Irish Journal of Medical Science (1971 -) (2019) 188:321–325
https://doi.org/10.1007/s11845-018-1795-0

ORIGINAL ARTICLE

Difference in intraocular pressure measurements between non-contact tonometry and Goldmann applanation tonometry and the role of central corneal thickness in affecting glaucoma referrals

Khalid Kamel[1] · Edward Dervan[1] · Kevin Falzon[2] · Colm O'Brien[1]

Received: 17 January 2018 / Accepted: 14 March 2018 / Published online: 4 April 2018

Abstract

Background Patients at glaucoma risk are commonly identified by optometrists and subsequently referred to glaucoma specialists. Optometrists mainly use non-contact tonometry (NCT) for intraocular pressure (IOP) measurement.

Aims To investigate the role of differences in IOP measurement between NCT and Goldmann applanation tonometry (GAT) and the effect of central corneal thickness (CCT) on these differences in optometrist referrals

Methods Details of the initial clinical visit of patients referred with IOP > 21 mmHg in either eye as measured by NCT to a consultant glaucoma specialist were retrospectively reviewed. Demographic and referral data, IOP, CCT, and glaucoma diagnosis were obtained. The main outcome measure was the IOP measurement differences between NCT and GAT.

Results Of the 98 patients referred, only 23% had IOP > 21 mmHg when measured by GAT. NCT (Nidek NT400, Reichert Puff, Pulsair Easy Eye) measured the IOP greater than GAT by a mean of 5.8 mmHg (NCT 24.1 ± 3.5, GAT 18.3 ± 3.0). The effect of CCT on IOP measurement was less for GAT (R^2 0.034, $p = 0.067$) than for NCT (R^2 0.088, $p = 0.003$). The NCT/GAT IOP differences increased with increasing CCT (R^2 0.166, $p < 0.0001$). The NCT/GAT differences decreased with patient age (R^2 0.048, $p = 0.03$). Patients were classified as normal 67% (66/98), ocular hypertension 11% (11/98), glaucoma suspect 14% (14/98), and glaucoma 7% (7/98).

Conclusions The difference in IOP measurement between NCT and GAT leads to a possible increase in glaucoma referrals, particularly in patients with thicker corneas. Repeat IOP using GAT and CCT measurement would help in triaging referrals.

Keywords Central corneal thickness · Goldmann tonometry · Intraocular pressure · Non-contact tonometry · Optometry

Introduction

Glaucoma describes a group of eye diseases in which there is progressive damage of the optic nerve characterised by a specific pattern of optic nerve head changes and visual field loss leading to blindness if untreated.

In most countries, a case-finding approach to identify individual patients who may be at risk of developing glaucoma is undertaken opportunistically by optometrists, who then refer patients for comprehensive specialist examination by ophthalmologists. Notably, a significant proportion of these patients are subsequently found to have neither glaucoma nor ocular hypertension (OHT), and nearly half of them are discharged after their first visit [1, 2]. The early and correct diagnosis of OHT and glaucoma is important because optic nerve damage from glaucoma is irreversible, and failure to identify it can lead to visual loss that could have been avoided. However, it is also important to avoid false-positive diagnosis that may lead to inappropriate anxiety, unnecessary exposure to potentially harmful treatments, and wastage of resources [2].

Non-contact tonometry (NCT) is commonly used by optometrists to screen for elevated intraocular pressure (IOP). A recent systemic review of the agreement of different tonometers with Goldmann applanation tonometry (GAT) showed that NCT seem to achieve a measurement closest to the GAT compared to other tonometers with a tendency to read higher than GAT. However, there was substantial variability in measurements both within and between studies [3].

✉ Khalid Kamel
kholod8383@hotmail.com

[1] Institute of Ophthalmology, Mater Misericordiae University Hospital, 60 Eccles Street, Dublin 7, Republic of Ireland

[2] Ophthalmology Department, York Hospital, York, UK

Measured IOP increases with increasing central corneal thickness (CCT) and all commonly used types of tonometers are affected [4–8]. However, NCT is more susceptible to the effects of CCT than GAT [4, 5, 7]. These two factors may increase the number of patients referred to ophthalmology departments with suspected OHT.

