Comparison of dynamic contour tonometry, Goldmann and pneumotonometer in ocular hypertension patients and their relationship to pachymetry and ocular pulse amplitude

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Purpose: To determine the relationship between dynamic contour tonometry (DCT), Goldmann applanation tonometry (GAT) and pneumotonomometry (PNT) in ocular hypertension patients (OHT) and their relationship to central corneal thickness (CCT) and ocular pulse amplitude (OPA).

Methods: Sixty patients (101 eyes) with intraocular pressure (IOP) ≥ 21 mmHg using GAT and normal appearing optic nerve heads and normal visual fields were included. The following tests were performed simultaneously during a single visit: IOP using DCT, GAT and PNT, OPA using DCT and CCT using ultrasound pachymetry. We studied the difference IOP between these 3 tonometers using Wilcoxon non-parametric test and the effect of CCT on IOP and OPA, as well as the relationship between OPA and IOP using Spearman correlation coefficient.

Results: The median PNT IOP was 24 mmHg (inter-quartile range [IQR]: 22–26), median GAT IOP was 22 mmHg (IQR: 22–24), and median DCT IOP was 28.2 mmHg (IQR: 24.1–30.7). PNT and DCT had higher IOP values than GAT (median 2 mmHg and 6.2 mmHg, respectively). Mean CCT was 594.5 μm (SD 30.0). GAT IOP and DCT IOP showed an increase with increased corneal thickness (r: 0.209; P = 0.036 and r: 0.195; P = 0.051, respectively). PNT IOP did not change with CCT (r: 0.15; P = 0.12). The median OPA was 4.8 mmHg (IQR: 3.6–6.1), and significantly increased with GAT IOP (r: 0.38; P < 0.001 and with CCT (r: 0.287; P = 0.004). This association was unclear with OIP PNT and IOP DCT (r: 0.17; P = 0.08, respectively).

Conclusions: DCT and PNT IOP values were higher than GAT IOP measurements in ocular hypertension patients. GAT IOP showed a significant increase with increased corneal thickness. Increased OPA seems to correlate with increased CCT and IOP, particularly if GAT is used.

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Palabras clave:
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Comparación de tonómetro de contorno dinámico, Goldmann y neumotonómetro en pacientes con hipertensión ocular y su relación con la páquimetría y amplitud del pulso ocular

RESUMEN

Objetivo: Determinar la relación entre el tonómetro de contorno dinámico (TCD), Goldmann (TG) y neumotonómetro (NT) en pacientes con hipertensión ocular (HTO) y su relación con el grosor central de la córnea (GCC) y amplitud del pulso ocular (APO).

Método: Se han incluido 60 pacientes (101 ojos) con presión intraocular (PIO) ≥ 21 mmHg con TG y sin alteraciones glaucomatosas en disco óptico y campo visual. Se ha medido la PIO con TG, TCD y NT, la APO con el TCD y el GCC con pácquimetría de ultrasonido. Se ha estudiado la diferencia de PIO entre los tres tonómetros mediante el test no paramétrico de Wilcoxon y la relación de la APO con el GCC y la PIO con el coeficiente de correlación de Spearman.

Resultados: La mediana de PIO con NT fue de 24 mmHg (RIC: 22–26), con TG de 22 mmHg (RIC: 22–24) y con TCD de 28,2 mmHg (rango intercancinal [RIC]:24,1–30,7). En comparación con el TG la PIO fue mayor con el NT y con el TCD, siendo la diferencia de medias de 2,0 y de 6,2 mmHg respectivamente. La media del GCC fue de 594,5 μm (DE 30,0), encontrándose una asociación estadísticamente significativa entre esta y la PIO con TG (r: 0,209; p=0,036) y de magnitud similar aunque no sin significativa con el TCD (r: 0,195; p=0,051). No se encuentra asociación entre GCC y NT (r: 0,15; p=0,12). La APO fue de 4,8 mmHg (RIC: 3,6–6,1), incrementándose significativamente con la PIO tomada por el TG (r: 0,388; p<0,001) y con el GCC (r: 0,287; p=0,004). Esta relación no fue significativa con el NT y TCD (r: 0,067; p=0,50 y r: 0,17; p=0,08 respectivamente).

