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Comparison of intraocular pressure measurement between Goldmann applanation tonometer and Tonopen

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ABSTRACT

Background: Primary open-angle glaucoma (POAG) is a chronic optic neuropathy causing visual field loss and open angles. It accounts for 90% of glaucoma cases and is linked to raise intraocular pressure (IOP). POAG is the most common type of glaucoma. It is a chronic, progressive optic neuropathy that leads to characteristic optic nerve damage and visual field loss, often associated with elevated IOP. IOP is currently the only modifiable risk factor in POAG that can be affected by family. The Goldmann applanation tonometer (GAT) is the international standard. **Aims and Objectives:** The objective is to compare IOP measurement by GAT and Tonopen in diagnosed glaucoma suspect patients. **Materials and Methods:** This is a hospital-based cross-sectional study done in the glaucoma clinic of Lumbini Eye Institute and Research Centre. A total of 88 Glaucoma suspect patients were recruited using a convenience sampling technique. IOP was measured in one eye, calibrated daily, and repeated if readings differed by more than 5 mmHg. Topical anesthesia was used. **Results:** The majority of participants in the study, representing 55.7% of the 88 patients, were female. About 58% of the study participants were from India, making up the majority. The largest percentage of participants (38.8%) was in the 25–40 age range. The mean corneal thickness was higher in men (544.41 ± 27.69 μm) than in women (535.71 ± 36.05 μm). In both eyes, the mean IOP readings are higher with Tonopen than GAT. **Conclusion:** IOP measurements obtained with the Tonopen often show higher readings compared to those from the GAT. While the Tonopen cannot replace GAT as the gold standard, it works as a valuable screening tool, especially in peripheral areas or in resource-limited settings.

Key words: Primary open-angle glaucoma; Goldmann applanation tonometry; Tonopen; Intraocular pressure; Center corneal thickness

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INTRODUCTION

Primary open-angle glaucoma (POAG) is a chronic, progressive optic neuropathy characterized by cupping and atrophy of the optic disc, visual field loss, and open angles.[1] Globally, 45 million people are blind, with 12.3% due to glaucoma, the second leading cause of irreversible vision loss. POAG, the most common form, accounts for 90% of glaucoma. It is associated with raised intraocular pressure (IOP), which is the major risk factor. Accurate IOP measurement is crucial for screening and managing patients with glaucoma.[2]

Lumbini Province has the greatest frequency of blindness (1.8%), while Bagmati and Sudurpaschim provinces have the lowest (0.7%) and 0.7%, respectively. The most common cause of blindness is cataract (65.2%), which is followed by age-related macular degeneration (5.3%), glaucoma (5.8%), and corneal opacity (6.4%). Other posterior segment disorders accounted for 8.4% of cases.[3] According

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to the Bhaktapur Glaucoma Study (2012), an age and sex standardized prevalence of POAG was found at 1.24%, with POAG accounting for 68% of all glaucoma cases. Notably, 96% of POAG cases were previously undiagnosed.[4] Similarly, Jirel Ethnic Group Study (2022) individuals aged 40 and above, the prevalence of POAG was 3.41%, with 73% of POAG cases being normal-tension glaucoma.[5] The study also highlighted a high rate of undiagnosed glaucoma, with 93.6% of cases previously undiagnosed.

A patient may be a POAG suspect due to family history, suspicious optic disc, or elevated IOP. Elevated IOPs, normal visual fields, optic discs, open angles, and no ocular or systemic disorders contribute to glaucoma.[1]

IOP measurements in clinical use are indirect, based on the eye's response to a force. Tonometers are traditionally divided into applanation and indentation instruments. Modern tonometers use contour matching, transpalpebral phosphene induction, indentation/rebound, and pressure sensor implantation.[6-8] The Goldmann applanation tonometer (GAT) is the international clinical standard for measuring IOP, determining the force needed to flatten a 3.06 mm corneal area. The IOP is measured in millimeters of mercury and is equal to the force of the tonometer in grams multiplied by 10.[6,9]