The objective of our study was to ascertain the role of differences in the IOP measurement between NCT and GAT in glaucoma referrals by optometrists to a specialist and to determine whether CCT is also a confounding factor using real-world data.

Materials and methods

The medical records of 145 patients were retrospectively reviewed who were referred by optometrists for specialist glaucoma assessment at the Mater Private Hospital, Dublin, Ireland, between January 2007 and June 2009. Cases were identified through the electronic database of new referrals to one consultant glaucoma specialist. The study adhered to the tenets of the Declaration of Helsinki.

Data was obtained on gender, age, race, ophthalmic and family history, visual acuity, IOP, CCT, cup to disc ratio (CDR), and Humphrey 24-2 visual fields. Referring optometrists were contacted to confirm the method and instrument used for tonometry. Where multiple IOP measurements were included by the optometrist, the mean value was calculated. Exclusion criteria were as follows: (1) referral IOP < 21, (2) significant corneal pathology that might influence CCT (e.g. corneal scars, endothelial guttata), (3) previous corneal surgery, (4) known history of glaucoma or intraocular pressure lowering treatment, and (5) incomplete data relating to the above criteria.

IOP was measured by slit lamp-mounted GAT (AT 900, Haag-Streit, USA). CCT measurement was measured by hand-held ultrasound pachymetry (Pachmate DGH 55, DGH Technology Inc., PA, USA). The same glaucoma specialist made both measurements. Because the inter-eye difference in CCT tends to be small, CCT measurements were repeated when inter-eye difference was > 40 μm. Instruments were calibrated on a monthly basis using the calibration device provided by the manufacturer.

A provisional diagnosis was made depending on the information available at the initial assessment. OHT was defined by an IOP > 21 mmHg, an open drainage angle, and an absence of glaucomatous optic disc or visual field changes. A diagnosis of glaucoma was made in patients with evidence of characteristic glaucomatous optic disc and/or visual field damage, irrespective of IOP. Patients with suspicious optic disc or suspicious visual field loss were classified as glaucoma suspects. Patients without any signs of OHT or glaucoma were classified as normal. A record was made of whether the patient was discharged from the ophthalmological review, scheduled for follow-up appointment, or IOP-lowering treatment was initiated.

For analysis purposes, including bivariate comparisons such as Wilcoxon and correlations and for simple descriptive statistics and graphically displayed data, one eye was randomly chosen per subject. Paired two-tailed Wilcoxon signed-rank test was used to test for differences in IOP as measured by the optometrist and the glaucoma specialist. Linear regression analysis was used to explore the relationship between tonometry inter-method differences and CCT using Prism (v 4.0 f or Macintosh, Graphpad Software, Inc., CA). All measurements are presented as mean ± standard deviation (mean ± SD), unless stated otherwise. A value of $p < 0.05$ (two-tailed) was considered significant.

Results

Of the 145 patients, 98 satisfied the criteria for inclusion in our study. All patients were Caucasian, 62% were female, and the mean age was 56.2 years (range 25 to 92 years). Thirty-eight individual optometrists referred the patients from 17 practices, all of which measured IOP by NCT {Nidek NT400 (Nidek Co., Ltd., Aichi, Japan), Pulsair Easy Eye (Keeler Co., Ltd., Windsor, UK), or Reichert Puff (Reichert Technologies, NY, USA)}. Twenty-five percent (24/98) of patients had two or more IOP measurements on different dates before referral. A family history of glaucoma was present in 28%.

The patients were classified as the following: normal 67% (66/98), OHT 11% (11/98), glaucoma suspect 14% (14/98), and glaucoma 7% (7/98). Thirty-five percent (35/98) of patients were discharged with follow-up planned with their optometrist. IOP-lowering treatment was instituted for seven patients. The rest of the patients were followed up by the glaucoma specialist.