Conclusiones: Los valores de PIO con TCD y NT son mayores que con TG en pacientes con HTO. La PIO con TG se ve influenciada por el aumento de GCC. El incremento de APO se asocia a un incremento del GCC y de PIO con los tres tonómetros (esta relación solo estadísticamente significativa con el TG).

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Introduction

In contrast with the Goldmann applanation tonometer (GAT) and the pneumotonometer (PNT), the dynamic contour tonometer (TCD) (Pascal; Swiss Microtechnology AG, Port, Switzerland) measures IOP through a piezoelectric sensor and a tip with a concave surface which adapts to the contour of the cornea, causing minimum distortion. The absence of significant corneal applanation means that the measurements are not influenced by corneal properties such as corneal central thickness (CCT) or curvature. Together with the intraocular pressure (IOP) value, it also measures the ocular pulse amplitude (OPA), defined as the difference between systolic and diastolic IOP during the period of contact between the tonometer and the eye. OPA indicates ocular blood flow and can be an important parameter in the clinical management of glaucoma.1–4

It is known that patients with ocular hypertension (OHT) are defined as exhibiting an IOP of ≥21 mmHg, without evidence of glaucomatous damage in the optic disc and with normal visual fields. Generally, these patients exhibit high CCT, which is frequently one of the causes of IOP overestimation with GAT or PNT.

Very few articles have studied OPA in this type of patients and its association with parameters such as CCT and IOP.

The aim of this article is to determine IOP with different tonometers (GAT, TCD, PNT) in patients with OHT and analyze their relationship with CCT and OPA.

Subjects, material and method

An observational study comprising 60 patients (101 eyes) with OHT (defined as IOP ≥ 21 mmHg, without glaucomatous damage in the optic nerve and with normal visual field) in the Ophthalmology Service of the del Tajo de Aranjuez hospital between October 2010 and May 2011. Both eyes were considered in 47 patients.

None of the patients had been submitted to previous ocular surgery or exhibited other ocular diseases or topical hypotensor treatment at the time of the study.

Complete visual acuity (VA) study was performed, together with slit lamp assessment, ocular fundus, IOP measurement with (AT90000.Haag Streit International, Swiss), TCD (Pascal; Swiss Microtechnology AG, Port, Switzerland) and PNT (CT-80; Topcon, Tokyo, Japan), CCT measured with contact pachymeter (Optikon 2000 S.P.A; Roma, Italy) and OPA measured with TCD. All patients were subjected to campimetry (Humphrey automatic perimetry) and optic coherence tomography (Cirrus; Carl Zeiss Meditec, Jena, Germany) of the optic nerve. Three IOP measurements were taken with each tonometer, taking the mean value. The same procedure was taken with pachymetry. In the case of TCD, the only
measures considered were those having a quality grade of Q ≤ 3 (the device considers Q1 as the optimum grade and Q5 as unacceptable, with Q3 being acceptable). New protecting tops were used for each patient. In the case of GAT, a 5 min wait was observed between each take in order to minimize the tonometer application effects. Pachymetry was performed in the center of the cornea without pupil dilatation. Before the GAT takes, one drop of oxybuprocaine 0.5% with sodium fluorescein 0.25% was applied on the eye to be studied. Before the TCD and contact pachymetry takes, one drop of oxybuprocaine 0.5% with tetracaine was applied. The order of all the measurements was random.

For the statistical analysis, the Intercooled Stata 9.1 for Windows (StataCorp LP, Tejas, USA) software was utilized. Nonparametric tests were applied in the case of variables exhibiting distributions significantly different to normal values (IOP and OPA), calculating the mean values and interquartile ranges. In the case of CCT, distribution followed a normal curve and therefore mean and standard deviation values were utilized. In the comparison of IOP between the various tonometers, Wilcoxon test was used. The analysis of the relationship between OPA, CCT and tonometry was performed with Spearman correlation analysis. The graphic representation comprised IOP box graphics on the basis of the utilized tonometer, Bland–Altman graphs with trend adjustment for comparing IOP measurements (2–2) and smoothed Lowess graphs for illustrating the relationship between OPA, CCT and IOP with each tonometer.