The GAT slit-lamp has limitations in remote areas due to its difficulty in carrying, need for electricity, and inability to be portable. It's not suitable for bedridden or arthritic patients, requires ophthalmologist expertise, and can transmit infections, impacting survey response rates in developing countries.[10,11]

The Tonopen is a small, lightweight, and portable digital tonometer that uses the MacKay-Marg tonometer principle. It is battery-operated, requires no slit-lamp, and has an applanating surface with a microscopically protruding plunger. The device analyzes waveforms, produces a readout on a liquid crystal display, and indicates an acceptable measurement sequence.[11]

Various studies have compared IOP measurement by GAT and Tonopen, and there are no significant differences observed.[12,13] The present study is also being done to compare the IOP measurement by these two instruments. The objective of the study is to compare the IOP using GAT and to open and the effect of central corneal thickness (CCT) on the IOP measurements.

Aims and objectives

To compare the intraocular pressure measurements obtained using Goldmann Applanation Tonometer and Tono-Pen, and to evaluate the level of agreement and reliability between the two methods in clinical practice.

General objectives

- To compare IOP measurement by GAT and Tonopen in POAG suspect patients.

Specific objectives

- To determine the demographic pattern of glaucoma suspect patients
- To measure IOP using GAT in glaucoma suspect patients
- To measure IOP with Tonopen in glaucoma suspect patients
- To evaluate the effect of CCT on the IOP measured by GAT and Tonopen.

MATERIALS AND METHODS

This is a hospital-based cross-sectional study done in the glaucoma clinic of Lumbini Eye Hospital and Research Centre. A total of 88 Glaucoma suspect patients were recruited using a convenience sampling technique.

Inclusion criteria

Glaucoma suspect patients presenting at the glaucoma clinic are granted informed consent.

Exclusion criteria

- Patients with ocular inflammation
- Patients with a history of intraocular surgery
- Patients with a history of contact lens wear
- Known cases of microphthalmia
- Patients with central corneal scar
- Known cases of phthisis bulbi.

A glaucoma suspect was made when the subject had 1 or more of the following:

a. IOP ≥21 mmHg in either eye
b. Vertical cup-to-disc ratio ≥0.7 in either eye or cup-to-disc ratio asymmetry ≥0.2
c. Focal thinning, notching, or splinter hemorrhage
d. The study abides by the principles of the Declaration of Helsinki, and informed consent was obtained from all patients included in this study
e. A detailed history of the patient was obtained
f. All patients underwent a comprehensive ophthalmological examination including:
g. Best corrected visual acuity evaluation
h. Slit-lamp examination of the anterior segment
i. Fundus biomicroscopy with a 90-diopter lens
j. Both the eyes of the patient were analyzed.

GAT (Haag-Streit, Bern, Switzerland) was performed first and immediately afterward with Tonopen (Tonopen XL Avia, USA). The GAT was calibrated according to the manufacturer's guidelines and used with the slit-lamp. Topical anesthesia (One drop of lignocaine hydrochloride (4%) was instilled, and fluorescein strips were used for the GAT (marketed by Acorn Inc. India). IOP was measured in one eye until three successive readings were within 1 mmHg. IOP was then measured in the other eye.

The Tonopen was calibrated daily as per the manufacturer's guidelines. One drop of lignocaine hydrochloride (4%) was used as a topical anesthetic before the procedure. The examiner gently touches the cornea with the pen tip several times until a reading is displayed. Only measurements with a standard error smaller than 5% were accepted. If the successive measurement readings differed by more than 5 mmHg, the procedure was repeated. The IOP measurement with the second instrument was performed after at least 5 min interval.

Ethical considerations

The will of the subjects was fully respected, and a written consent was taken after fully explaining all the relevant details, the importance of the study, and its future implications. Those who do not give consent for any reason were excluded from the study. Confidentiality was maintained to the utmost. No names, documents or results are disclosed or circulated anywhere other than to the hospital other than to the hospital doctors or research guides. The extra financial burden was limited by providing the ancillary investigation for free.