NCT had a tendency to measure the IOP higher compared to those obtained with GAT. Only 23% (22/98) of patients had an IOP > 21 mmHg in either eye when measured by GAT. Fifty-two percent (51/98) had an IOP > 18 mmHg in either eye when measured by GAT. Of the 24 patients with multiple measurements by NCT before referral, 29% (7/24) had an IOP > 21 mmHg in either eye when measured by GAT. The Bland-Altman plot seen in Fig. 1 shows that there is a consistent bias to measure the IOP higher at all levels of IOP with NCT compared to GAT. This higher reading of IOP was true for all three NCT instruments (Table 1). In the patients with multiple NCT IOP measurements, the mean NCT IOP was 23.8 ± 4.1 as compared to the mean clinic GAT IOP of 19.5 ± 3.6 ($p = 0.001$), a difference of 4.3 mmHg.

CCT was normally distributed in the randomly selected 98 eyes with a mean CCT of 576.9 μm (SD 33.54, range 490–675 μm). Twenty percent of patients had a CCT > 600 μm.

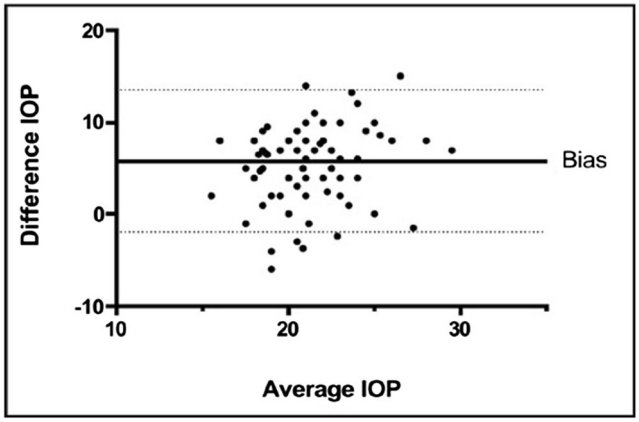

Fig. 1 Bland-Altman plot of intraocular pressure (IOP) differences between non-contact tonometry and Goldmann applanation tonometry measurements, plotted against the average of the two measurements

IOP increased with increased CCT with all instruments with the effect less for GAT than for NCT, although the 95% confidence limits for the slopes overlapped for all instruments (Table 2). The NCT/GAT IOP difference increased with increasing CCT (slope 0.048, 95% CI for slope 0.026 to 0.069, adjusted R^2 0.166, $p < 0.0001$) (Fig. 2). The NCT/GAT IOP difference was not related to CCT using the Nidek NT4000 but was for the Pulsair Easy Eye and the Reichert Puff (Fig. 2). The NCT/GAT IOP differences decreased with patient age ($p = 0.03$).

Discussion

The diagnosis of glaucoma, particularly in the early stages, can be extremely difficult, and community-based optometrists are under pressure to detect every case whilst avoiding unnecessary referrals [9]. The outcomes of patients referred to ophthalmologists with suspected glaucoma have been previously reported, with a significant proportion of glaucoma referrals being normal as in our study [10–14]. Glaucoma referrals based on a possible overestimated IOP can increase patient's stress and impact their well-being [15].

In our study, some of the referring optometrists repeated the IOPs using NCT to out rule variability so as to refine the referral. Referral refinement by repeating IOP pulses four times [16] and repeating visual fields to obtain meaningful results has been shown to increase predictive power and reduce false-positive referrals by as much as 40% [17]. Whilst we did not detect this in our study, the numbers of patients and its retrospective nature were not sufficient to adequately assess this.

We found substantial differences in IOP measurements between NCT and GAT. These findings may represent regression towards the mean [18]. It has been explored in the past in the context of NCT and optometric referrals [19]. However, the Bland-Altman plot (Fig. 1) demonstrates that the IOP difference between NCT and GAT was consistent throughout all levels of IOP. Therefore, this difference cannot be accounted for only by regression to the mean (RTM). We have demonstrated that there is a greater IOP difference between NCT and GAT with increasing CCT. RTM is purely a statistical sampling phenomenon unaffected by any physical process. So by showing that there is a greater difference with CCT (a physical and plausible causal mechanism), this would strongly argue that this is a real effect and sets the maximum impact of RTM as the mean difference at the smallest CCT (approx 2 mmHg). In 24 patients, the optometrist based their referral on multiple IOP measurements on different days. This should reduce the potential RTM, and indeed the mean difference in IOP was 4.3 mmHg in these patients compared with the total mean difference in IOP of 5.8 mmHg.

