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Original Research Article

A brief history of the evolution of tonometers and comparison of goldmann applanation tonometer versus non–contact tonometer and their correlation to central corneal thickness

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ABSTRACT

Purpose: This study was designed to evaluate and compare differences between Goldmann applanation tonometer's (GAT) values and non-contact tonometer's (NCT) values In various central corneal thickness(CCT).

Materials and Methods: This prospective study of 100 eyes of 50 subjects was done for the age group of 25 yrs – 75 yrs, who did not have any glaucomatous changes in the optic disc.

Intraocular pressure readings were taken by GAT and NCT was measured within a fixed time range of 10:00 AM to 1:00 PM to minimize the effect of diurnal variation. CCT and NCT readings were measured by NIDEK 530P while GAT was performed by Appasamy ref AATM-K001 after 20 minutes and was recorded from both eyes of 50 subjects.

Then the CCT effect was correlated with the intraocular pressure values, which were obtained by GAT and NCT.

Result: The data were recorded from 100 eyes of 50 subjects, of whom 24 were females and 26 were males. The mean age was 51.22 ± 2.7 years, while the mean CCT value was 530.6 ± 5.7 μ.

The mean IOP values respectively for NCT and GAT were 15.41 ± 0.6 mmHg, and 15.11 ± 0.5 mmHg, respectively (Table 1).

The data shows a significantly strong positive correlation between NCT and CCT (r= 0.73, P< .0001), and a strong positive correlation between GAT and CCT (r= 0.55, P< .0001) (Table 2, 5 and 6).

The Pearson coefficient value between NCT and GAT was also strong (r = 0.76, P< .00001)(Table 3).

Conclusion: The findings in our study correlate with earlier research. It demonstrates that, with the application of appropriate correction factors for CCT, NCT can be considered a good screening tool for the measuring Intraocular pressure.

1. Introduction

Intraocular pressure (IOP) evaluation is most important in thedetection and management of glaucoma as it's the only factor that can be modified. So, the measurement of IOP is required to be done accurately and reliably.

Many types of tonometers have been devised for measuring IOP, namely Indentation tonometer types Schiotz Bailliart tonometer, Applanation tonometer types - Maklakoff tonometer, Posner tonometer, Goldmann applanation tonometer (GAT), Perkin's handheld tonometer; non-contact tonometer (NCT); Combination of Applanation and Indentation Tonometry includes The Mackay Marg tonometer, Pneumatonometer, Tonopen,

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Rebound Tonometer includes I CARE, which have their advantage and disadvantage.

Among them, GAT is the gold standard[1] and most accurate while NCT is most widely used due to its convenience.

Weber was not convinced by the Accuracy of conventional tonometry. He suggested flattening a small area of the cornea and with this hypothesis, he became the first to invent the principle of applanation. In 1867, he presented his first tonometer with his novel physical principle.

He stated that the size of the flattened area does not play any important role and chose a plunger of a random diameter of 2 mm.

Imbert and Fick started continuing to work on this hypothesis and stated that the pressure inside anelastic sphere with thin walls can be closely estimated by knowing the force needed to just flatten a fixed area of a sphere.

Maklakoff tonometer came out towards the end of the 19^{th} century

However, Imbert Fick's law became the physical basis for all types of applanation tonometry.

Finally, in 1888 Fick designed a tonometer with a fixed area of applanation.

On the year 1955, Goldmann revealed his novel concept regarding fixed area applanation tonometry and developed a tonometer, which become the goldstandard, and all other tonometersare compared with this till today.

The applanating surface area of the Goldmann tonometer has a 3.06 mm diameter and is positioned in the center of a plastic cylinder, which has a total diameter of 7 mm.

This device is usually mounted on a slit lamp biomicroscope.

To do the procedure of applanation tonometry, a topical anesthetic and fluoresce in dye is instilled in the eye either in form of a drop or in a strip. The dye gets mixed with tears and gets activated in presence of cobalt blue light of the slit lamp and starts emitting fluoresces of bright yellowish-green light.