RESULTS

The majority of participants in the study, representing 55.7% of the 88 patients, were female. About 58% of the study participants were from India, making up the majority. The largest percentage of participants (38.8%) was in the 25–40 age range. The mean corneal thickness was more in men (544.41±27.69 μm) than in women (535.71±36.05 μm).

Figure 1 shows right eye GAT determined IOP by CCT. Pearson's r was found to be 0.56, which shows that there is a strong positive correlation between IOP and CCT (P=0.0001).

Figure 2 depicts right eye Tonopen determined IOP by CCT. Pearson's r was found to be 0.61, which shows that there is a strong positive correlation between IOP and CCT (P=0.0001).

Figure 3 shows the difference in IOP (Tonopen minus Goldmann) against the mean of the two measurements. The inter-method agreement between GAT and Tonopen with 95% limits of agreement falling between −4.57 and 1.89.

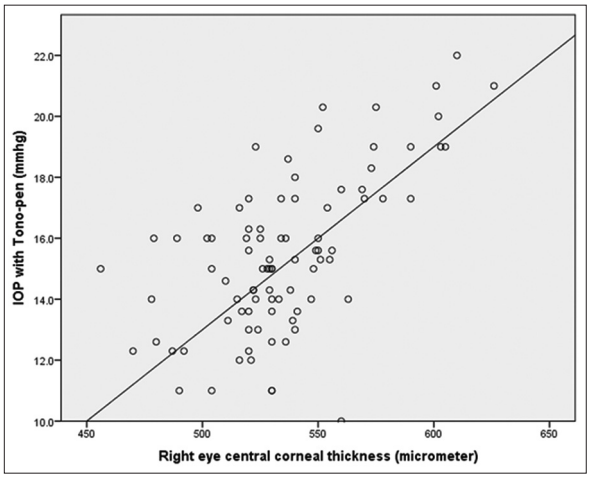

Figure 2: Correlation between tonopen intraocular pressure and central corneal thickness

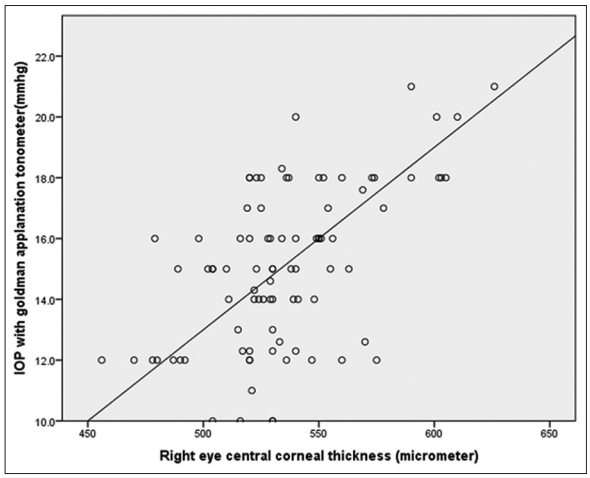

Figure 1: Correlation between the Goldmann applanation tonometer intraocular pressure and central corneal thickness

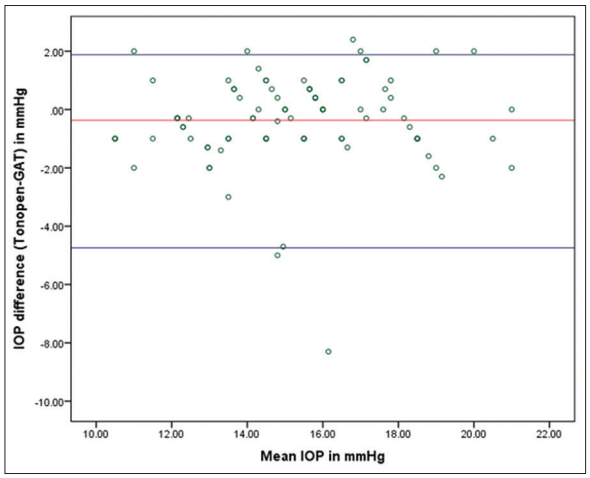

Figure 3: Bland-Altman plot for Goldmann applanation tonometer and tonopen

Table 1: Comparison of the IOP readings with the Goldmann applanation tonometer and the Tonopen by classification into quartiles (%)