NCT is significantly more susceptible to the effects of CCT than GAT particularly at higher levels similar to previous studies [4, 6, 7]. High IOP readings made especially by NCT in the community will lead to a concentration of thicker corneas in clinic populations. The reported population mean CCT measured by ultrasound pachymetry is 544 μm. In our study, the mean CCT was

Table 2 Association between intraocular pressure and central corneal thickness for each instrument, as determined by linear regression analysis

	N	Slope	95% CI for slope	Adjusted R^2	*p* value
GAT	98	0.016	0.001 to 0.034	0.034	0.067
NCT	98	0.031	0.011 to 0.052	0.088	0.003
Nidek	33	0.022	0.009 to 0.052	0.069	0.155
Pulsair	48	0.046	0.012 to 0.079	0.142	0.008
Reichert	17	0.026	0.025 to 0.077	0.072	0.296

Table 1 Differences between intraocular pressure (IOP) measurements made with the three different non-contact tonometry (NCT) instruments and Goldmann applanation tonometry (GAT)

Difference	*N*	Mean referral NCT IOP (mmHg)	Mean clinic GAT IOP (mmHg)	Mean difference (mmHg)	*p* value
NCT/GAT	98	24.1 ± 3.5	18.3 ± 3.0	5.8	< 0.001
Nidek/GAT	33	23.9 ± 2.6	17.8 ± 2.1	6.1	< 0.001
Pulsair/GAT	48	24.6 ± 3.8	18.5 ± 3.2	6.1	< 0.001
Reichert/GAT	17	23.8 ± 4.2	19.5 ± 3.1	4.3	= 0.004

