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Original Research Article

Goldmann applanation tonometry versus non-contact tonometry: a comparative study

Lipi Chakrabarty*

Department of Ophthalmology, Chandulal Chandrakar Memorial Medical College & Hospital, Durg, Chhattisgarh, India

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***Correspondence:**
Dr. Lipi Chakrabarty,
E-mail: dr.lipi@gmail.com

ABSTRACT

Background: Intraocular pressure (IOP) measurement is a routine procedure in complete ophthalmologic examination and finds importance in diagnosis and monitoring of glaucoma. Goldmann applanation tonometry and non-contact tonometry, though age old, are still widely used methods of measuring IOP, especially in developing countries like India. This study was undertaken to compare IOP measured with Goldmann applanation tonometer (GAT) and non-contact tonometer (NCT) and to determine the correlation between intraocular pressure and central corneal thickness (CCT).
Methods: This was a cross sectional and observational study wherein adult patients visiting a medical hospital were included. IOP measurements of one hundred and forty four eyes (glaucomatous and non-glaucomatous) were performed using GAT and NCT. The IOP values were compared in different IOP ranges using Bland Altman graph. CCT was measured and its correlation with GAT and NCT analyzed using linear regression analysis.
Results: Both methods of tonometry correlated significantly with each other. The mean of paired difference between GAT and NCT was 1.24±1.38 mmHg ($r=0.95$, $p<0.001$). A positive correlation between CCT and both GAT and NCT was found with a regression of 0.35 mmHg per 10 micrometer change in corneal thickness.
Conclusions: Pressure readings of GAT and NCT are comparable. Ophthalmologists need to keep in mind the variation of IOP with CCT. Suitable correction table needs to be devised when considering different CCT ranges for both methods of tonometry.

Keywords: Central corneal thickness, Goldmann applanation tonometry, Intraocular pressure, Non-contact tonometry, Tonometer

INTRODUCTION

Intraocular pressure (IOP) remains the only modifiable risk factor in the management of glaucoma.[1]Goldmann Applanation tonometer (GAT) which was introduced in 1954 has been widely accepted as the gold standard for IOP measurement.[2]

Goldmann based his concept of tonometry on a modification of the Maklakoff-Fick law, also referred to as the Imbert-fick law. Non-Contact tonometer (NCT) introduced by Grolman in 1972, is a commonly used tonometer in ophthalmological practices. It uses a puff of air to deform the cornea and measures the time or force of the air puff that is required to create a standard amount of corneal deformation.[2] NCT has certain advantages over conventional applanation as corneal anesthesia and staining of tear film is not required and infection risks are reduced.[3]

Central corneal thickness (CCT) has been an important and confounding variable for both GAT and NCT

measurements.[4] The mathematical calculation for Goldmann applanation tonometry is based on a presumed average CCT of 520µm.[2] NCT acts on a larger corneal surface and more susceptible to variations in CCT.[1]

There are a wide range of IOPs and CCTs in normal population. This study was undertaken to know how GAT and NCT compare with each other in different IOP ranges. Also we need to know the influence of CCT on IOP measurements by these two commonly used tonometers.

METHODS

A prospective cross sectional study was conducted over a period of six months at a medical hospital. Sample was taken from the patients visiting the hospital. Written informed consent was obtained from the patients to participate in the study. The institutional review board of the hospital approved the study and all methods adhered to the tenets of the Declaration of Helsinki for research involving humans.

Measurements of IOP were obtained from 144 adult eyes of a heterogeneous clinical population. Both glaucomatous and non-glaucomatous eyes were taken.

Exclusion criteria

- History of corneal disease including but not limited to: Major dystrophies, Keratoconus, Connective tissue disorders, Stevens Johnson Syndrome , severe dry eyes, Corneal edema and scars
- Use of eye drops or contact lens
- History of inflammatory eye disease
- One eyed subjects
- History of major ocular trauma
- History of major ocular infection
- Uncontrolled diabetes mellitus
- Any abnormality preventing reliable IOP readings (High corneal astigmatism, uncooperative subjects etc.)
- History of hypersensitivity to topical fluorescein
- Pregnant or breast feeding women

Study methods

NCT was taken using Topcon CT80 (Topcon Medical, NJ, USA) and GAT model was Slit lamp mounted AT 900 (Haag Streit, Bern, Switzerland). CCT was measured using Pacscan 300AP (Sonomed, NewYork, USA). All instruments were calibrated periodically. Eye was anaesthetized using paracaine 0.5% eye drops for GAT and CCT measurements.

