and thus thorax compression may cause transitory elevations of IOP, the Perkins tonometer may provide more reliable measurements in these cases of falsely elevated IOP.[36]

Due to its high agreement with GAT and with intracameral measurements readings, Perkins tonometry could be considered the gold standard for portable tonometry.[37]

**Ocular Response Analyzer (Reichert Ophthalmic Instruments, Depew, New York, USA)**

The ocular response analyzer (ORA) uses an air-pressure-triggered, dynamic, bi-directional corneal applanation method to measure corneal biomechanical parameters. An air pulse on the cornea causes its movement inward, and creates a slight concavity. The device makes two measurements of the corneal response to the air pulse—the force necessary to flatten the cornea as the pressure of the air pulse rises, and the force at which the cornea flattens again after the air pump shuts off. The difference between the two measurements (inward and outward applanation) is termed corneal hysteresis. Based on this initial evaluation, the device provides 4 different parameters: Goldmann-correlated IOP, corneal-compensated IOP (IOPcc), corneal resistance factor (CRF) and corneal hysteresis (CH).[38] Among these parameters, CH is the one that has been most evaluated in previous studies and is considered an indicator of the viscoelastic properties of the cornea.[31] CH is weakly correlated with CCT, is almost constant throughout the day,[39] and seems unassociated with refractive error or axial length.[40,41]

ORA measurements show good within-session repeatability in normal volunteers.[42] Mean values of IOPcc, CH and CRF in a study including healthy patients (CCT=557 ± 36µm; GAT=14.8±3 mmHg) were 16.2±4.1 mmHg, 10.6 ±2.3 mmHg, 10.9±2.4 mmHg, respectively.[43] Regarding the device's IOPcc, it seems to provide higher IOP readings than GAT in normal subjects. Moreover, IOPcc measurements could provide an estimate of IOP that is less influenced by corneal properties than that provided by GAT.[31,39-44] Patients with lower CCT and CH values tend to have higher IOPcc values, compared to GAT results. Conversely, patients with higher CCT and CH values tend to get lower IOPcc values.[43,44] Furthermore, Medeiros et al.[13] demonstrated that IOPcc was not correlated with CCT or corneal curvature, but it was positively associated with age. Even though the overall difference between GAT IOP and IOPcc was not significant, it tended to be bigger for increasing CCT values.

Glaucoma patients appear to have lower CH values with ORA than normal subjects, and lower CH values have been associated with progressive visual field worsening.[45] Lower CH was observed in glaucoma patients with acquired pits of the optic nerve head compared to patients who did not. This could suggest that corneal biomechanical properties may reflect viscoelastic properties of the lamina cribrosa, for example.[46]

In keratoconus eyes, both CH and CRF seem to be lower than in a normal population (10.6±2.2 versus 8.7 ± 2.2 mmHg, and 10.0±2.5 versus 6.9±2.4 mmHg, respectively).[32] There is also a significant decrease of both CH and CRF following LASIK,[47] which could probably account for the changes observed in GAT measurements as described previously.

Although interesting initial results have been published with regard to various diseases, there is still a need to better understand their clinical value. ORA has shown to provide reproducible and stable values within different day-time measurements,[48,49] which were independent from the IOP fluctuation detected by GAT.[48] These findings suggest a promissory role of ORA in understanding the effect of different corneal conditions on tonometry.

