Comparative Evaluation of Rebound and Perkins Tonometers in Pediatric Glaucoma With Varied Corneal Characteristics

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Precis: Icare tonometer overestimated intraocular pressure (IOP) as compared with Perkins and this variation was higher in IOP > 19 mm Hg and corneal opacity in patients with pediatric glaucoma.

Purpose: To compare the IOP measured by Icare ic200 with Perkins tonometer in pediatric glaucoma with different corneal characteristics.

Methods: Patients of pediatric glaucoma posted for routine examination under anesthesia, age below 12 years were enrolled. All patients underwent IOP measurement with Perkins and Icare ic200 tonometer by the same observer. Basic demographic data and other relevant clinical data were recorded. Central corneal thickness (CCT), horizontal corneal diameter, and corneal characteristics such as cornea clarity was recorded.

Results: A total of 194 eyes of 105 patients were analyzed. The difference between Perkins and Icare IOP was −0.816 mm Hg with the Bland-Altman plot 95% limits of agreement (LoA) from −11.194 to 9.562 mm Hg and 5.1% (10) values lying outside LoA. At IOP < 19 mm Hg, the difference was −0.65 mm Hg and IOP ≥ 19 mm Hg, the difference was higher, −1.12 mm Hg. In the clear cornea group (123 eyes), the difference in IOP by 2 tonometers was −0.776 mm Hg with the Bland-Altman plot 95% LoA between −10.679 and 9.128 mm Hg. In hazy corneas (36 eyes), the difference in IOP was 0.531 mm Hg. The Bland-Altman plot showed 95% LoA between −6.242 and 7.303 mm Hg. In the scarred cornea group (35 eyes), the difference in IOP between the 2 was −2.343 mm Hg and the Bland-Altman plot showed wide 95% LoA from −16.302 to 11.616 mm Hg.

Conclusion: Icare tonometer overestimated IOP as compared with Perkins and this variation was higher in eyes with IOP ≥ 19 mm Hg, CCT > 615 μm, and scarred corneas. A moderate correlation between IOP and CCT for both tonometers was noted.

Key Words: rebound vs. Perkins tonometer, Icare vs. Perkins tonometer, pediatric glaucoma, corneal opacity

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METHODS

The study was approved by the Institution Ethical Committee (IEC/19/1/2020) and was done following the tenets of the Declaration of Helsinki. It was a cross-sectional observational study conducted in a tertiary eye care center of a University Hospital. Consecutive patients presenting to the congenital glaucoma clinic at our center posted for examination under anesthesia (EUA) were enrolled after taking informed consent from the legal guardian/parent. Children with primary or secondary glaucoma, aged below 12 years and those who were routinely posted for EUA were enrolled in the study. Children aged above 12 years, those with operable penetrating keratoplasty, and those whose parents refused to give consent were excluded from the study.

The baseline demographic data such as age, sex, and the diagnosis were noted for all patients. All patients underwent evaluation under anesthesia. All measurements were done by a single observer. The IOP was measured first using the Icare tonometer. An average of 6 readings was taken and the measurements were repeated if there was a wide variation in the readings. A different probe was used for each patient and between the 2 eyes, the same probe was used. Perkins applanation was performed next and an average of 3 readings was taken. In the case of eyes with astigmatism > 3D, for Perkins IOP an average of 4 readings (2 horizontally and 2 vertically) was taken. The central corneal thickness (CCT) was measured using an ultrasonic pachymeter. The characteristics of the cornea such as horizontal corneal diameter, presence of corneal opacity, presence of Haab’s striae, corneal edema, or corneal haze was noted. Further, the eyes were divided into 5 groups based on corneal characteristics. First group with eyes having clear cornea, second group (corneal haze group) with eyes having either corneal edema or corneal opacity with visible iris details, the third group (scarring cornea group) with eyes having dense corneal opacity wherein the iris details were not visible.

Sample Size and statistical Analysis

The sample size was estimated with the help of the Biostatistics department at AIIMS, New Delhi. The Bland-Altman plot was used to statistically calculate the limits of agreement (LoA) between the Icare and Perkins tonometer. It gives a 95% confidence interval of the LoA and the formula for this was given by Bland and Altman. A sample size of 200 which constitutes a margin of error +/- 0.24 s for more precise estimates of the LoA was selected (s is the SD of the difference between the measurements by the 2 methods used in the study). Data were recorded in Excel software (Microsoft Corp.) and were analyzed using SPSS software (version 25.0, SPSS, Inc.). The Bland-Altman plot was used to measure the agreement between the 2 tonometers. While measuring correlation, we adjusted standard error for the presence of clustering by using cluster robust standard errors. For all analyses, a P-value <0.05 was considered as statistically significant.

