

Comparison of Goldmann Applanation, Diaton Transpalpebral and Air Puff Tonometers

Sana Nadeem, B. A. Naeem, Rabeea Tahira, Shizza Khalid, Abdul Hannan

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See end of article for authors affiliations

Correspondence to:
Sana Nadeem
Department of Ophthalmology
Foundation University Medical
College/Fauji Foundation
Hospital, Rawalpindi
doctorsana@hotmail.com

Purpose: To compare the intraocular pressure (IOP) measurements in normal subjects, between the newly developed, Transpalpebral tonometer (Diaton®), Goldmann Applanation tonometer (GAT), and Air-puff Tonometer (APT), and to assess agreement between the three devices.

Material and Methods: A total of 400 eyes of 200 random subjects were included in this cross-sectional, comparative study. IOP was measured with APT (Canon Full Auto Tonometer TX-F®), followed by Diaton®, and lastly GAT (Haag Streit AT 900® tonometer) in both eyes. The mean IOPs and the differences between IOPs of the tonometers were calculated by the paired *t*-tests. Their correlations were calculated using the Pearson correlation coefficients, mean differences were analyzed by one-way analysis of variance, and agreement was analyzed by the Bland-Altman method.

Results: The mean IOPs noted for Diaton, GAT, and APT were 14.78 ± 3.22 , 14.62 ± 3.01 , and 14.42 ± 3.22 mm of Hg, respectively. The Pearson's correlation coefficient (*r*) between Diaton and GAT was 0.314, between Diaton and APT; 0.334, and between GAT and APT; was 0.745. Hence, the strongest correlation was between GAT and APT, followed by moderate correlation of Diaton with APT, and least between Diaton and GAT. However, correlations between all three tonometers were significant at the 0.01 level. Bland-Altman analysis revealed that the mean differences between Diaton and GAT measurements was 0.16 ± 3.6 mm Hg, between GAT and APT was 0.20 ± 2.2 mm Hg, and between Diaton and APT was 0.36 ± 3.7 mm Hg. The 95 % limits of agreement were smallest between GAT and APT, as compared to the other two pairs. Thus good agreement was observed between GAT and APT, and there was fair agreement of Diaton with both GAT and APT.

Conclusion: Measurement of intraocular pressures by all three tonometers was comparable with good correlation in normal adults. There was good agreement between GAT and APT, and fair agreement of Diaton with GAT and APT. APT can be used as a screening device for patients. However, Diaton is not a very useful device for screening purpose, because of wider variations.

Key words: Intraocular pressure, Transpalpebral tonometry, Goldmann Applanation tonometer, Air-puff tonometry.

Glaucoma is a leading cause of irreversible blindness worldwide. Intraocular pressure (IOP) is a monumental parameter in the diagnosis and monitoring of glaucoma. Accurate measurement of IOP is the hallmark for the management of glaucoma patients. IOP is the sole

modifiable risk factor; the reduction of which is known to slow the progression of this potentially blinding condition.¹⁻⁶

Goldmann Applanation tonometer (GAT) is considered the 'gold standard' in IOP measurement being the most accurate and reliable of all the tonometers invented so far. This slit-lamp mounted device is based on the Imbert-Fick^{2, 7} principle, which states that the pressure (P) inside an ideal, dry thin-walled sphere is equal to the force (F) required to applanate its surface, divided by the area (A) {3.06 mm} of flattening ($P=F/A$).

Air puff tonometers (APT) are non-contact devices that applanate the cornea by a puff of air and measure IOP by the time required to flatten a given area of the cornea. Due to wide variations in readings, they are used largely for screening purposes.⁷

Transpalpebral tonometers like Diaton have been developed recently and considered by some^{8,9} to be well-tolerated, portable, user-friendly, light weight instruments that do not need topical anesthesia.

Whenever a new tonometer is developed, it is routine practice to compare it to the existing, reliable tonometers. No local studies have been performed on this transpalpebral tonometer to compare it with other devices. Hence, we embarked on a study to assess this transpalpebral tonometer, in terms of practicality and accuracy of IOP measurements, and compared it with the precise and renowned Goldmann tonometer; used routinely in glaucoma patients, and with our air-puff tonometer used for routine screening of every patient arriving at our out - patient department.

