Comparison of Goldmann Applanation, Noncontact Air Puff, and Tono-Pen XL Tonometry in Normal Controls versus Glaucoma Patients at a University Hospital in Riyadh, Saudi Arabia

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Abstract:
PURPOSE: The purpose of this study is to compare intraocular pressure (IOP) measured by the Goldmann applanation tonometer (GAT), the Tono-Pen XL (TPXL), and a noncontact airpuff tonometer (NCT) in glaucoma patients and normal controls.

METHODOLOGY: In the current study, two groups of individuals were recruited; the first group included glaucoma patients (glaucoma group) while the second one was a glaucoma-free group. The IOP was measured through GAT, NCT, and TPXL for the same participants by three different physicians in both groups. Measurements through the three devices were compared statistically. Correlations between different methods of assessment were also assessed.

RESULTS: In the glaucoma group, the mean IOP measured was 16.0 ± 5.5 mmHg (range, 6–40 mmHg) with GAT, 20.5 ± 6.9 mmHg (range, 10–52 mmHg) with the TPXL, and 20.2 ± 6.5 mmHg (range, 8–50 mmHg) with the NCT. In the control group, the mean IOP was 14.0 ± 2.7 mmHg (range, 9–19 mmHg) with GAT, 17.3 ± 3.8 mmHg (range 6–30 mmHg) with the TPXL, and 17.9 ± 3.9 mHg (range 10–27 mmHg) with the NCT.

CONCLUSION: IOP measurements were approved among the three devices with relatively higher readings using both NTC and TPXL. All three methods are required to address different situations that present in the daily clinical and surgical practice.

Keywords: Goldmann applanation tonometer, noncontact tonometry, tonometry, Tono-Pen

Introduction
Glaucoma is the second leading cause of irreversible blindness worldwide. In the developed and developing countries, a significant proportion of glaucoma usually presents to eye care facilities in the advanced stages when the optic nerve is already damaged. Hence, the risk of vision loss dramatically increases. The pattern of glaucoma in the Saudi population suggests that open angle and closed angle glaucoma subtypes are the most common forms of glaucoma and approximately one-third of the glaucoma patients are at a high risk of vision loss. Glaucoma is characterized by a significant optic disc damage with corresponding visual field changes. Intraocular pressure (IOP) is the most important modifiable risk factor to reduce the sequelae associated with glaucoma. There is a well-established
evidence that decreasing IOP to a safe threshold value decreases the rate of glaucomatous progression, mitigating visual morbidity.[6-10]

Measurement of the IOP is fundamental for the detection of ocular hypertension in the majority of the glaucoma types. In addition, IOP measurement determines the severity of glaucoma and aids the clinician in instituting appropriate treatment. Currently, there is no harmless invasive method of measuring the IOP. Moreover, IOP is actually “estimated” rather than “measured” in clinical practice. Under-or over-estimation of IOP may result in inappropriate treatments of glaucoma cases, ocular hypertension, and glaucoma suspects.

There is a number of methods and tools for the assessment of IOP. Goldmann applanation tonometer (GAT), developed in the 1950s, is the most commonly used and it remains the gold standard tonometer. Hence, comparisons of the different types of tonometers are usually performed in relation to GAT. Utilization of GAT involves flattening of a small central area of the cornea. However, corneal thickness and irregularities may affect GAT more than scleral rigidity. Goldmann and Schmid[11] suggested that GAT would be more precise in patients with an average central corneal thickness between 500 and 525 µm. Hence, a slit lamp apparatus is required for measurement with sterilization (alcohol swab) between patients to minimize the potential risk for transmission of infection. Alternatively, the Tono-Pen XL (TPXL) (Reichert Inc., Buffalo, NY, USA) is more commonly used among infants and children as well as for recumbent patients because it is easily portable. Moreover, the Tono-Pen follows an objective method of assessment, and it is easy to use after instillation of topical anesthesia which does not require fluorescein dye. In addition, the Tono-Pen can be used by well-trained technicians, and it is suitable for community-based studies. It can be also used in hospital-based assessments of IOP in cases with corneal scarring and corneal edema.[12,13] Finally, air puff tonometry is another useful method for IOP estimation. Its major advantage is to be a noncontact method for estimating IOP. Air puff tonometry is also useful for ophthalmological screening, and it is user-friendly, relatively quick, and carries minimal risk of contamination.