The force knob is then adjusted till the area of applanation becomes 3.06 mm in diameter and for this, the force knob is rotated until the inside border of each split mire just touches each other.

At the final stage, the applanation area achieves a diameter of 3.06 mm.

The corneal rigidity and tear surface tension cancel out each other at this point.

Noncontact tonometers also work on principles similar to the Goldmann tonometer.

An air puff is directed toward the cornea, and the force of the air stream keeps increasing for a few milliseconds.

The air puff is devised so that when it strikes the cornea with a predesignated area, then the air puff gradually flattens the cornea and in the final stage produces a slight corneal concavity. An optical device screens the exact point of applanation and directs information to the mainframeso that the air beam generator shuts off.

A microcomputer measures the strength of the air puff produced at the moment of applanation and thus analyzes the IOP from it.

Few patients find the air puff mildly uncomfortable. However, this process of taking IOP is painless and so it can be taken without the need for any anesthetic agent.

As there is no physical contact with the cornea in the air puff tonometer, the transmission of any microbes from eye to eye is unlikely.

However, all contact tonometers are rather expensive and require regular calibration.

CCT already has anidentified effect on the exactness of IOP valuation by Applanation Tonometers.

A thicker cornea requires more force for applanation and likewise thinner cornea requires less force for flattening. Thin corneas have a higher risk of developing glaucoma.

GAT is developed based on Imbert-Fick law, which considers the cornea with a dry surface and asan infinitely thin membrane, and thus the applanating pressure become sequal to IOP.

The resistance force is due to the effect of corneal thickness and surface tension is the consequence of the tractional force inside the tear film layer. Both of these forces affect the applanation probe and make the membrane assumption inappropriate.

However, the precision of GAT depends on several factors, corneal thickness, corneal curvature, and corneal structure.

Precisely, central corneal thickness has a greater influence on IOP reading when evaluated by GAT.

The typical CCT of 520μm is generally used for the scientific calculation of Goldmann applanation tonometry.[2]. NCT values get affected more by the changes in CCT as it acts on a larger corneal surface for IOP measurement.[1]

Moseley et al. after associating GAT with NCT and defined that NCT underestimated IOP when it was <10 mmHg, and it overestimated IOP when it was>19 mmHg.[3]

A lot of dissimilarities were noted in the values of IOP and CCT in the general population.

This study aimed to evaluate and compare the difference between the two most widely used Goldmann applanation tonometer (GAT), and noncontact tonometer (NCT) IOP readings and correlate them to the CCT in different IOP ranges.

The purpose is to obtain a procedure to measure IOP accurately with the least optical and pathological disturbance to the eye.

2. Materials and Methods

2.1. Subjects

This was a prospective study done on 100 eyes of 50 subjects (among them 24 female and 26 male) of age between 25 years – 75 years, who did not have any glaucomatous changes in the optic disc. This study was conducted and approved by the institutional board of Narayana Nethralaya, Bangalore.

All patients' data were taken after obtaining written informed consent.

2.2. Technique

Intraocular pressure valuations were measured by GAT and NCT. Intraocular Pressure was evaluated between 10:00 AM to 12:00 PM to minimize the effect of diurnal differences as much as probable.

CCT and NCT readings were measured by NIDEK 530P and were taken from both eyes of 50 subjects. Three measurements were taken at the 1-minute interval and the average reading was taken.

GAT was performed by Appasamy ref AATM-K001 after 20 minutes to reduce aqueous outflow and topical anesthesia drop-induced error. The Tip of the applanation probe was cleaned with a 70% Isopropyl alcohol swab before every examination to remove any presence of fluoresce in dye and to prevent micro-organism transmission from the applanation prism. Proparacaine hydrochloride 0.5% eye drop along with a fluoresce in stain was administered in the inferior conjunctival fornix and within a few seconds, IOP was documented.

The effect of CCT was then interrelated with the GAT and NCT readings separately.