MATERIAL AND METHODS

A total of 400 eyes of 200 random subjects were included in this cross-sectional, comparative study carried out in the last two weeks of November, 2013. The subjects included consenting presumably normal adults attending our out-patient department, their attendants, hospital staff and doctors volunteering for the study, 16 years of age and above (range 16-67).

Exclusion criteria included uncooperative patients to any method of tonometry, previously known glaucomatous patients, history of antiglaucoma drugs, trauma, ocular disease, scarred corneas, or intraocular or refractive surgery, astigmatism² of 3 diopters or more by autorefraction, diabetes or other serious systemic ailments.

Air-puff Tonometry, followed by Diaton Tonometry, and lastly Applanation Tonometry was

performed in both eyes, to prevent applanation induced lowering of IOP. The Air-puff tonometer that used was Canon Full Auto Tonometer TX-F®. APT was done first by a single observer and a mean of three readings was taken (Fig. 1).

Then transpalpebral tonometry using the Diaton® tonometer (Fig. 2) was done by two observers with comparable readings. This instrument is based on the principle¹⁰ of determining the acceleration of a rod during free fall, with a definite weight on interactive with the elastic eyeball through the lids. The patient must be sitting in a chair with the head in horizontal position, and the eyes gazing at the patient's thumb used for fixation at 45° angle. The observer should be at the side of the patient. The tonometer must be vertical when switched on. The upper eyelid should be manually retracted 1 mm above the limbus, and three readings should be taken with the tonometer tip touching the lid parallel to the lid margin, and the mean IOP is read on the scale (Fig. 3).

Lastly, applanation tonometry was done by a single observer using the same Goldmann Tonometer (Haag Streit AT 900®) (Fig. 4). The instrument was calibrated according to the manufacturer's instructions. The eye was anaesthetized with Alcaine® (proparacaine hydrochloride 0.5 %) eye drops (Alcon) and a fluorescein strip was placed in the inferior conjunctival fornix to stain the tear film. Three consecutive IOP readings were taken for each eye, with aseptic precautions and the mean was calculated for each eye. All types of tonometry were performed between 8:00 a.m. to 2:00 p.m. The difference in IOP readings were compared between the three tonometers.

The data was collected on a performa noting the age, gender, and IOP measurements of all three tonometers in a tabulated form.

Data was analyzed by SPSS version 20. Mean IOPs and the differences between IOPs of the tonometers were calculated using the paired *t*-tests. The correlations between the tonometers were calculated using the Pearson correlation coefficients and the mean differences between the tonometers was analyzed by one-way analysis of variance. The agreement between the devices was analyzed by the Bland-Altman method and plots were constructed between the means of IOPs (*x* axis), and the difference of IOPs (*y* axis), between the pairs of devices. The mean IOP difference (bias) and the 95% limits of agreement; which represent the range in which 95% of



Fig. 1: The Air Puff Tonometer.



Fig. 3: Procedure of Diaton tonometry.

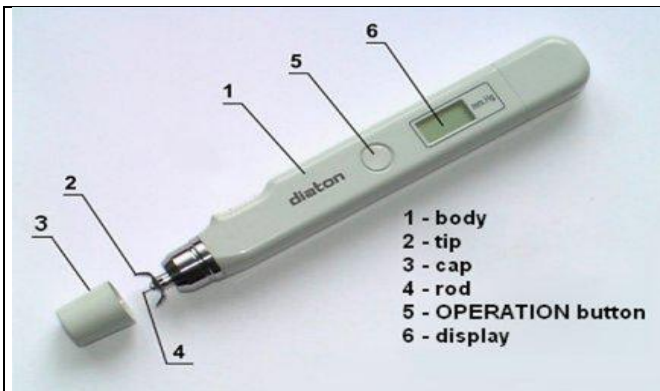


Fig. 2: The Diaton tonometer.



Fig. 4: The Goldmann Applanation tonometer.

the differences between IOP measurements by the instruments would occur; were analyzed for each pair. Linear regression analysis was conducted on the IOP measurements of the three devices, and regression based limits of agreement were analyzed.