**Non-contact Tonometer or Air-puff Tonometer (Reichert Ophthalmic Instruments, Depew, New York, USA)**

Grolman created this non-contact applanation tonometer in the 1950s aiming to make it available for optometrists to perform tonometry measurements. Briefly, an air-puff causes a transient applanation of the cornea, while an infrared light beam is reflected by the flattened surface. The amount of light reflected during the applanation period is compared with the time the air-puff took to cause applanation, allowing this device to provide an electronic measurement of the IOP. It also provides the ocular pulse amplitude and tonographic measurements that estimate the aqueous outflow efficiency of the trabecular meshwork according to manufacturer information. Historically, non-contact tonometers were not considered to be the most accurate way to measure IOP. There were concerns that low pressures were overestimated and high pressures underestimated. The oldest versions of this tonometer showed a fair agreement with GAT (±3 mmHg), but tended to overestimate the IOP for pressures lower than 10 mmHg and underestimate it for values above 19 mmHg.[50] However, modern non-contact tonometers correlate very well with GAT IOP, even though they tend to systematically overestimate it by between 0.12–0.58 mmHg.[51-53] With regard to the influence of corneal properties on non-contact tonometry measurements, it is likely that they are more influenced by CCT than GAT. In thinner corneas, there seems to better correlation between the tonometers, while in thicker corneas, non-contact tonometry systematically yields higher readings than GAT.[54]

In summary, non-contact tonometers have generally been considered a fast and simple way to screen IOP. The benefits of non-contact tonometry include patient preference, less operator dependence, and no risk of infection transmission.[50-53]

**Pneumatonometer (Mentor, Model 30 Classic, Reichert, New York, USA)**

This is an easy-to-use instrument which provides fast and accurate tonometry readings. Utilizing a pneumatic pump, it can provide real time readings of IOP through a noninvasive applanation method. A gentle, floating pneumatic sensor touches the surface of the anesthetized cornea with the exact amount of applanation force required to take the measurement. Another advantage would be its use in measuring IOP in contact-lenses wearers.[55] The overall values obtained are usually slightly lower than those furnished by Goldmann tonometry, and they are also significantly associated with CCT and IOP itself. In this sense, pneumatonometry significantly underestimates GAT measurements at lower IOP and overestimates these at higher IOP. For example, for GAT IOP measurements <10 mmHg, the difference is around 2.0 mmHg, while for GAT IOPs ≥25, the difference is -0.6 (GAT - pneumotonometer).[56] Also, as the GAT values increase, the pneumatonometer increasingly overestimates IOP.[57] On the other hand, in eyes with keratoconus, the pneumatonometer underestimates IOP, yielding values that are lower than GAT ones by about 1.5 mmHg.[20]

Similarly to the air-puff tonometer, this device finds large applicability as a screening tool by non-specialized personnel. In a clinical setting, the results should be analyzed cautiously.

## Non-Applanation Tonometry Devices

**Rebound Tonometry- I-Care Tonometer (Tiolat, Helsinki, Finland)**

Based on the rebound principle described by Dekking and Coster in 1967, this is a contact rebound tonometer that uses a light probe containing a permanent magnet that is launched towards the eye using a solenoid. The probe hits the eye and bounces back. The same solenoid, inside which moves the probe, is used to detect the movement and impact of the probe, because the moving magnet induces voltage in the solenoid. The motion parameters measured during impact are used to estimate the IOP.[58,59] It is a handheld, portable tonometer that displays the IOP reading digitally and does not require topical anesthesia. Following 6 measurements, the device automatically determines the mean pressure and the standard deviation.

I-Care has been found to be of clinical usefulness as a self-tonometer and among non-specialized personnel. Thus, it has been proposed that it could be used in screening studies by non-medical staff. Recent reports about its accuracy have been conflicting. Van der Jagt and Jansonius[60] found that I-Care slightly overestimated GAT by 0.6 mmHg (mean difference between 0.0 and 1.2 mmHg) even though such difference was not significant. Also, the authors described that adding corneal thickness to the regression analysis did not yield any increase in the variance of IOP measurements. On the other hand, Nakamura et al.[61] studying a population that ranged from normal subjects to ocular hypertensives and glaucoma patients found that I-Care overestimated IOP, as compared to GAT, by 1.40±4.29 mmHg, and that this disparity tended to increase along with corneal thickness. They suggested that corneal thickness could affect the duration of the impact of the rebound tonometer, causing an overestimation in thicker corneas. These results are confirmed by several other reports[62-65]. Even though little information is available on its use in irregular corneas, Jóhannesson et al.[63] found that, unlike what was observed for GAT, corneal curvature was not correlated with I-Care IOP measurements. In general, I-Care seems to be a reasonable option for screening purposes,[63] and measurements should always be interpreted with regard to CCT when used in a clinical basis.