RESULTS

A total of 200 eyes of 105 patients with pediatric glaucoma posted for routine EUA were enrolled. After excluding 6 fellow eyes, 194 eyes were analyzed. Of this 135 eyes had primary congenital glaucoma (PCG), 20 eyes had anterior segment dysgenesis, 24 had postcataract surgery secondary glaucoma, 9 had retinopathy of prematurity with secondary glaucoma, 6 had other secondary glaucoma like posttraumatic (3 eyes), nevus of ota with glaucoma (1 eye), Congenital hereditary endothelial dystrophy (2 eyes). Details of baseline characteristics are given in Table 1.

The mean difference in the IOP measured between Perkins and Icare was −0.816 mm Hg with the Bland-Altman plot 95% LoA from −11.194 to 9.562 mm Hg (Fig. 1). The correlation between Perkins and Icare was 0.49 (P=0.10) and with corneal diameter was 0.08 (P=0.52). The correlation between Icare IOP and CCT was 0.50 (P=0.15) and with corneal diameter was 0.10 (P=0.46). The correlation between corneal diameter and CCT was 0.09 (P=0.54).

Further, subgroup analysis was done using the IOP measured by Perkins as those having IOP of <19 mm Hg and those having IOP of ≥ 19 mm Hg. A total of 126 eyes (64.9%) had IOP ≤ 19 mm Hg and 68 (35.1%) had IOP > 19 mm Hg. The difference between Perkins and Icare in the group having IOP <19 mm Hg was −0.65 mm Hg and in the group having IOP ≥19 mm Hg was −1.12. On another subgroup analysis with CCT, the median CCT (615 microns) was taken as cut off for division. The difference

![FIGURE 1. Bland-Altman plot showing the agreement for intraocular pressure measurements between the Icare and the Perkins tonometer in pediatric glaucoma eyes. Figure 1 can be viewed in color online at www.glaucomajournal.com.](www.glaucomajournal.com)
between Perkins and Icare IOP in the group having CCT <615 μm was −0.32 mm Hg and in the group having CCT ≥615 μm was −1.12.

Considering a difference in IOP measured by the 2 tonometers of ±2 mm Hg to be acceptable, 95 eyes (49%) had IOP difference within this range. Fifty-three eyes (27.3%) had difference of <−2 mm Hg, and 46 eyes (23.7%), had a difference of >2 mm Hg.

The 194 eyes were further divided into 3 groups based on the corneal characteristics as (i) clear cornea, (ii) corneal haze, and (iii) corneal scarring, Table 2. The clear cornea group had 123 eyes. The Bland-Altman plot showed a mean difference of −0.776 mm Hg between Perkins and Icare with LoA from −10.679 to 9.128 mm Hg (Fig. 2). The difference between Perkins and Icare reading was within the acceptable range of ±2 mm Hg in 58 eyes (47.2%). It was <−2 mm Hg in 32 eyes (26%) and >2 mm Hg in 33 eyes (26.8%). The corneal haze group had 36 eyes. The Bland-Altman plot showed the mean difference between Perkins and Icare was 0.531 mm Hg with LoA between −6.242 to 7.303 mm Hg (Fig. 3). Nineteen eyes (52.8%) had a difference within ±2 mm Hg which is in the acceptable range. 6 eyes (16.7%) had difference of <−2 mm Hg and 11 eyes (30.5%) had difference of >2 mm Hg. The scarred cornea group had 35 eyes. The Bland-Altman plot showed a mean difference of −2.343 mm Hg between the 2 tonometers with LoA from −12.25 to 16.46 mm Hg (Fig. 4). Eighteen eyes (51.4%) had