Quartiles (%)	≤10 mmHg	11–12 mmHg	13–14 mmHg	15–16 mmHg	17–18 mmHg	19–20 mmHg	≥20 mmHg
GAT							
RE	4.5	15.9	19.3	30.7	22.7	4.5	2.3
LE	6.8	25.0	17.0	25.0	21.6	2.3	2.3
Tonopen							
RE	1.1	14.8	23.9	30.7	15.9	8.0	5.7
LE	3.4	13.6	28.4	19.3	19.3	10.2	5.7

IOP: Intraocular pressure, RE: Right eye, LE: Left eye

Table 1 depicts that when IOP readings were classified into quartiles, it was observed that most patients had IOP within 15–16 mmHg with two instruments, except for the left eye with Tonopen, which showed that 28.4% of those patients had IOP within 13–14 mmHg.

Table 2 shows the mean IOP of the right eye with GAT was 15.07 mmHg (Standard deviation [SD]±2.68), and the left eye was 14.78 mmHg (SD 2.78). The mean IOP with Tonopen was found to be 15.44 mmHg.

(SD±2.57) and 15.50 mmHg (SD±2.79) for the right eye and left eye, respectively. In both eyes, the mean IOP readings are higher with Tonopen than GAT. Minimum IOP was 10.0 mmHg in both eyes with two instruments. The maximum IOP (23.0 mmHg) recorded was with GAT in the left eye.

Table 3 shows that in both eyes, the Tonopen readings were significantly higher (P=0.028, 0.001) than the GAT readings. The mean difference between the two instruments in the right eye and left eye was found to be 0.37 and 0.72, respectively.

Table 4 depicts that with both the Tonopen and GAT, IOP was higher in male than in female (15.12±2.59 mm Hg; GAT: Tonopen: 15.38±2.38 mmHg.

Table 5 shows that the mean CCT of the right eye and left eye was found to be 535.14 mcm (SD±32.44) and 535.25 mcm (SD±35.33), respectively. The minimum CCT of the right eye was 456 while in the left eye, it was 437 mcm. In the right eye, the maximum CCT was 626 mcm, and that of the left eye was 622 mcm.

Table 2: IOP readings with GAT and Tonopen in glaucoma suspect patients

Methods of measuring IoP	Minimum	Maximum	Mean	Standard deviation
GAT				
RE	10.0	21.0	15.07	2.68
LE	10.0	23.0	14.78	2.78
Tonopen				
RE	10.0	22.0	15.44	2.57
LE	10.0	22.0	15.50	2.79

IOP: Intraocular pressure, GAT: Goldmann applanation tonometry

Table 3: Differences between IOP measurements with the two instruments among glaucoma suspects

Methods of measuring IoP	Mean IOP right eye±SD, mmHg	Mean IOP left eye±SD, mmHg
Tonopen	15.44±2.57	15.50±2.79
GAT	15.07±2.68	14.78±2.78
Mean difference (Tonopen-GAT)	0.37	0.72
P-value	0.028	0.001

IOP: Intraocular pressure, GAT: Goldmann applanation tonometry, SD: Standard deviation

Table 4: IOP readings according to gender in glaucoma suspects

Mean IOP±SD, mmHg	Male	Female
GAT	15.03±2.59	15.12±2.76
Tonopen	15.14±2.38	15.38±2.75

IOP: Intraocular pressure, GAT: Goldmann applanation tonometry, SD: Standard deviation

Table 5: Central corneal thickness among glaucoma suspect patients

CCT (mcm)	Minimum	Maximum	Mean	SD
RE	456	626	535.14	32.44
LE	437	622	535.25	35.33

SD: Standard deviation, CCT: Central corneal thickness

DISCUSSION

This is a hospital-based cross-sectional study, done in Lumbini Eye Institute and Research Centre, to compare IOP measurement using GAT and Tonopen. Using two devices, the majority of patients in this investigation had IOPs between 15 and 16 mmHg. Nearly 30% of the total patients were in the same group, which is similar to earlier research.[14]