RESULTS

The average age of subjects enrolled in the study was 36.44 ± 13.76 years (range 16-67). There were 70 (35%)

males and 130 (65%) females. The mean IOPs noted for Diaton, GAT, and APT were 14.78 ± 3.22 mm Hg (range 8-23 mm Hg), 14.62 ± 3.01 mm Hg (range 8.6-25 mm Hg), and 14.42 ± 3.22 mm of Hg (range 7.5-24.4 mm Hg), respectively (Table 1). The difference of mean IOPs between GAT and Diaton was 0.16 ± 3.65 mm Hg, between Diaton and APT was 0.36 ± 3.72 mm Hg, and between GAT and APT was 0.20 ± 2.23 mm Hg. The mean Diaton IOP was higher than GAT, while mean APT IOP was lower than GAT.

Table 1: Descriptive Statistics for the Tonometers.

	Minimum	Maximum	Mean
Diaton	8.00	23.00	14.78
Air Puff	7.50	24.00	14.42
GAT	8.60	25.00	14.62

Table 2: Correlations between the tonometers and ANOVA.

	Pearson Correlation	Analysis of variance (Regression)	
		F	Sig.
Diaton - CAT	.314**	2.130	.145
GAT - APT	.745**	4.302	.039
Diaton- APT	.334**	.000	.998

Table 3: Linear Regression Analysis.

	R	R ²	Adjusted R ²	Std. Error of the Estimate
Diaton - GAT	.73 ^a	.005	.003	3.65
GAT - APT	.103 ^a	.011	.008	2.22
APT - Diaton	.000 ^a	.000	-.003	3.72

Diaton was seen to overestimate IOP in 195 (48.8%) eyes, in comparison to Goldmann IOP, underestimate IOP in 174 (43.5%), and gave equivalent IOP in 31 (7.8%) eyes. The APT was found to be underestimating IOP in 204 (51%) eyes as compared to GAT, overestimating in 179 (44.8%) eyes, and equal

IOP in 17 (4.3%) eyes.

The Pearson's correlation coefficient (r) between Diaton and GAT was 0.314, between Diaton and APT was 0.334, and between GAT and APT was 0.745 (Table 2). Hence, the strongest correlation was between GAT and APT, followed by Diaton and APT, and least between Diaton and GAT. However, correlations between all three tonometers were significant at the 0.01 level.

Agreement between the three devices was analyzed by the Bland-Altman analysis, which revealed the mean difference (bias) between Diaton and GAT measurements to be 0.16 ± 3.6 mm Hg (+7.33 to -7.01 mm Hg) (Fig. 5), and the mean difference between GAT and APT was 0.20 ± 2.2 mm Hg (+ 4.57 to -4.17mm Hg) [Fig. 6], and between Diaton and APT was 0.36 ± 3.7 mm Hg (+7.65 to -6.93mm Hg) (Fig. 7). This shows good agreement between GAT and APT, and fair agreement of Diaton with both GAT and APT.

Linear regression analysis (Table 3) was done which revealed R² values between GAT and Diaton, GAT and APT, and APT and Diaton to be 0.05, 0.01, and 0.00 respectively, indicating comparable performance between the three. Analysis of variance between the three tonometers, showed that GAT and APT could be used interchangeably (p=0.03) (Table 2).

DISCUSSION

Accuracy of IOP measurement is the need for doctors managing glaucoma patients. Goldmann Applanation tonometer has surpassed all other tonometers in terms of reliability, accuracy, and is the benchmark of IOP measurement. It is precise, easy to use with the slit lamp, and has low intra- and inter-observer variability¹¹. However, the effect of central corneal thickness, astigmatism, and corneal curvature, on influencing IOP measurements with GAT, is well-known.^{2,7,12-15} A thick central cornea leads to overestimating of the IOP, and vice versa. The IOP is underestimated for with-the-rule astigmatism and overestimated for against-the-rule astigmatism.¹⁶ Tonometers that have been developed over the years have often been compared to this indisputable tonometer.

Our study shows that IOPs measured with GAT and APT have good correlation, while both APT and Diaton, and GAT and Diaton have moderate correlations; with the least correlation was found between GAT and Diaton. Amongst the three devices, good agreement was seen between GAT and APT, and