### TABLE 2. Showing the Various Parameters Based on Different Corneal Characteristics

| Characteristics (n = 194) | Clear Cornea (n = 123) | Corneal Haze (n = 36) | Corneal Scar (n = 35) |
|---------------------------|------------------------|-----------------------|-----------------------|
| Mean ± SD; (Minimum to Maximum) | Mean ± SD; (Minimum to Maximum) | Mean ± SD; (Minimum to Maximum) |
| Age (mo) | 40.63 ± 25.7; (11-144) | 42.3 ± 29.2; (9-144) | 40.82 ± 29.6; (6-144) |
| Horizontal corneal diameter (mm) | 12.26 ± 1.4; (8.5-15) | 12.98 ± 1.38; (9-15.5) | 12.74 ± 1.43; (9-15.5) |
| CCT (μm) | 597.91 ± 122.2; (466-1370) | 699.7 ± 116.3; (468-955) | 844.26 ± 186.9; (511-1800) |
| Perkins IOP (mm Hg) | 15.05 ± 8.8; (2-50) | 19.1 ± 10.8; (2-40) | 23.71 ± 11.6; (6-40) |
| iCare IOP (mm Hg) | 15.83 ± 10.4; (2.4-54) | 18.59 ± 10.74; (2.1-38.7) | 26.05 ± 15.09; (6.1-64.2) |
| Perkins and Icare | | | |
| Mean difference (mm Hg) | −0.776 | 0.531 | −2.343 |
| Limits of agreement (LoA) (mm Hg) | −10.679 to 9.128 | −6.242 to 7.303 | −16.302 to 11.616 |
| Correlation between Perkins IOP and CCT* | 0.29 (P = 0.46) | 0.17 (P = 0.31) | 0.60 (P = 0.10) |
| Correlation between Perkins IOP and CD* | 0.04 (P = 0.15) | 0.25 (P = 0.06) | 0.01 (P = 0.95) |
| Correlation between iCare IOP and CCT* | 0.29 (P = 0.58) | 0.20 (P = 0.02) | 0.57 (P = 0.58) |
| Correlation between iCare IOP and CD* | 0.01 (P = 0.71) | 0.33 (P = 0.71) | 0 (P = 0.85) |

*Correlation adjusted for presence of clustering by using cluster robust standard errors.
P-value <0.05 is statistically significant.

CCT indicates central corneal thickness; CD, corneal diameter; IOP, intraocular pressure; LoA, limits of agreement.

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**FIGURE 2.** The Bland-Altman plot showing the agreement for intraocular pressure measurements between the Icare and the Perkins tonometer in eyes with the clear cornea. Figure 2 can be viewed in color online at www.glaucomajournal.com.

**FIGURE 3.** The Bland-Altman plot showing the agreement for intraocular pressure measurements between the Icare and the Perkins tonometer in eyes with corneal haze. Figure 3 can be viewed in color online at www.glaucomajournal.com.
an acceptable range of difference (± 2 mm Hg) between the 2 methods. Eleven eyes (31.4%) had a difference <−2 mm Hg and 6 eyes (17.2%) had a difference of >2 mm Hg.

**DISCUSSION**

In our study with 194 eyes, we found that the Icare overestimated the IOP by around 0.816 mm Hg and this was higher (2.343 mm Hg) in eyes with the scarred cornea. Arribas-Pardo et al18 conducted a study in 173 healthy nonanesthetized children and also found that the Icare pro overestimated the reading by around 0.26 mm Hg. Another study conducted in children with congenital glaucoma showed that the Icare overestimated the IOP by around 0.42 mm Hg.19 Grigorian et al20 also found that Icare overestimated the IOP by an average of 1.38 mm Hg. The Bland-Altman plot showed the LoA between −11.194 and 9.562. These limits are wide apart when compared with what was reported by Arribas-Pardo et al18 who reported 95% LoA to be 2.8 to −3.4. Borrego Sanz et al19 reported a higher LoA from 7.7 to −6.8. Thus the wide range in the LoA puts some ambiguity in the agreement between the 2 tonometers.

We also found that the overestimation by the Icare was more in eyes with higher IOP (≥19 mm Hg). In the group with IOP ≥19 mm Hg, the Icare was overestimated by 1.12 mm Hg as compared with 0.65 mm Hg in the group with IOP <19 mm Hg. This difference has to be kept in mind while interpreting higher IOP ranges. Badakere et al11 also reported a similar trend with a higher degree of overestimation at higher IOPs. Chen and colleagues also compared the IOP measurements by NCT, the Icare, and GAT in 3 IOP ranges. They found that the overestimation of IOP by Icare was more in IOP ranges 22 to 30 mm Hg and >30 mm Hg (2.3 ± 1.9 and 2.1 ± 1.9 mm Hg, respectively) when compared with overestimation at lower IOP ranges of <10 mm Hg and 10 to 21 mm Hg (1.3 ± 1 and 1.3 ± 1.2 mm Hg, respectively). The number of patients with IOP difference within the range of ±3 mm Hg was also lower in the higher IOP ranges (80%) as compared with the normal IOP ranges of 10 to 21 mm Hg (91%).22