The study showed that the mean GAT and Tonopen readings were generally higher in women than in men, which is consistent with the findings of Jeelani et al.[15] Furthermore, women had a lower CCT than men, which

was similar to the findings of other studies.[16] This may be due to the observed anatomical variations in overall corneal thickness between males and females. A multiracial study involving Caucasians, Asians, Hispanics, and African Americans reported that male subjects had thicker corneas than their female counterparts.[17]

The study found that the Tonopen significantly increased the mean IOP compared to the GAT, a finding consistent with previous studies.[14,18,19] Horowitz et al., found a mean difference of −0.41 mmHg between Tonopen and Goldmann tonometers, similar to the current study.[20] However, for high-pressure patients, the difference was −4.2 mmHg. 18 Combining the analysis for both groups, the Tonopen significantly underestimated the IOP when the pressure was >20 mmHg.

The mean difference between two instruments in the right eye and left eye was found to be 0.37 mmHg and 0.72 mmHg, respectively, in current study and Christoffersen et al., study showed very similar mean difference in IOP which was found to be 0.43 mmHg, and 0.48 mmHg in right eye and left eye, respectively.[21] Frenkel et al., noted that the difference between the two instruments was as low as 0.07 mmHg.[22]

The mean IOP of two instruments was plotted against paired differences, showing that IOP differences were evenly distributed across the range without any noticeable pattern. The magnitude of the paired difference did not depend on the mean IOP. A recent survey found a small between-instrument average measurement difference, suggesting that IOP measurements are comparable with both instruments. This suggests that IOP measurements are comparable in practice.[23]

In the present study, the mean CCT was found to be around 535 um. There was no statistically significant difference between CCT of men and women. These values are comparable to what Ehlers et al. observed in their study.[24] They found that the mean midperipheral corneal thickness (578 um) was significantly higher than the mean central thickness (538 um) ($P<0.001$). The positive correlation noted between the GAT IOP measurement and CCT (Figure 1) indicates that GAT measurements increase as CCT increases, which is consistent with the knowledge that GAT overestimates IOP in thicker corneas. A linear relationship would indicate that there is a predictable change in one variable when the other changes. This is in agreement with studies by Bandyopadhyay et al.,[14] and Frenkel et al.[22]

There was a positive correlation between the Tonopen IOP measurement and CCT as well as shown in (Figure 2). However, Mok et al.,[25] in their study, observed that even though there was a statistically significant difference between peripheral corneal thickness and CCT, there was no clinically significant difference between the IOP readings of central and mid-peripheral cornea measured by the Tonopen.

The Tonopen is useful for measuring IOP in scarred, irregular, or edematous corneas. There is good agreement between the Tonopen and GAT in the normal pressure range. The Tonopen tends to under-read at high IOPs and over-read at low IOPs. The tip of the instrument is covered with a plastic film to prevent the possible spread of infection.

A recent survey reported that the between-instrument average measurement difference was small, and there was no tendency for the difference to vary with the level of the IOP.[26] The implication for practice is that IOP measurements are comparable with both instruments.

Limitations of the study

Limitations of the current study include that the corrected IOP of GAT was not included in the study, and the difference between the corrected GAT IOP and Tonopen IOP was not assessed.

CONCLUSION

IOP measurements obtained with the Tonopen often show higher readings compared to those from the GAT. While the Tonopen cannot replace GAT as the gold standard, it works as a valuable screening tool, especially in peripheral areas or in resource-limited settings. Its portability and ease of use make it effective for quickly identifying individuals with elevated IOP who may be at risk for optic nerve damage. However, large-scale population studies are essential to validate these differences and establish standardized protocols for the Tonopen's clinical application.

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Authors' Contributions:
SD- Definition of intellectual content, literature study, prepared first draft of manuscript, implementation of study protocol, data collection, data analysis, manuscript preparation and submission of article; **BB-** Implementation of study protocol data collection, data analysis, manuscript preparation and submission of article; **SUD-** Data analysis and interpretation, preparation of tables, editing, and manuscript revision; **RK-** implementation of study protocol data collection, data analysis, manuscript preparation and submission of article.

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