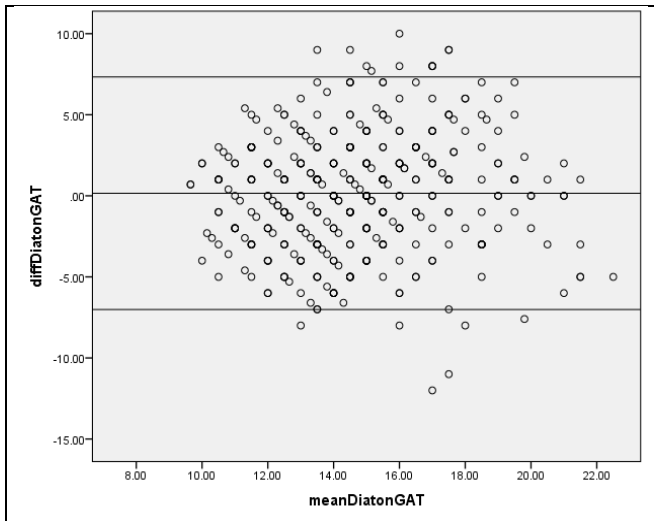


Fig. 5: Agreement between GAT and Diaton (Bland-Altman plot). Difference between Goldmann Applanation Tonometer (GAT) and Diaton transpalpebral tonometer plotted against mean IOP. The middle line indicates the estimated mean GAT-Diaton difference. The upper and lower lines represent the 95% limits of agreement for the difference (+7.33 to -7.01 mm Hg).

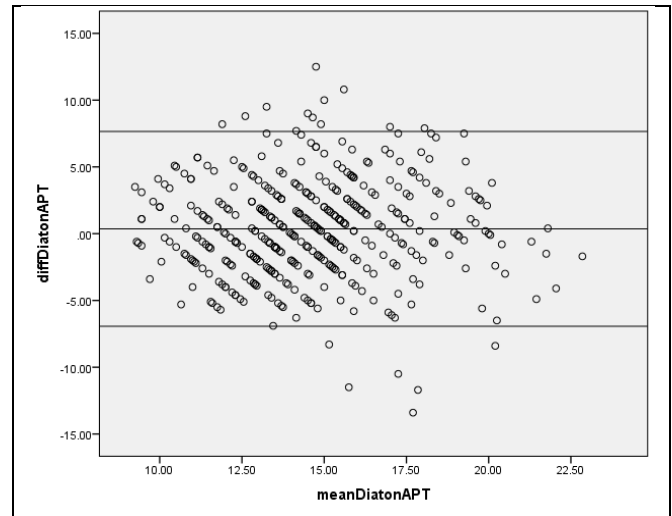


Fig. 7: Agreement between Diaton and APT (Bland - Altman plot). Difference between Diaton and Air Puff tonometer (APT) plotted against mean IOP. The middle line indicates the estimated mean Diaton - APT difference. The upper and lower lines represent the 95% limits of agreement for the difference (+7.65 to -6.93mm Hg).

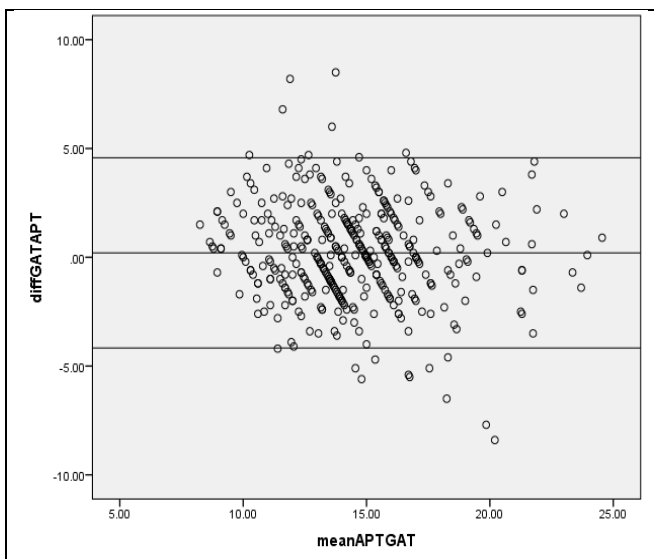


Fig. 6: Agreement between GAT and APT (Bland-Altman plot). Difference between Goldmann Applanation Tonometer (GAT) and Air Puff tonometer (APT) plotted against mean IOP. The middle line indicates the estimated mean GAT-APT difference. The upper and lower lines represent the 95% limits of agreement for the difference (+4.57 to -4.17mm Hg).

there was fair agreement of Diaton with both GAT and APT.