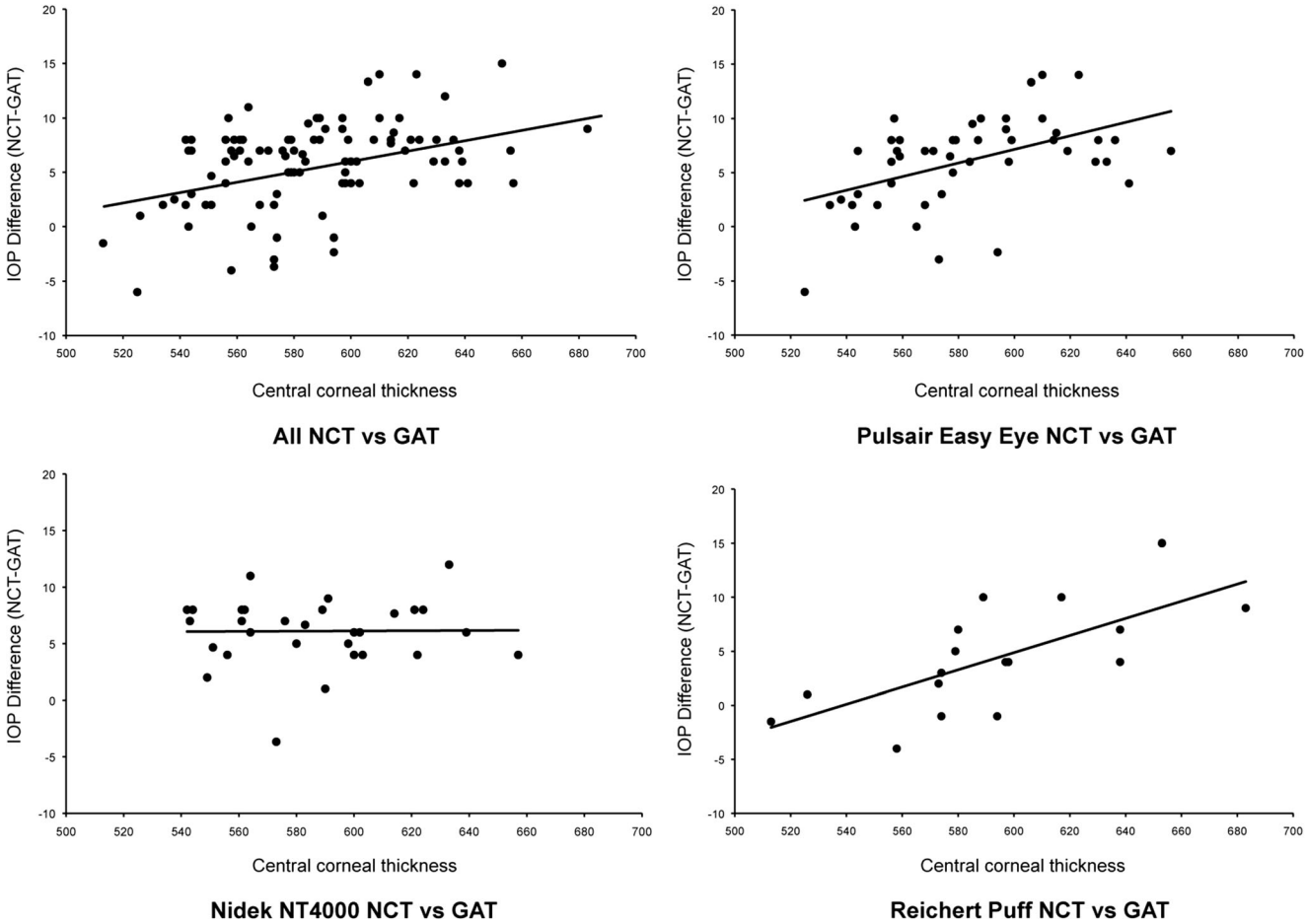

Fig. 2 The association of measured intraocular pressure (IOP) and central corneal thickness with **a** all non-contact tonometry instruments and **b**–**d** each instrument vs Goldmann applanation tonometry (GAT)

576 μm suggesting a higher concentration of patients with thicker corneas referred. Whilst CCT accounts for some of the variability in measured IOP among individuals and different instruments, other corneal biomechanical properties may have an important influence [20]. An overestimation of IOP by NCT relative to GAT at higher IOP levels may occur due to the non-linear increase in corneal stiffness as IOP rises and corneal viscoelastic properties that are not accounted for by CCT [20]. Corneal hysteresis, which is a direct measure of the corneal biomechanical properties, may therefore more completely describe the contribution of corneal resistance to IOP measurements than does CCT alone [21].

A few limitations of our study should be noted. As it was a clinic-based study rather than a population-based study, the slope estimates for NCT/GAT differences and the effect of CCT would be steeper than in population-based studies. Repeat NCT IOP measurements were not performed by the specialist in clinic to measure inter-observer repeatability. Also diagnostic outcomes are based exclusively on information available at the initial consultation. It should also be noted that the patients were referred privately so the optometrist referral was based on discussion with the patient considering their preference. Finally, the lack of a large database for glaucoma IOP profile by NCT measurements makes it difficult to diagnose or follow up glaucoma depending solely on NCT.

In conclusion, the effect of NCT and GAT IOP differences confounded by CCT contribute to increased referrals for assessment of OHT based on IOP measurement alone. Many of these are subsequently found to have normal IOP on GAT measurement as shown by real-world data. The difference in measurement is due to inherent properties of the instruments and regression to the mean rather than due to a technical error in measurement. In a screening programme, it may be beneficial to incentivise optometrists to measure GAT and CCT for patients with IOP > 21 mmHg on NCT. This could reduce the amount of referrals and aid in the triaging of the referral letter. However, patients with suspected optic nerve damage and/or repeatable visual field defect should be referred for specialist assessment irrespective of IOP.

Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest The authors declare that they have no conflicts of interest.