**Results**

The study included 60 patients (101 eyes), 27 females and 33 males with a mean age of 59.2 years (31–86 years).

The median IOP with GAT was of 22 mmHg (RIC: 22–24), with TCD of 28.2 mmHg (RIC: 24.1–30.7) and with PNT of 24 mmHg (RIC: 22–26) (Fig. 1). Both PNT and Pascal found significantly higher IOP values than GAT, with a statistical z in the Wilcoxon test of 3625 and 6838 respectively (p<0.001), with the difference of mean values between GAT and PNT of 2.0 and 6.2 mmHg between GAT and TCD. For ranges between 20–24 mmHg, the measurements between

![Figure 1](image1.png)

**Fig. 1** – Intraocular pressure box plot (mmHg) on the basis of the tonometer utilized for measuring it.

GAT and PNT were similar. However, the difference increased proportionally with higher IOP values, where PNT gave increasingly higher values than GAT (Fig. 2). The measurements taken with TCD tended to be greater than those taken with GAT and PNT, being moderate in lower IOP ranges. However a surprisingly high degree of variability was found in the TCD measurements, including with lower IOP values (differences of up to ±10 mmHg were found with GAT or PNT) (Figs. 3–4).

The mean CCT was of 594.6 μm (SD 30.0). An assessment of IOP taken with the different tonometers on the basis of the CCT shows that the only statistically significant association was with GAT (r: 0.209; p = 0.036). This relationship was of similar magnitude even though it was not significant with TCD (r: 0.195; p = 0.051). No association was found between CCT and PNT (r: 0.15; p = 0.12) (Fig. 5a–c).

![Figure 2](image2.png)

**Fig. 2** – Bland–Altman graph illustrating the difference in intraocular pressure measurements between Goldmann applanation tonometer and pneumotonometer.

A proportional increase of the difference between both tonometers can be observed when increasing intraocular pressure values, with the pneumotonometer giving increasingly higher values.

![Figure 3](image3.png)

**Fig. 3** – Bland–Altman graph illustrating the difference in the measurement of intraocular pressure between dynamic contour tonometer and pneumotonometer. High variability can be seen in the measurements with dynamic contour tonometer.
The median OPA was of 4.8 mmHg (RIC: 3.6–6.1). OPA values increased together with IOP. This relationship was more evident and became statistically significant only with GAT (r: 0.38; p < 0.001), but is not significant for PNT and TCD (r: 0.067; p = 0.5 and r: 0.17; p = 0.08 respectively) (Fig. 6a–c). A significant association was also found between OPA and CCT (r: 0.287; p = 0.004).

Discussion

OHT patients are defined as having an IOP ≥ 21 mmHg without alterations in the optic disc or the visual field. Generally, they associate above average CCT values (usually >580 μm). This characteristic can induce error in diagnostics because, as it is well known, GAT tends to overestimate IOP when CCT is high.5–9 However, as repeatedly described, TCD is less affected by CCT and other corneal characteristics.10–13

One of the objectives of this study was to determine IOP taken with different tonometers (GAT, TCD, PNT) in OHT patients. In the majority of studies with healthy or glaucoma patients, IOP obtained with TCD is always higher than that obtained with GAT or PNT, although this association is controversial in patients with OHT.1,14 Some authors like Chungkwon et al. observed that in patients with IOP > 30 mmHg, IOP with TCD was lower than with GAT, and Barleon et al. found the same association for patients with IOP ≥ 25 mmHg.15,16 However, Milla et al. described with TCD a mean IOP value of 5.5 mmHg higher than with GAT, with this difference being increased with higher IOP values.17 In this study, higher IOP values were found with PNT and TCD (mean value differences of 2.0 and 6.2 mmHg when compared with GAT respectively) and, matching the findings of Milla et al., this study found that for ranges between 20 and 24 mmHg the measurements between GAT and PNT are similar and the difference between TCD and GAT is only moderate although for higher values the difference increases proportionally to the increase of IOP values.