Studies carried out by Doherty,⁸ Bali,¹⁷ Li¹⁸ and Lösch¹⁹ et al, showed that Diaton and other transpalpebral tonometer measurements did not correlate much with GAT, and the two devices had poor agreement. The mean IOP difference was 1.62 ± 3.60 mm Hg in the study by Li,¹⁸ and in numerous other studies, the limits of agreement were found to be very wide, + 8.4 to - 9.6 observed by Doherty⁸ et al, + 4.4 to -11.8 seen by Losch¹⁹, and -9.9 to + 11.2 in Bali's study.¹⁷ Similarly, studies¹⁹ carried out by Troost²⁰ et al revealed transpalpebral tonometry to significantly underestimate IOP compared to GAT, with the effect being more pronounced as the IOP rises. This contrasts with our study, in which Diaton overestimated IOP in the majority of eyes. Sandner²¹ and Toker²² et al have showed moderate correlation between GAT and lid tonometry, with a wide variation²¹ in IOP noted with the latter. We too noted the wide variation in IOP measured by Diaton. The above, in their experience recommend lid tonometry as a screening tool or, in cases where GAT is not possible like scarred corneas. However, we would not recommend usage of Diaton in routine clinical practice and do not consider it to be a useful device.

Numerous studies have been carried out comparing the Air-puff tonometers with GAT. A study carried out in Bahawalpur²³ listed the accuracy of APT as 49.7% with greater accuracy in the lower IOP range, when compared to GAT. Similarly, a study conducted in North India²⁴ shows a fair agreement between APT and GAT when the IOP is in the lower range (mean IOP 1.2 mm Hg with limits of agreement +4.7 to -2.3), but a high correlation, similar to our study. Here too, the air puff was found to underestimate IOP in the majority of cases, like we noted in our study. Salim²⁵ et al in their study in USA found a mean difference of -0.3 with limits of agreement of +6.8 to -7.4, and Parker²⁶ et al in UK noted mean IOP of -0.11 mm Hg (limits +2.10 to -2.33) thus revealing comparable performance of APT with GAT, with good agreement in the normal IOP range; however the variation began with higher IOP range. On the contrary, a study carried out in Iraq by Farhood²⁷ et al, found significant differences between the two devices, with APT overestimating IOP in as many as 74% cases with a mean difference of 2.72 ± 2.34 mm Hg.

A major limitation of our study is that we have carried out the study on presumably normal subjects because we wanted to compare IOP measurement by the three devices, in the normal range of IOP. A few subjects with high IOPs were eventually diagnosed as glaucomatous later on. This prevents us from comparing the devices in the higher range of IOPs. Because of the smaller sample size, we were unable to assess the above. We believe a larger scale study would be needed to assess the devices in extremes of IOP. Another limitation is our lack to assess the central corneal thickness of our subjects, and to evaluate its effect on the three individual devices. We plan to investigate the above at a later stage, in a separate study.

Some may consider transpalpebral tonometry to be useful for screening purposes, because it is portable, user friendly, and non-contact, but we do not deem it very useful in our practice, due to variability of IOP, difficult positioning of the patient, and wide variation in measurement. Also, the slit-lamp mounted applanation tonometer is far more useful, accurate and convenient for us to use. The air-puff tonometer has been used and recommended largely for screening of patients, and has good agreement with GAT, so we consider it to be a useful tonometer in our out-patient department for screening of every patient presenting to us. However, we do confirm the IOP by GAT in cases of glaucoma and when suspicion may arise.

CONCLUSION

Compared to Goldmann tonometry, both air-puff tonometer and Diaton have good correlation; however, only APT has good agreement with GAT, while Diaton has fair agreement with the two devices. APT is a useful tool for screening of IOP, but Diaton cannot be recommended as an accurate screening tool, due to wider variations in IOP.

Author's Affiliation

Dr. Sana Nadeem
Assistant Professor
Department of Ophthalmology
Foundation University Medical College /
Fauji Foundation Hospital, Rawalpindi

Dr. B.A. Naeem
Professor and Head Department of Ophthalmology,
Foundation University Medical College/
Fauji Foundation Hospital, Rawalpindi

Dr. Rabeea Tahira
Postgraduate Trainee, Department of Ophthalmology
Foundation University Medical College/
Fauji Foundation Hospital, Rawalpindi

Dr. Shizza Khalid
House Surgeon, Department of Ophthalmology
Foundation University Medical College/
Fauji Foundation Hospital, Rawalpindi

Dr. Abdul Hannan
Post-graduate trainee
Al-Shifa Trust Eye Hospital, Rawalpindi

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