Although there are some variations among the three methods and each of them has its own advantages and disadvantages, the issue of interchangeability of methods remains contentious. In the current study, we compare the three methods for IOP assessment and evaluate the level of variation among methods and whether the IOP values are interchangeable between methods or not.

### Methodology

The current study is a cross-sectional study of a representative sample of glaucoma cases (glaucoma group) from the outpatient clinic of the glaucoma unit at King Abdul-Aziz University Hospital (KAUH), Riyadh, Saudi Arabia. Glaucoma cases were identified as having an increased IOP (>21 mmHg) with apparent sign(s) of defect on the disc or the retinal nerve fiber layer (thinning or notching of disc rim), in the absence of other causative reason or explanation. On the other hand, a group of healthy controls without glaucoma (confirmed diagnosis) were recruited from the internal medicine clinic as a control group, in spite of the potential source of bias for containing a potential number of diabetic patients, but KAUH has a special clinic only for diabetic patients and that is why the internal medicine clinic is chosen to decrease the bias. This study adhered to the tenets of the Declaration of Helsinki regarding research-involving humans. All subjects were voluntarily recruited after giving oral consent based on a thorough explanation of the study purpose and methodology. This study was approved by the Institutional Research Board of the College of Medicine, King Saud University. The sample size was estimated considering α = 0.05; confidence interval (CI) 95%, power as 80% while the expected mean difference range across assessment methods was 2.5 mmHg and the worst acceptable difference was 5 mmHg. The estimated N for each arm was 42 eyes (46 with a 10% contingency). The inclusion criteria included patients with confirmed diagnosis of glaucoma at presentation. Meanwhile, the exclusion criteria included patients having previous surgical interventions and any other ocular comorbidities. The control group had to be free of glaucoma based on clinical ophthalmic examination.

The IOP in both groups was assessed by GAT, Tono-Pen, and air puff tonometry by three different clinicians. We started with the airpuff as a noninvasive technique having no effect on IOP measuring. It was followed by the tonopen for having less effect on IOP and ended with applanation. To start with applanation may affect the other tools of measurement.

Clinicians were masked to the study objectives and maintained an average interval of 10 min between different assessments. Calibration of the tonometers was performed periodically, and all assessments were conducted at more or less similar times of the day to avoid any potential bias due to diurnal variations. The order of assessments was NCT followed by instillation of Alcaine® 0.5% (Alcon Laboratories Inc., Fort Worth, TX, USA) and assessment with the TPXL after applying local anesthesia using Alcaine® 0.5% eye drops (Alcon Laboratories Inc., Fort Worth, TX, USA). Finally,
Alcaine® drops were instilled along with a fluorescein strip to the inferior conjunctival fornix, and IOP was reassessed using GAT through a cobalt blue filter in the biomicroscope. Each assessment was conducted by a different clinician who was completely masked about the findings by the previous assessment. The same protocol was applied to both of the glaucomatous and nonglaucomatous groups.

**Statistical methods**

Data were collected and stored in a spreadsheet using Microsoft Excel 2010® (Microsoft Corp., Redmond, WA, USA) software. Data management and coding were also performed in Excel. Data were analyzed using SPSS® version 20.0 (IBM Inc., Chicago, Illinois, USA).

Descriptive analysis was done where categorical variables were presented as frequencies and percentages and continuous variables as mean and standard deviation (SD). Inferential analysis was performed using Kruskal–Wallis H-test to detect the difference between groups. Student’s t-test was used to detect the source of pairwise differences between different methods of assessment. Meanwhile, Spearman’s correlation test was used to assess the potential correlation between findings from different types of assessment. Bland–Altman plots were used to assess the consistency between the different methods of assessment. The CI level was set to 95% where a corresponding P value threshold was set to 0.05. Accordingly, P < 0.05 was interpreted as denoting a statistical significance. Both eyes were included in the analysis of the data.