References

1. Bowling B, Chen SD, Salmon JF (2005) Outcomes of referrals by community optometrists to a hospital glaucoma service. Br J Ophthalmol 89(9):1102–1104. https://doi.org/10.1136/bjo.2004.064378
2. Tuck MW, Crick RP (1991) Efficiency of referral for suspected glaucoma. BMJ 302(6783):998–1000
3. Cook JA, Botello AP, Elders A, Fathi Ali A, Azuara-Blanco A, Fraser C, McCormack K, Margaret Burr J, Surveillance of Ocular Hypertension Study G (2012) Systematic review of the agreement of tonometers with Goldmann applanation tonometry. Ophthalmology 119(8):1552–1557. https://doi.org/10.1016/j.ophtha.2012.02.030
4. Bhan A, Browning AC, Shah S, Hamilton R, Dave D, Dua HS (2002) Effect of corneal thickness on intraocular pressure measurements with the pneumotonometer, Goldmann applanation tonometer, and Tono-Pen. Invest Ophthalmol Vis Sci 43(5):1389–1392
5. Brubaker RF (1999) Tonometry and corneal thickness. Arch Ophthalmol 117(1):104–105
6. Ko YC, Liu CJ, Hsu WM (2005) Varying effects of corneal thickness on intraocular pressure measurements with different tonometers. Eye (Lond) 19(3):327–332. https://doi.org/10.1038/sj.eye.6701458
7. Tonnu PA, Ho T, Newson T, El Sheikh A, Sharma K, White E, Bunce C, Garway-Heath D (2005) The influence of central corneal thickness and age on intraocular pressure measured by pneumotonometry, non-contact tonometry, the Tono-Pen XL, and Goldmann applanation tonometry. Br J Ophthalmol 89(7):851–854. https://doi.org/10.1136/bjo.2004.056622
8. Whitacre MM, Stein RA, Hassanein K (1993) The effect of corneal thickness on applanation tonometry. Am J Ophthalmol 115(5):592–596
9. Stevenson R (1999) Automated perimetry by optometrists in patients at low risk of glaucoma. Br J Ophthalmol 83(6):759–760
10. Bell RW, O'Brien C (1997) The diagnostic outcome of new glaucoma referrals. Ophthalmic Physiol Opt 17(1):3–6
11. Bell RW, O'Brien C (1997) Accuracy of referral to a glaucoma clinic. Ophthalmic Physiol Opt 17(1):7–11
12. Sheldrick JH, Ng C, Austin DJ, Rosenthal AR (1994) An analysis of referral routes and diagnostic accuracy in cases of suspected glaucoma. Ophthalmic Epidemiol 1(1):31–39
13. Theodossiades J, Murdoch I (1999) Positive predictive value of optometrist-initiated referrals for glaucoma. Ophthalmic Physiol Opt 19(1):62–67
14. Vernon SA (1998) The changing pattern of glaucoma referrals by optometrists. Eye (Lond) 12(Pt 5):854–857. https://doi.org/10.1038/eye.1998.217
15. Azuara-Blanco A, Burr J, Thomas R, Maclennan G, McPherson S (2007) The accuracy of accredited glaucoma optometrists in the diagnosis and treatment recommendation for glaucoma. Br J Ophthalmol 91(12):1639–1643. https://doi.org/10.1136/bjo.2007.119628
16. Vernon SA, Jones SJ, Henry DJ (1991) Maximising the sensitivity and specificity of non-contact tonometry in glaucoma screening. Eye (Lond) 5(Pt 4):491–493. https://doi.org/10.1038/eye.1991.80
17. Henson DB, Spencer AF, Harper R, Cadman EJ (2003) Community refinement of glaucoma referrals. Eye (Lond) 17(1):21–26. https://doi.org/10.1038/sj.eye.6700261
18. Bland JM, Altman DG (1994) Regression towards the mean. BMJ 308(6942):1499
19. Henson DB, Harper RA (1998) Do non contact tonometers read high? Ophthalmic Physiol Opt 18(3):308–310
20. Liu J, Roberts CJ (2005) Influence of corneal biomechanical properties on intraocular pressure measurement: quantitative analysis. J Cataract Refract Surg 31(1):146–155. https://doi.org/10.1016/j.jcrs.2004.09.031
21. Kotecha A, Elsheikh A, Roberts CR, Zhu H, Garway-Heath DF (2006) Corneal thickness- and age-related biomechanical properties of the cornea measured with the ocular response analyzer. Invest Ophthalmol Vis Sci 47(12):5337–5347. https://doi.org/10.1167/iovs.06-0557