**Dynamic Contour Tonometry – Pascal Tonometer (SMT Swiss Microtechnology AG, Zurich, Switzerland)**

The dynamic contour tonometer (DCT) is a novel digital non-applanation contact tonometer designed to be largely independent of the structural properties of the cornea, possibly giving IOP measurements that are closer to the true IOP.[15,16,66] It is a useful tool in situations where the clinician suspects inaccurate IOP measurements that could be caused by corneal biomechanical properties. It is particularly accurate in eyes with keratoconus,[20,21,67] corneal edema,[68] and those that have undergone penetrating keratoplasty[21,22,69] and refractive surgery.[25,70]

The DCT provides a score (Q) representing the quality of the IOP measure. The score ranges from 1 (optimum) to 5 (unacceptable). For clinical and scientific purposes, only those measurements with Q scores of 1 or 2 are considered reliable reliable according to manufacturer information.

Along with the IOP and Q score, the digital screen also displays the ocular pulse amplitude (OPA), which represents the average difference between the systolic and diastolic IOP within 6 hear beats. It has been suggested that OPA provides a surrogate measure of the ocular blood flow, mostly due to the choroid.[71,72]

Most of the studies agree that DCT tends to overestimate GAT by about 2.3 -3.4 mmHg, depending on the IOP level, CCT and other corneal properties.[15,16,30,73] Milla et al.[73] found an optimal agreement between DCT and GAT when the CCT was between 540 and 545 µm. As the CCT and the IOP increase, the difference between both tonometers also

**TABLE 1**
Advantages and disadvantages of the different commercially available tonometers

| Tonometer* | Portability | Accuracy (relative to GAT) | Accuracy (irregular corneas) | Accuracy (corneal thickness) | Corneal contact |
|---|---|---|---|---|---|
| GAT | - | | - | - | + |
| PAT | + | good agreement | - | - | + |
| TAT | + | depends on IOP level | + | - | + |
| ORA | - | overestimates | - | + | - |
| I-Care | + | conflicting reports (good agreement or overestimates) | little information available | - | + |
| NCT | +/- | depends on device model and IOP level | - | - | - |
| DCT | - | overestimates | - | + | + |
| PT | +/- | overestimates | + | - | + |
| PPT | + | underestimates | + (applied through the eyelid) | + (applied through the eyelid) | - |

**GAT, Goldmann applanation tonometer; PAT, Perkins applanation tonometer; TAT, Tono-Pen applanation tonometer; ORA, Ocular Response Analyzer; NCT, Non-contact tonometer; DCT, Dynamic Contour Tonometer; PT, Pneumatonometer; PPT, Phosphene tonometer.*

increases.[30] In eyes with keratoconus, the difference between DCT and GAT ranged from 4.3 to 5.3 mmHg.[20,32,67] Pascal tonometry seems to be largely independent of the IOP and CCT in those patients.[32] In eyes that had undergone keratoplasty and refractive surgery, DCT seems to be less influenced by changes in corneal properties following these procedures.[19,25,74]

As a digital tonometer with an automated IOP quality-check, together with the increasing evidence of being largely independent of corneal properties, Pascal tonometry seems to be a promising tool for IOP determination in different pathological conditions in clinical practice.