**Results**

A total of 222 eyes of 111 patients were enrolled in this study. There were 130 eyes of 65 patients in the glaucoma group and 92 eyes of 46 patients in the control group. In the glaucoma group, the mean age was 57.4 ± 21.8 years (range, 5–93 years), there were 26 (40%) females, and the majority (45 [69.2%] patients) of this group was Saudi citizens. Comorbidity with other systemic diseases in the glaucoma group included 37 (56.9%) patients with hypertension, 1 (1.5%) patient with hypercholesterolemia while 1 (1.5%) patient was a smoker. Meanwhile, among controls, 24 (52.2%) were male and 22 (47.8%) were female in the mean (±SD) age of 50.9 (17.3). Systemic diseases in the control group included 9 (19.6%) patients with hypertension, 1 (2.2%) patient with hypercholesterolemia, and no (0.0%) smokers. At baseline, the control group was slightly but statistically significantly younger than the glaucoma group (P = 0.005) while there was a statistically greater number of Saudis in the glaucoma group (P < 0.001).

In addition, at baseline, there were a statistically significantly greater number of hypertensive patients in the glaucoma group than the control group (P < 0.001). Details of the baseline demographic and clinical data are presented [Table 1].

The major glaucoma subtypes were chronic angle closure with 46 (35.4%), primary open angle with 21 (16.2%), neovascular with 12 (9.2%), pseudoexfoliation with 10 (7.7) and primary congenital with 8 (6.2%) while the others represented around 25.3% of our sample (namely; juvenile, normal tension, optic nerve atrophy, pigmentary, Riger’s, steroid induced, and secondary glaucomas). The IOP was statistically significantly higher in the glaucoma group than the control group for all the methods of assessment (airpuff tonometer [P = 0.003], Tono‑Pen [P < 0.001], applanation [P = 0.002] [Table 2]). Moreover, the IOP in the glaucoma group differed statistically significantly among the three methods (P < 0.001). Pairwise comparison in the glaucoma group and across the three assessment methods indicated that the mean IOP assessed by applanation was statistically significantly lower than the other methods (P < 0.001 for both comparisons). The mean IOP assessed with the airpuff tonometer, and the Tono‑Pen was not significantly different in the control group (P = 0.547).

Furthermore, the mean IOP in the control group has statistically significantly differed among the three methods (P < 0.001). In addition, conduct of a pair-wise comparison of the mean IOP assessed by all the methods showed that the mean IOP assessed by both airpuff tonometer and the Tono‑Pen was not statistically significantly different on such pairwise comparison of the control group. However, the mean IOP with GAT was statistically significantly different from the other two methods in the control group (P < 0.001) for both comparisons [Table 2].

Finally, there was a highly significant direct correlation among all methods of assessment in the glaucoma group. Similarly, there was a highly significant direct

**Table 1: Demographics and systemic diseases**

| Characteristics               | Cases (n=65) | Controls (n=46) | P     |
|-------------------------------|-------------|----------------|-------|
| Gender, n (%)                 |             |                |       |
| Male                          | 39 (60.0)   | 23 (50.0)      | 0.173 |
| Female                        | 26 (40.0)   | 21 (45.7)      |       |
| Nationality, n (%)            |             |                |       |
| Saudi                         | 45 (69.2)   | 29 (63.0)      | <0.001*|
| Others                        | 20 (30.8)   | 1 (2.2)        |       |
| Smoking, n (%)                | 1 (1.5)     | 0              | 0.398 |
| Hypertension, n (%)           | 37 (56.9)   | 9 (19.6)       | <0.001*|
| Hypercholesterolemia, n (%)   | 1 (1.5)     | 1 (2.2)        | 0.804 |
| Age (years), mean±SD (range)  | 57.4±21.8 (5-93) | 50.9±17.3 (19-99) | 0.005* |

*P<0.05 denotes statistical significance. SD: Standard deviation
correlation between all methods of assessment in the control group [Table 2]. Furthermore, Bland–Altman plots indicated that there was a greater consistency between airpuff and Tono‑Pen measures in both groups while Goldman applanation was relatively consistent with the other two methods [Figures 1‑3].