Followings are inclusion criteria

1. Normal Individual In the age range of 25 and 75 years
2. Healthy individuals with no history of any systemic diseases
3. Patients without any glaucomatous disc damage were selected

Following are excusion criteria:

1. Patients with corneal diseases like keratoconus and dystrophies
2. Patients with anocular surgical history or any type of ocular trauma
3. Patients with inflammatory eye diseases like uveitis
4. Patients having a systemic disease history such as diabetes, cardiac disease, hypertension, pulmonary disease, etc
5. Patients not having a stable fixation
6. Patients with higher astigmatism of more than 3 diopters

2.3. Statistical analysis

Vivid statistical analysis was executed to formulate different frequency tables.

The mean CCT and IOP separately for GAT and NCT were evaluated.

Pearson's correlation coefficient was utilized to measure the relationship between NCT with CCT values and similarly for GAT with CCT values. Correlation between NCT and GAT was also established using Pearson's Coefficient and the Bland Altman plot was created as well.

In Band Altman Plot Mean difference between NCT IOP and GAT IOP reading and Standard deviation was plotted with a 95% confidence Level.(Graph 4)

3. Results

The data were gained from 100 eyes of 50 subjects, of which 24 were females and 26 were males.

The mean age for this data was 51.22 ± 2.7 years, while the mean CCT value was 530.6 ± 5.7 μ.

The mean IOP values respectively for NCT and GAT were 15.41 ± 0.6 mmHg, and 15.11 ± 0.5 mmHg, respectively (Table 1).

The data shows a significantly strong positive correlation between NCT and CCT (r= 0.73, P< .0001)(Table 2 and 5), with a regression equation NCT= 0.0848 CCT – 29.579, r^2 = 0.537 and a strong positive correlation between GAT and CCT (r= 0.55, P< .0001)(Table 2 and 6) with regression equation GAT= 0.0503 CCT – 11.595, r^2 = 0.3061 (Table 5 and 6).

GAT and NCT were correlating well with CCT in this study. The Bland Altman plot (Table 5) shows sufficient agreement between both methods of tonometry. The Mean of the difference between NCT and GAT was 0.30 mmHg. With a confidence level of 95%,the limits of agreement (Mean±2.18D) were -3.98 mmHg to + 4.58 mmHg. The Pearson coefficient value between NCT and GAT was strong (r = 0.76, P< .00001)(Table 3).

This study revealed a correction factor of 0.84 mmHg for a 10μm change in CCT for NCT and a correction factor of 0.50 mmHg for a 10μm change GAT IOP measurement.

Table 1: Range IOP value and mean ± SD for NCT, GAT, and CCT

	Range	Mean ± SD
nct	8 – 25 mmHg	15.41 ± 0.6
GAT	10 – 19 mmHg	15.11 ± 0.5
CCT	445 - 598 μ	530.6 ± 5.7
Age	28– 74 Years	51.22 ± 2.7

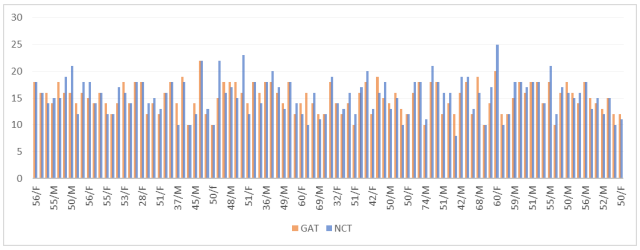
Graph 2 Scatter plot for IOP measured by NCT (Non-contact tonometry) correlating Measured CCT (Central corneal thickness). This is a significantly strong positive relationship between NCT and CCT (r= 0.73, P< .0001),

Table 2: Correlation of Tonometers (NCT and GAT) with CCT

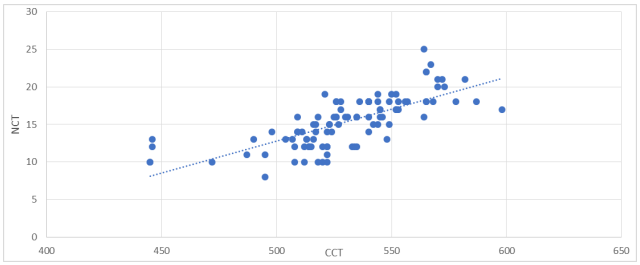
	IOP (In mmHg)	CCT (In μ)	Corelation Coefficient	P value
nct	15.41 ± 0.6	530.6 ± 5.7	0.73	< 0.0001
GAT	15.11 ± 0.5	530.6 ± 5.7	0.55	< 0.0001