Careful and complete history of present complaints was taken. Past history of ocular disorder, glasses/contact lenses, surgery was taken. Any topical or systemic medical history was also obtained.

After taking an informed consent, the IOP was measured by NCT by an experienced paramedical staff. Thereafter, GAT was measured by a single experienced ophthalmologist on a single slit lamp unit. CCT was taken by another experienced ophthalmologist. Three readings of IOP by each method and three readings of CCT was taken. Mean of the three readings was recorded under each section. Fifteen minute interval was given between NCT, GAT and CCT readings which are considered to be a safe interval. The observers were masked to the other readings. We took all precautions in recording the readings, explaining the procedure to the subject and discarding the first reading in each section.

Statistical analysis

Sample size was determined assuming 5% alpha error and 90% study power .Statistical software used was Stata Version 11 (StataCorp. 2009. Stata Statistical Software: Release 11. College Station, TX: StataCorp LP). Statistical analysis was done calculating mean of all readings and noting age, gender, diagnosis and IOP distributions of the subjects. Correlation between NCT and GAT was determined using Pearson's correlation coefficient and Bland Altman graph was plotted. Inter-method agreement between tonometers was assessed using the method devised by Bland and Altman, which included calculation of the mean difference between measurements, the standard deviation and the 95% confidence interval of the differences.

CCT was divided into four quartiles based on median value and the NCT and GAT values were compared in different CCT ranges. Linear regression analysis was used to examine the role of CCT in IOP measurement by each method. A regression equation was calculated after plotting IOP against CCT. From the graphs, the apparent increase in IOP per 10 µm increase in CCT was computed. A P value of less than 0.05 was considered significant.

RESULTS

There were a total of 72 patients (144eyes). 57% were females and 44% were males. The intraocular pressures by GAT and NCT and corneal thickness values are listed in Table 1. The distribution of eyes (non-glaucomatous and glaucomatous) and the mean of GAT, NCT and CCT categorically are tabulated (Table 2). There were 45 eyes on antiglaucoma medications.

NCT and GAT readings were analyzed in three IOP groups of less than 12 mmHg (n=9), 12-21 mmHg (n=99) and more than 21 mmHg (n=36). Most of the NCT and GAT readings were found to be in 12-21 mmHg group (Table 3). There was a significant correlation between NCT and GAT ($r=0.95$, $p<0.001$). The mean of paired difference between GAT and NCT was 1.24±1.38 mmHg. When evaluated for different IOP ranges it was

observed that GAT and NCT had a less significant correlation at lower IOP ranges (<12mmHg).

The Median CCT value was 551µm. GAT and NCT were found to correlate well in all CCT ranges (Table 4). The Bland Altman plot (Figure 1) shows good agreement between both methods of tonometry. Mean of the difference between GAT and NCT was -0.18 mmHg.

The 95% limits of agreement (Mean±1.96SD) were -3.87 mmHg to +3.51 mmHg. Intraclass coefficient value between GAT and NCT was 0.97.There was a positive correlation with CCT with a regression of 0.35mmHg per 10µm for both GAT and NCT (Figure 2 and 3).

Table 1: Demographic and clinical data.

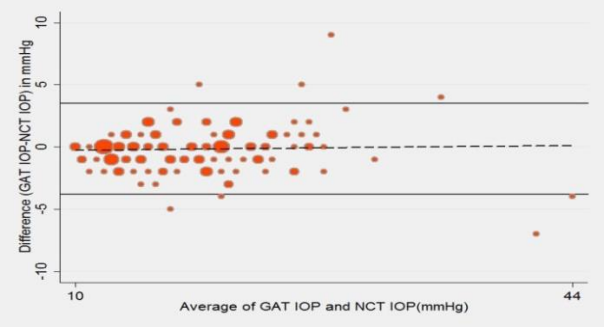
Variable	Mean	SD	Minimum, maximum (range)
Age (years)	52.48	11.81	25 – 83
GAT (mmHg)	18.25	5.75	10 – 46
NCT (mmHg)	18.07	5.81	10 – 42
CCT (micrometer)	544.89	36.76	469 – 617

GAT: Goldmann applanation tonometer, NCT: Non-contact tonometer; CCT: Central corneal thickness, SD: Standard deviation.

Table 2: Distribution and characteristics of non-glaucomatous and glaucomatous eyes.