**Phosphene Tonometry (Proview, Bausch & Lomb Pharmaceuticals, Inc., Tampa, Fla.)**

The pressure phosphene tonometer (PPT) is a self-tonometry device that was first described in 1998.[75] It uses the entoptic phenomenon of pressure phosphene to evaluate IOP.[76,77] The PPT is initially applied perpendicular to the eyeball through the partially closed eyelid, and no topical anesthesia is required. Afterward, the applied pressure is increased gradually until the moment when the patient clearly perceives a well-formed phosphene (usually described as a dark circle with a ring of light around the outer circumference). The device is then removed from the eyelid and IOP can be read from the dial.[76,77] The PPT presents several advantages, such as: a) no contact with the cornea and no anesthetic drop required; b) it seems not to be influenced by corneal biomechanical properties; c) it allows for insights into patient-specific, diurnal variations.[75-78] Also, it has been reported to present good reproducibility when used by patients.[78] On the other hand, there is controversy regarding its accuracy. Most studies have compared the PPT to the GAT and some of them found a poor agreement between the two devices, even when measurements were done by a trained examiner.[78,79] PPT, compared to GAT, consistently underestimated the IOP by approximately 3.5 mmHg,[79], and was not able to detect IOPs above 22 mmHg in as much as 82% of patients.[78] PPT IOP should be evaluated carefully in clinical practice, and has limited applicability as population screening device, mostly due to its low sensitivity in detecting high IOP values.[78]

**SUMMARY**

There are many different commercially available tonometers, each of them showing specific advantages and disadvantages *(Table 1)*. Furthermore, before determining which device is more accurate one should determine for what purpose it is going to be employed. In general, there are two main situations in which these devices are currently used: a) clinically, for diagnosis and patient follow-up; b) as a population screening tool. In the first case, new devices such as DCT and ORA seem to be largely independent of the corneal biomechanical properties and may be particularly helpful in eyes with corneal abnormalities and following keratoplasty or refractive surgery. Since these are devices that have shown relatively good reproducibility/repeatability in different studies,[49,56] they might add more relevant information longitudinally. For instance, in a patient that presents corneal edema secondary to cataract surgery (*bullous keratopathy*), a single IOP measurement using DCT may not be as relevant as the information provided during follow-up, such as whether a new treatment resulted in increased or decreased IOP. On the other hand, GAT measurements are irreplaceable in this situation since most available studies that evaluate the efficacy of antiglaucoma drugs or procedures are based on GAT values. As far as their use as a screening tool, hand-held non-contact tonometers show a fairly good agreement with GAT in eyes with statistically normal IOP (15 – 22 mmHg) and CCT (525- 555). Except for PPT, most of the devices described above could provide reproducible and reliable IOP measurements even when used by non-trained personnel in screening projects. Moreover, portable tonometers with reduced applanation area (such as Tono-Pen) are especially helpful in non-collaborative patients and when corneal irregularities may be affecting the accuracy of the measurement.

Although new non-invasive technologies seem to be getting closer to a precise estimation of the true IOP, most of the available literature and large clinical trials in glaucoma (e.g., OHTS, EMGT, AGIS)[1-5] were based on GAT readings. We believe that even if a new technology one day proves itself to provide a very precise estimation of the true IOP regardless of corneal properties, such information would be at first of limited applicability for the clinician. New definitions of "statistically normal" or "target" IOP will need to be reformulated before the practitioner can actually start making decisions based on a new tonometer.

On the other hand, these new devices provide not only information about IOP, but also new ocular parameters, such as corneal hysteresis (ORA) and ocular pulse amplitude (DCT). As some studies have reported differences in these parameters between glaucomatous and non-glaucomatous patients,[20,31,39,45,46,71,72] we believe that in the future these parameters might prove useful to better understand the pathophysiology in different eye conditions.

It is important to emphasize that the IOP readings from these devices are not interchangeable, and even in patients with regular and corneal thickness in the average range, some of them seem to constantly disagree with GAT values. Rather then using multiple devices in the same patient, the clinician should choose one that better fits each clinical indication and use it consistently.

Among all the available tonometers, there is still no device capable of providing IOP readings with high accuracy regardless of the value of the corneal thickness, the surface irregularities, or the particular conditions the patient may have. A customized application seems more reasonable. Fifty years after its invention, Goldman tonometry has helped build most of the knowledge available regarding aqueous humor dynamics and IOP monitoring whereas it remains as the gold standard all new technologies should be compared with.

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