Table 3: Correlation of NCT and GAT

CCT	GAT NCT Mean Difference	Corelation Coefficient	P value
530.6 ± 5.7	0.30 ± 2.18D	0.76	< 0.00001

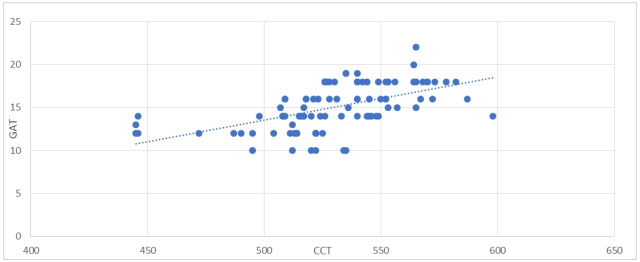


Graph 1: This column pattern shows how the difference between the IOP measured by NCT and GAT



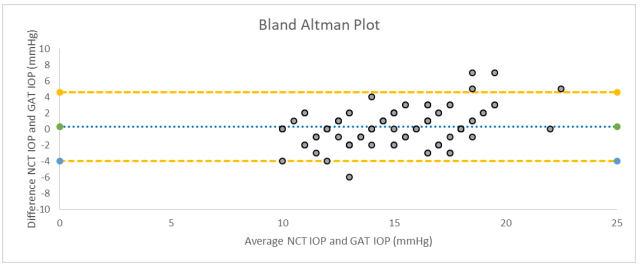
Graph 2:

with regression equation NCT= 0.0848 CCT – 29.579, r2 = 0.537.



Graph 3:

Graph 3 Scatter plot for IOP measured by GAT (Goldman-Applanation tonometry) correlating Measured CCT (Central corneal thickness). This is a strong positive relationship between GAT and CCT (r= 0.55, P< .0001), with regression equation GAT= 0.0503 CCT – 11.595, r^2 = 0.3061.



Graph 4:

Graph 4 The difference in intraocular pressure measurement's mean was 0.30 mmHg. 95% confidence limits (reference range for difference) are plotted as two bold lines with the agreement limit of - 3.984 to +4.584 mmHg.

Fig. 1: IOP and CCT measured by Nidek NT- 530P

4. Discussion

IOP values are affected by CCT as well as in the methods, that are used for IOP measurement. The two commonly and widely used methods for measurement of IOP are GAT and NCT and both are influenced by corneal characteristics.

In this study, NCT and GAT measurements have good agreements with Pearson coefficient value (r = 0.76, P< .00001), which establish the fact that both methods of taking IOP are reliable.

Many previous studies have also reported good agreement, with correlation values ranging from 0.27 - 0.9 (p=0.03 to p<0.001).[3–5]

The correlation coefficient in this investigation r = 0.73, (P< .0001) for NCT with CCT and r= 0.55, (P< .0001) for GAT with CCT.

In our study, IOP measurement by NCT was showing a higher value in all IOP ranges. A good link was found between GAT and NCT at all IOP ranges.

Limits of agreement (Mean±2.18D) were -3.98 mmHg to + 4.58 mmHg in Bland Altman Plot.

This study revealed a correction factor of 0.84 mmHg for a 10μm change in CCT for NCT and a correction factor of 0.50 mmHg for GAT IOP measurement.

Most studies have conveyed that NCT models tend to overvalue IOP at low pressures and underrate IOP at high pressures when the IOP evaluations are associated with GAT.[6–8]

Tonnu et al. were the only authors to show that NCT undervalued IOP at lower IOP ranges and overvalued it at higher IOP ranges while utilizing the Canon T-10 NCT.[9] The majority of studies have found that CCT has a greater impact on NCT.[3–6] Similar results were obtained in our study.