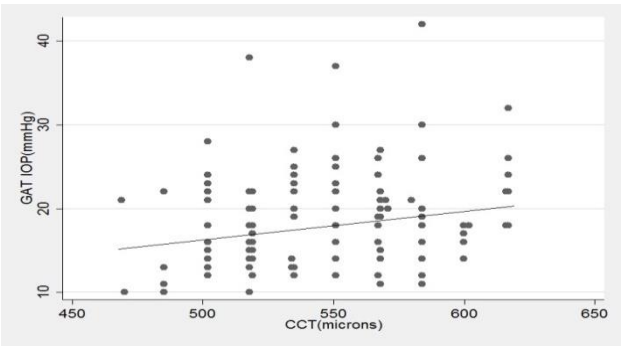
Diagnosis	Number of eyes (Percentage)	GAT (mmHg) Mean, SD	NCT (mmHg) Mean, SD	CCT(µm) Mean, SD
Normal	41 (28.5)	16.73, 3.42	17.19, 3.48	554.88, 37.19
OHT	16 (11.1)	23.69, 1.54	23.69, 2.15	547.06, 35.77
PACG	6 (4.2)	30.17, 8.30	32.50, 10.52	556.67, 30.79
PACS	36 (25)	14.56, 2.99	15.03, 3.13	538.67, 36.35
Glaucoma Suspect	12 (8.3)	14.42, 3.40	14.92, 3.23	525.25, 41.07
POAG & PXFG	33 (22.9)	19.97, 6.54	19.06, 5.29	543.21, 34.52

GAT: Goldman applanation tonometer, NCT: Non-contact tonometer, CCT: Central Corneal thickness, SD: Standard deviation; OHT: Ocular Hypertension, PACG: Primary angle closure Glaucoma, PACS: Primary angle closure Suspect, POAG: Primary open angle glaucoma, PXFG: Pseudoexfoliative glaucoma.



The mean of the differences between intraocular pressure measurement was -0.181mmHg. The 95% confidence limits (reference range for difference) are depicted as two bold lines with limits of agreement -3.873 to +3.511mmHg.

Figure 1: Bland Altman plot of the agreement between intraocular pressure measurements of Goldman applanation tonometer (GAT IOP) and non-contact tonometer (NCT IOP).



The scatter plot shows a positive correlation with regression equation GAT=0.035CCT – 1.131, $r^2 = 0.05$.

Figure 2: Linear regression plot for intraocular pressure measurement by Goldman applanation tonometer (GAT IOP) versus central corneal thickness (CCT).

Table 3: Correlation of tonometers in different IOP group.

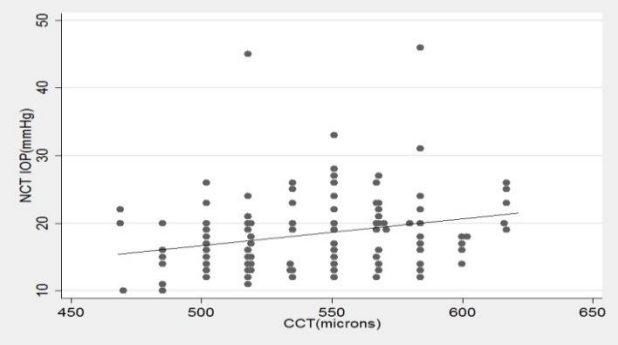
Variable	Entire group (n=144)	<12 mmHg group (n=9)	12 to 21mmHg group (n=99)	>21 mmHg group (n=36)
GAT-NCT (mm Hg) (Absolute difference, SD)	1.24, 1.38	0.78, 0.83	1.09, 1.09	1.75, 1.97
Correlation (P value)	0.95 (<0.001)	0.63 (0.068)	0.88 (<0.001)	0.89 (<0.001)

IOP: Intraocular pressure, GAT: Goldmann applanation tonometer, NCT: Non-contact tonometer, SD: Standard deviation.

Table 4: Correlation of tonometers in different corneal thickness group.

CCT (µm)	Mean GAT ± SD (mmHg)	Mean NCT ± SD (mmHg)	Correlation (P Value)
Entire group	18.07 ± 5.81	18.25 ± 5.75	0.79(<0.05)
≤518	16.67 ± 5.66	16.98 ± 6.07	0.81(<0.05)
519-551	18.06 ± 5.92	18.08 ± 5.39	0.93(<0.001)
552-569	19.23 ± 4.56	19.59 ± 4.33	0.82(<0.05)
≥570	19.17 ± 6.22	19.33 ± 6.27	0.85(<0.05)

GAT: Goldmann applanation tonometer, NCT: Non-contact tonometer; CCT: Central corneal thickness, SD: Standard deviation



The scatter plot shows a positive correlation with regression equation; NCT=0.035CCT – 0.77, r^2 = 0.05.