Analyzing the IOP taken with the different tonometers on the basis of CCT, most of the studies show that for corneas with a medium CCT (520–579 μm) there are virtually no differences between GAT, PNT and TCD and that GAT tends to underestimate IOP in thin corneas (<520 μm) and to overestimate it in thick corneas (≥580 μm), being more influenced by CCT than TCD.10,13,18 An additional objective of this study was to observe the influence of high CCT in different

**Fig. 4** – Bland–Atman graph illustrating the difference in the measurement of IOP between dynamic contour tonometer and Goldmann applanation tonometer.

**Fig. 5** – (a–c) Lowess smoothed graph illustrating the association between intraocular pressure measured with different tonometers and cornea central thickness.
a non-significant increase of GAT (r: 0.14; p = 0.09). Doyle and Lachkar observed that for thin corneal TCD was independent, whereas for thick cornea it was also influenced and therefore did not yield any benefits vis-à-vis GAT. Ku et al. found important disparities in thick cornea between GAT and TCD. Wang et al. observed a positive and significant correlation between GAT and TCD with CCT. In this study, the mean CCT value was of 594.6 μm, finding a statistically significant association between GAT and CCT (r: 0.209; p = 0.036) and a relationship having a similar although not significant magnitude with TCD (r: 0.195; p = 0.051). However, no association was found between CCD and PNT (r: 0.15; p = 0.12). The high degree of disparity between results in different studies with patients exhibiting high CCT values increases the complications to obtain a correct diagnostic for OHT.

OPA is a parameter which could be useful in the clinical management of glaucoma. Some papers go to the extent of proposing that increased OPA is related to a lower degree of severity in glaucoma and that low OPA is a parameter of detection and monitoring in glaucoma patients with normal IOP values. It can be affected by corneal parameters such as curvature, CCT or ocular globe wall elasticity, as well as by blood flow. One of the aims of this study was to determine OPA in patients with OHT as well as the possible influence of CCT and IOP in the measurement thereof.

It seems clear that in OHT patients OPA is higher than in healthy subjects or glaucoma patients. Punjabi et al. found OPA of 3.61 in OHT against 2.86 mmHg in the control group. In this study, the median OPA was of 4.8 mmHg.

Most of the studies found a positive relationship between OPA and IOP in healthy subjects. Kaufmann et al. described an OPA increase of 0.12 mmHg for each 1 mmHg of IOP (p < 0.001). What is not as clear is whether this relationship is also positive in subjects with OHT. Punjabi et al. did not observe increased OPA with IOP in this group of patients. However, in this study a relationship between IOP and OPA was found, and it became statistically significant when measuring IOP with GAT. Chungkwan et al. also found that OPA diminished together with IOP after hypotensor treatment in a group of patients with IOP > 30 mmHg. However, said study cannot be extrapolated to the OHT population as it also included patients with various degrees of glaucoma.

The relationship between OPA and CCT is also controversial. Kaufmann et al. and Weizer et al. found this association to be positive (p = 0.08 and p ≤ 0.01, respectively), whereas Punjabi et al. found it to be negative, suggesting that thinner cornea could lead to an overestimation of OPA due to underestimation of diastolic IOP. In this study a positive and clearly significant relationship between OPA and CCT was found (r: 0.287; p = 0.004).

In contrast with healthy or glaucoma patients, where the association between different tonometers and the influence of pachytermy and OPA seems clearer, in OHT patients these relationships are more controversial. The fact of exhibiting more extreme IOP and CCT values makes it difficult to study and diagnose. In addition, the clinical significance of the fact that this type of patients exhibits higher IOP is similarly unclear. It is necessary to carry out additional studies and research with live manometry in order to

![Fig. 6](a-c) Lowess smoothed graph illustrating the association between intraocular pressure measured with different tonometers and ocular pulse amplitude.  

Erickson et al. found that in subjects corneal ≥580 μm, the IOP obtained with GAT was significantly higher than that obtained with TCD (1.19 mmHg; p < 0.005), finding differences of ≥3 mmHg in some cases. In the group of OHT patients studied by Punjabi et al., when CCT increased, IOP with TCD diminished slightly (r: −0.37; p = 0.25) and IOP with...
correctly compare the relationship between TCD, GAT and PNT and their association with parameters such as CCT and OPD.

Conflict of interest

No conflict of interest has been declared by the authors.

REFERENCES