Our study showed a good correlation between the Icare and Perkins tonometer. Similarly, other studies have also shown a good correlation between the 2 methods.8,18,19 We also found that both the Perkins and the Icare IOP had a moderate positive correlation with CCT (0.49 to 0.59). Gao et al18 also found a similar correlation of around 0.39 between the CCT and Icare. In our study, the overestimation of IOP by Icare was more in eyes with CCT ≥615 (1.12 mm Hg) compared with eyes with CCT <615 (0.315). Zakezewska et al studied the difference between Icare and GAT readings in 2 groups, one with CCT >600 μm and the other with CCT <600 μm, and found that in eyes with CCT <600 μm, the Icare underestimated the IOP compared with GAT by around 1.6 mm Hg. Whereas, in eyes with CCT >600 μm, the underestimation was by around 1.9 mm Hg. They also found a correlation of 0.35 between Icare and CCT.23 Chen et al23 found that the Icare was less affected by the CCT as compared with the non-contact tonometer (NCT). In our study there was a poor correlation between IOP and corneal diameter. We did not correlate with the highest baseline IOP, which could explain its poor correlation with corneal diameter. Also, there was poor correlation between CCT and corneal diameter.

In 49% of the eyes, the difference between Perkins and Icare was within ±2 mm Hg which can be considered to be acceptable. In 27.3% of cases, there was an overestimation in Icare by >2 mm Hg and in 23.7% of the cases, there was an underestimation by more than 2 mm Hg. This suggests that about half the readings (49%) taken, were in the acceptable range. Grigorian et al20 found that around 74% of their measurements were within ±3 mm Hg from the GAT. Chen et al22 found 95% of the difference in measurements fell in the ±3 mm Hg range when IOP was <10 mm Hg and 91% when IOP was between 10 and 21 mm Hg.

Many studies have compared Icare with the gold standard, that is, applanation tonometer. However, the measurements of the Icare could vary with the characteristics of the cornea. To have a better understanding, we did a subgroup analysis of the eyes into 3 groups based on the corneal characteristics namely clear cornea, corneal haze, and corneal opacity groups. The overestimation of IOP by the Icare was much higher in the scarred cornea group as compared with the clear cornea group (2.34 vs. 0.78 mm Hg). This suggests that in the presence of dense corneal opacity, the Icare values do tend to be less reliable and are influenced heavily by the corneal thickness. The Bland-Altman plots also showed a wider 95% LoA for the corneal opacity group as compared with the clear corneal group. Badakere et al also divided the eyes into 2 groups one with a corneal scar and the other with a clear cornea. They found that the difference in the IOP measured by the 2 methods was 2 mm Hg in the clear cornea group and 1.7 mm Hg in the corneal scar group. The LoA were −5.4 to 9.4 mm Hg in the clear cornea group and −3.8 to 7.2 mm Hg in the corneal scar group.21

In our study, the number of measurements in the acceptable range of ±2 mm Hg was around 50% (47% to 53%) in both the corneal scar and the clear cornea groups, Stoor and colleagues studied the effect of refractive error and astigmatism on the measurements by Icare and GAT. They found that the difference between the 2 methods was >±2 mm Hg in 27% of eyes with myopia, 24% in emmetropes, 21% with hyperopia, and 25% with any astigmatism. They found that the rebound tonometer was less affected by corneal astigmatism as compared with the GAT and they proposed that it could be due to the less area of contact between the probe and the cornea.24

The limitations of this study include a relatively small sample size in the different subgroups. Also, the study was done on anesthetized children, therefore, the compliance
and the ease in measuring IOP using the Icare in children could not be evaluated.

The Icare tonometer could be a good option in pediatric glaucoma patients. There is a definite logistic advantage of using the Icare as it reduces the need for sedation or EUA and it is more tolerable to the patient as compared with applanation tonometer.\textsuperscript{10,20} It was also found that manual elevation of the upper lid did not significantly alter the readings and measurements could be done over an extended wear bandage contact lens making it a good tool.\textsuperscript{25,26}

Our study found that Icare ic200 overestimated IOP as compared with Perkins and this variation was higher in eyes with IOP > 19 mm Hg. CCT ≥ 615 μm, and scarred cornea. To conclude, Icare is a good alternative to Perkins tonometer in pediatric glaucoma eyes. However, in eyes with the scarred cornea and IOP > 19 mm Hg, the IOP should be rechecked with a Perkins tonometer.