Figure 3: Linear regression plot for intraocular pressure measurement by non-contact tonometer (NCT IOP) and central corneal thickness (CCT).

DISCUSSION

The technique of IOP measurement and CCT are two important factors that influence IOP measurement. Both GAT and NCT are widely used methods, both being influenced by corneal properties.

In the present study, NCT and GAT measurements showed good agreements proving that both are reliable methods of measuring IOP. In past studies also, good agreement has been found with the correlation value ranging from 0.27 to 0.9 (p=0.03 to p<0.001).[1,3-8]

In present study, the Pearson's correlation was 0.95 which is quite significant (p<0.001). Also, intraclass coefficient between NCT and GAT was 0.97 (p<0.001).

Table 5: Summary of previous studies in comparison to present study regarding IOP change (in mmHg) for every 10 µm change in central corneal thickness.

Author	Country	GAT (mmHg)	NCT (mmHg)	Mean IOP ± SD (mmHg)	Mean CCT ± SD (µm)
Foster etal[11]	Mongolia	0.18	-	12.6±3.4	495±32
Bhan et al[4]	UK	0.23	-	15.1±5	551.53±49
Gunvant et al[10]	UK, India	0.27	-	16 (range8-30)	518 (range 426-616)
Christoph et al[12]	USA	0.25	-		
Tonnu et al[9]	UK	0.28	0.46	17.3±4.5	546.5±39.8
Ko et al[3]	Taiwan	0.37	0.63	15.5±4.6	559.4±40.8
Viney gupta et al[1]	India	0.32	0.4	18.5±6.7	557±54.6
Aysel Pelit et al[13]	Turkey	0.19	0.21	15.07±2.35	549.23±29.2
Present	India	0.35	0.35	18.25±5.75	544.89±36.76

IOP: Intraocular pressure, GAT: Goldmann applanation tonometer, NCT: Non-contact tonometer; CCT: Central corneal thickness, SD: Standard deviation.

In past studies, most authors have not mentioned a careful method of GAT and NCT recordings, though we assume that they have taken all routine precautions to record the values. In our study, we were particularly careful with the measurements and explained the procedure to the patient and also discarded the first reading. This may account for the high correlation. The limits of agreement between GAT and NCT by Bland Altman plot was -3.87 to +3.51 mmHg which is within the acceptable limit of 3 to 5 mmHg.[1,10]

In our study, slight overestimation of IOP measurement was found by NCT in lower IOP ranges (<12mmHg). Contrary to some studies, we found good correlation between GAT and NCT in higher IOP ranges. Past studies have showed that NCT overestimates IOP at

lower values and underestimates at higher values when compared with GAT.[5-8] Tonnu et al were the only authors to show using the Canon model of NCT that NCT underestimated IOP at lower ranges and overestimated it at higher IOP ranges.[9]

Our study showed a correction factor of 0.35mmHg for 10µm change in CCT for both GAT and NCT. Previous clinical studies have shown a correction factor ranging from 0.18 to 0.63 mmHg per 10 µm change in CCT (Table5). Ehlers et al showed a 0.7 mmHg change per 10 µm change in CCT in canulated eyes where true IOP was measured by a manometer.[14] Most studies have shown NCT to be affected more by CCT.[1,3,9,13]

The shortcomings of present study were dependency bias since both eyes of a subject was included. Also, certain biases like observer bias may creep in, though measures were taken to avoid same by taking average of multiple readings and masking. There may be a change in CCT with topical medication usage. Our population sample is based on patients with glaucoma and non-glaucomatous patients. Our study had 69% virgin eyes and 31% eyes on anti-glaucoma medications. Many previous studies have also included eyes on anti-glaucoma medications.[1,3,8,10,13] The effect of treatment on the hydration properties of the cornea was overlooked as this was not the aim of the present study.

CONCLUSION

In conclusion, present results concur with the previous studies indicating that NCT can be used as a safe alternative to GAT, if taken properly. Our study also reemphasizes the importance of adjusting IOP readings according to individual corneal thickness to avoid intraocular pressure overestimation or underestimation, both of which could lead to wrong diagnosis and affect the assessment of prescribed treatment, which is relevant and important in the clinical evaluation of glaucoma.

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Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee

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