Taking an average of multiple readings and measuring IOP within a time range from 10 AM-12 PM were done to reduce the observer bias and diurnal variation errors in the study. The use of topical medications may cause a change in CCT. Both glaucomatous and non-glaucomatous patients make up our sample population. Eyes on anti-glaucoma drugs not have been included in this study to avoid antiglaucoma therapy's effect on the cornea's moisture qualities.

In addition, previous studies have revealeda reverse association between corneal hysteresis with IOP[10] while measuring IOP from the ocular response analyzer e (version 1.20), which uses the same technology of Air puff Non-Contact Tonometry.

In Shah et al.[11] studies of 207 normal eyes an average corneal hysteresis of 10.7 (for a mean age of 62.1 years) was found.

Hysteresis is not a fundamental or constant property, instead, it's a dimension characterizing how a material or system responds to the loading and unloading of a functional force.[8]

However, in this study, we were unable to consider the effects of corneal hysteresis because of the unavailability of an ocular response analyser (ORA).

5. Conclusion

The findings in our study correlate with earlier research. It demonstrates that, if taken correctly, NCT can be considered a safer alternative to GAT. IOP measurement of NCT showed a higher value than by GAT in mmHg, p value and corneal thickness affects NCT reading more than the GAT readings. With the application of appropriate correction factors for CCT, NCT can be considered a good screening tool for measurement of IOP

6. Financial Support

Nil

7. Conflicts of Interest

There are no conflicts of interest.

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References

1. Allingham R, Damji KF, Freedman S, Moroi SE, Rhee DJ. Shields Textbook of Glaucoma. 6th ed. New Delhi: Wolters Kluwer/Lippincott Williams & Wilkins; 2012.
2. Bhan A, Browning AC, Shah S, Hamilton R, Dave D, Dua HS. Effect of corneal thickness on intraocular pressure measurements with the pneumotonometer, Goldmann applanation tonometer, and Tono-Pen. *Invest Ophthalmol Vis Sci*. 2002;43(5):1389–92.
3. Moseley MJ, Evans NM, Fielder AR. Comparison of a new non-contact tonometer with Goldmann applanation. *Eye (Lond)*. 1989;3(Pt 3):332–7.
4. Ko YC, Liu CJL, Hsu WM. Varying effects of corneal thickness on intraocular pressure measurements with different tonometers. *Eye (Lond)*. 2005;19(3):327–32.
5. Gupta V, Sony P, Agarwal HC, Sihota R, Sharma A. Inter-instrument agreement and influence of central corneal thickness on measurements with Goldmann, pneumotonometer and noncontact tonometer in glaucomatous eyes. *Indian J Ophthalmol*. 2006;54(4):261–5.
6. Pelit A, Altan-Yaycioglu R, Pelit A, Akova YA. Effect of corneal thickness on intraocular pressure measurements with the Pascal dynamic contour, Canon TX-10 non-contact and Goldmann applanation tonometers in healthy subjects. *Clin Exp Optom*. 2009;92(1):14–8.
7. Verdoorn C, Deutman AF. Clinical evaluation of the Topcon CT10 tonometer. *Int Ophthalmol*. 1988;12(4):223–5.
8. Parker VA, Herrtage J, Sarkies NJ. Clinical comparison of Keeler Pulsair 3000 with Goldmann applanation tonometry. *Br J Ophthalmol*. 2001;85(11):1301–4.
9. Tonnu P, Ho T, Newson T, Sheikh AE, Sharma K, White E, et al. 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*. 2005;89(7):851–4.
10. Ang GS, Bochmann F, Townend J, Azuara-Blanco A. Corneal biomechanical properties in primary open angle glaucoma and normal tension glaucoma. *J Glaucoma*. 2008;17(4):259–62.
11. Shah S, Laiquzzaman M, Bhojwani R, Mantry S, Cunliffe I. Assessment of the biomechanical properties of the cornea with the ocular response analyzer in normal and keratoconic eyes. *Invest Ophthalmol Vis Sci*. 2007;48(7):3026–31.

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