REFERENCES

1. Weinreb RN, Aung T, Medeiros FA. The pathophysiology and treatment of glaucoma: a review. JAMA. 2014;311:1901–1911.
2. Thau A, Lloyd M, Freedman S, et al. New classification system for pediatric glaucoma: implications for clinical care and a research registry. Curr Opin Ophthalmol. 2018;29:385–394.
3. Alodhayb S, Morales J, Edward DP, et al. Update on pediatric glaucoma. Semin Ophthalmol. 2013;28:131–143.
4. Dandona L, Williams JD, Williams BC, et al. Population-based assessment of childhood blindness in Southern India. Arch Ophthalmol (Chicago, Ill : 1960). 1998;116:545546.
5. Arora R, Bellamy H, Austin M. Applanation tonometry: a comparison of the Perkins handheld and Goldmann slit lamp-mounted methods. Clin Ophthalmol Auckl NZ. 2014;8:605–610.
6. Stevens S, Gilbert C, Astbury N. How to measure intraocular pressure: applanation tonometry. Community Eye Health. 2007; 20:74–75.
7. MA Fayed, Chen TC. Pediatric intraocular pressure measurements: tonometers, central corneal thickness, and anesthesia. Surv Ophthalmol. 2019;64:810–825.
8. Gao F, Liu X, Zhao Q, et al. Comparison of the iCare rebound tonometer and the Goldmann applanation tonometer. Exp Ther Med. 2017;13:1912–1916.
9. Nakakura S. Icare® rebound tonometers: review of their characteristics and ease of use. Clin Ophthalmol Auckl NZ. 2018; 12:1245–1253.
10. Grigorian F, Grigorian AP, Olitsky SE. The use of the iCare tonometer reduced the need for anesthesia to measure intraocular pressure in children. J AAPOS. 2012;16:508–510.
11. Dahlmann-Noor AH, Puertas R, Tabasa-Lim S, et al. Comparison of handheld rebound tonometry with Goldmann applanation tonometry in children with glaucoma: a cohort study. BMJ Open. 2013;3:e001788.
12. Sinha G, Gupta S, Temkar S, et al. IOP agreement between I-Care TA01 rebound tonometer and the Goldmann applanation tonometer in eyes with and without glaucoma. Int Ophthalmol. 2015;35:89–93.
13. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet (London, England). 1986;1:307–310.
14. Bland JM, Altman DG. Sample size for a study of agreement between two methods of measurement. Available at: https://www-users.york.ac.uk/~mb55/meas/zimeth.htm. Accessed April 30, 2020.
15. Cameron AC, Miller DL. A practitioner’s guide to cluster-robust inference. J Hum Resour. 2015;50:317–372.
16. Sihota R, Angmo D, Ramaswamy D, et al. Simplifying “target” intraocular pressure for different stages of primary open-angle glaucoma and primary angle-closure glaucoma. Indian J Ophthalmol. 2018;66:495–505.
17. The Advanced Glaucoma Intervention Study (AGIS): 7. The relationship between control of intraocular pressure and visual field deterioration. The AGIS Investigators. Am J Ophthalmol. 2000;130:429–440.
18. Arribas-Pardo P, Mendez-Hernández C, Valls-Ferran I, et al. Icare-pro rebound tonometer versus hand-held applanation tonometer for pediatric screening. J Pediatr Ophthalmol Strabismus. 2018;55:382–386.
19. Borrego Sanz L, Morales-Fernandez L, Martinez de-la-Casa JM, et al. The Icare-pro Rebound tonometer versus the hand-held applanation tonometer in congenital glaucoma. J Glaucoma. 2016; 25:149–154.
20. Grigorian F, Grigorian AP, Li A, et al. Comparison of the Icare rebound tonometry with the Goldmann applanation tonometry in a pediatric population. J AAPOS. 2019; 23:572–574.
21. Schreiber W, Vorwerk CK, Langenbuecher A, et al. A comparison of rebound tonometry (iCare) with TonoPenXL and Goldmann applanation tonometry. Ophthalmology. 2007;104:299–309.
22. Chen M, Zhang L, Xu J, et al. Comparability of three intraocular pressure measurement: iCare pro rebound, non-contact and Goldmann applanation tonometry in different IOP group. BMC Ophthalmol. 2019;19:225.
23. Zakrzewska A, Wiacek MP, Machalinska A. Impact of corneal parameters on intraocular pressure measurements in different tonometry methods. Int J Ophthalmol. 2019;12:1853–1858.
24. Stoor K, Karvonen E, Ohtonen P, et al. Icare versus Goldmann in a randomised middle-aged population: the influence of central corneal thickness and refractive errors. Eur J Ophthalmol. [Epub ahead of print].
25. Nakakura S, Mori E, Fujiy Y, et al. Effect of manual upper eyelid elevation on intraocular pressure measurement by four different tonometers. Optom Vis Sci. 2020;97:128–133.
26. Azarcon CP, Dela Cruz RC. Rebound tonometry measurements over extended-wear bandage contact lenses. Cont Lens Anterior Eye. 2020;43:505–506.