**Discussion**

There is considerable literature on studies that compare different methods and tools for assessing the IOP. In the majority of ophthalmic institutes, GAT is the most commonly used and reliable instrument. In addition, it is still considered the gold standard for assessment of IOP. In the current study, we compared the mean IOP measured by three commonly used instruments in glaucomatous and nonglaucomatous eyes. Meanwhile, there was a need to recruit matching control “glaucoma‑free cases” for comparison purposes; therefore, we targeted the internal medicine clinic, which would facilitate referring of volunteers for a free examination in the same hospital to rule out glaucoma suspected and ocular hypertension cases.

As expected, we found that the mean IOP was significantly higher in the glaucoma group than the control group which reflects equivalent validity of all of the three methods. Our findings revealed that there is a good agreement with minimal but insignificant differences between the Tono‑Pen and the air‑puff. However, the average IOP measured by GAT was relatively and significantly smaller among all methods for both groups. These findings differ from Yilmaz et al. study[14] which included only normal cases; furthermore, the study did not provide evidence on difference in measurements while using the three methods. Reviewing their findings, we can conclude that there was an apparent difference in their measurements (in nonglaucoma cases as follows: IOP is 16.1, 16.1, and 15.5 (for the GAT) which shows that their findings – despite the insignificance – are agreeing with our findings which are briefly showing that the GAT has a lower pattern of IOP (17.9, 17.3 and 14.0); however, in our case, it is statistically significant. However, it concurs with Shah et al. study 2012[15] who reported a significant difference between the mean IOP assessed by GAT and airpuff tonometry. A study by Bradfield et al.,[16] on children, reported similar findings to ours. They found that in cases with IOP higher than 11 mmHg, the Tono‑Pen assessment of IOP is slightly higher than GAT, while among those with IOP lower than 11 mmHg, the Tono‑Pen assessed IOP is relatively lower than GAT’s.[16]

Iester et al.[17] reported that the mean IOP assessed by Tono‑Pen versus GAT is significantly different. Moreover, their[17] study concluded that Tono‑Pen may not be accurate in both higher and lower extreme values.[17] However, Tonnu et al.[18] performed a study on 105 ocular hypertensive and glaucoma patients to compare the inter‑method agreement of 4 different tonometers and they found that there was a good agreement between GAT and the Tono‑Pen and moderate agreement between the GAT and the air puff which copes with our findings, yet differs from our mean difference findings. Popovich and Shields[19] evaluated 421 eyes and reported that the air puff was a reliable measurement compared to the GAT within the normal range of IOP. This fact is rarely supported in most of the published
studies, where the majority of reports suggest that the GAT is the most consistent method of IOP assessment. A population-based survey by Bandyopadhyay et al.,[20] reported a convenient agreement between the GAT and the Tono-Pen. However, the same study raised a concern in the agreement due to the presence of a subset group (7.4% of 203 subjects) that showed a large difference between the two methods. Although this study was repeatedly tackled in the literature, we think that it should be conducted in several regions in a localization mode because of the variation nature of the human eye; some enhancements would be still added such as assessment of optical coherence tomography and pachymetry that may help in a better understanding of the difference in assessment methods.

**Conclusion**

In this study, we found that there is a little difference among the three methods of measuring IOP. The IOP assessed with GAT is lower while both Tono-Pen and the airpuff are more likely to be similar. However, all of
the three methods are required to cope with different clinical situations that present in the daily practice. Therefore, caution is required before making a decision when assessing glaucoma patients, especially with those with advanced disc damage or even cases of glaucoma suspect and the cases between primary open angle glaucoma and normal tension glaucoma. The generalizability of our findings may be limited by some potential, rather slight bias, due to the recruitment of cases with bilaterally affected eyes.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

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