• Brief Report •

Comparison of intraocular pressure readings with Perkins, Tonopen, iCare 200, and iCare Home to manometry in cadaveric eyes

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Received: 2021-09-02 Accepted: 2022-03-11

Abstract

● **AIM:** To compare intraocular pressure (IOP) readings obtained with Perkins tonometry, iCare Home, iCare 200, and Tonopen to IOP readings obtained with the manometer of a perfusion system to assess the accuracy and reproducibility of each method of tonometry at set pressures.

● **METHODS:** The IOP of human cadaveric eyes (*n*=2) was measured using a manometer inserted into the eye through the optic nerve. IOP measurements were obtained using a Perkins tonometer, iCare Home, iCare 200, and Tonopen. These measurements were compared to set point IOP measurements of a manometer to determine accuracy and reproducibility of each device.

● **RESULTS:** Mean IOP readings obtained with the Perkins tonometer compared to manometer readings demonstrated a difference of -1.0±5.0 mm Hg (*P*=0.45), indicating a lower reading on average than manometery although not significant. Mean IOP difference between iCare 200 and manometer was 5.3±2.2 mm Hg (*P*<0.0001). Mean difference in IOP between iCare Home and manometer was 3.5±2.4 mm Hg (*P*=0.0004). Mean IOP difference compared to manometer was 4.6±4.0 mm Hg for the Tonopen (*P*<0.0001). IOP measurements obtained with the Perkins tonometer demonstrated a standard deviation of 5.0 mm Hg while the Tonopen measurements demonstrated a 4.0 mm Hg standard deviation. In comparison, iCare 200 and iCare Home demonstrated 2.2 and 2.4 mm Hg standard deviation, respectively.

● **CONCLUSION:** Applanation tonometry produces more accurate IOP readings than rebound tonometry or Tonopen, however it demonstrates greater variability than the other forms of tonometry. Rebound tonometry is more reproducible but tends to over-estimate IOP.

● **KEYWORDS:** intraocular pressure; ocular tonometry; manometry

DOI:10.18240/ijo.2022.12.19

Citation: Ertel MK, Seibold LK, Patnaik JL, Kahook MY. Comparison of intraocular pressure readings with Perkins, Tonopen, iCare200, and iCare Home to manometry in cadaveric eyes. *Int J Ophthalmol* 2022;15(12):2022-2027

INTRODUCTION

Glaucoma is a leading cause of blindness worldwide, estimated to affect 76 million adults between 40-80 years of age in 2020[1-2]. The disease is characterized by optic nerve cupping with corresponding retinal nerve fiber layer thinning and irreversible vision loss. While elevated intraocular pressure (IOP) is not included in the definition of glaucoma, several major clinical trials have demonstrated that lowering IOP can slow and/or prevent the progression of glaucoma, making the accurate and reproducible measurement of IOP essential for glaucoma providers[3-5]. Multiple methods of tonometry exist, each offering certain advantages and disadvantages based on patient characteristics[6].

The most commonly used methods of tonometry include Goldmann applanation tonometry (GAT), Tonopen, and rebound tonometry using the iCare tonometer. GAT is currently considered the gold standard for IOP measurements and is extensively use in both clinical and research settings[6-7]. The Tonopen is also commonly used given its portability, ease of use, and ability to measure patients who cannot position in the slit lamp[8]. Studies have shown significant variability between IOP measurements obtained with GAT and Tonopen[9-11]. Rebound tonometry, using the iCare tonometer (iCare, Raleigh, NC, USA) is a newer method of tonometry that allows for acquisition of IOP readings without topical anesthesia and fluorescein instillation. It has proven particularly useful in children and allows for self-tonometry at home.

It is important to understand the accuracy and reproducibility of these various tonometer devices. Several clinical studies have been performed comparing IOP readings obtained with various methods of tonometry. Most of these papers use GAT as the standard against which other methods of tonometry are compared[6,9-15]. In this study, we utilize the manometer of a perfusion system to set IOP in human cadaveric eyes to allow for comparison between different tonometers. Specifically, our study sought to compare various tonometers by comparing IOP readings obtained with a Perkins applanation tonometer, Tonopen, iCare 200, and iCare Home at set manometer readings to better understand the accuracy and repeatability of these devices. This is the first study to compare multiple readings of tonometry in an eye with a set IOP verified by intraocular manometry to assess accuracy and reproducibility of various methods of tonometry.

SUBJECTS AND METHODS

Ethical Approval Exemption for this preclinical study was in place from the Colorado Multiple Institutional Review Board (COMIRB) for the use of human material prior to initiation of this study and the tenets of the Declaration of Helsinki were followed.

Human cadaveric eyes were obtained from the Lions Eye Institute for Transplant and Research, Tampa, Florida. Both eyes were phakic and each came from a patient who was 39 years of age. There was no evidence of corneal pathology in either eye. The eyes were brought up to physiologic IOP with balanced salt solution (BSS) through the optic nerve. A 1-millimeter sideport blade was used to make a peripheral corneal paracentesis and the eye was filled with viscoelastic (Viscoat, Alcon, Fort Worth, Texas, USA). The paracentesis was not sealed after filling of the anterior chamber. However, throughout data acquisition, the eyes remained formed and no reflux of viscoelastic from the eye was noted. The eyes were then wrapped in moist gauze and refrigerated for 4h prior to the start of the experiment. Pachymetry was then performed on each eye using a portable pachymeter (PACHMATE 2, DGH Technology, Inc., Exton, PA,USA).

Manometry A mobile perfusion test station was used as the manometer to determine IOP of the cadaveric eyes. The manometer set up consisted of a 27-gauge needle inserted through the optic nerve of and attached to a syringe. Placement of the manometry needle in the vitreous cavity was performed as published data shows greater stability in IOP reading with this approach compared to intracameral placement of the needle[16]. The syringe was attached *via* tubing to a transducer suspended in a transducer stand connected to syringe pump which allowed for adjustments in IOP. Both the transducers and syringe pump were connected to an external hard drive that collected pressure readings through a computer running software to acquire steady state pressure measurements. The system was primed with BSS prior to measurements to remove all air bubbles. We then ensured each eye achieved steady state IOP maintaining the designated IOP reading for 30-60s prior to tonometry data acquisition. All measurements were obtained with the same set-up allowing for direct comparison between the different tonometers.

Tonometry Tonometry was performed using multiple methods, including: 1) applanation tonometry with a Perkins tonometer, 2) indentation/applanation tonometry using a Tonopen AVIA (Reichert, Dewpew, NY, USA), 3) rebound tonometry using an iCare 200, and 4) rebound tonometry using an iCare Home. Central corneal thickness (CCT) of each eye was measured. Two measurements of CCT were performed for each eye: The first eye measured 681 and 697 microns and the second eye measured 643 and 647 microns. The protocol for reading was as follows: eyes were brought to a desired IOP range with BSS infusion and confirmed with manometer readings that remained stable over approximately 30-60s. Due to the need for BSS infusion to achieve a desired IOP and because of the sensitivity of the manometer, each IOP set point was measured in hundredths of an mmHg, care was taken to ensure that the IOP reading was steady prior to obtaining measurements. IOP readings were obtained between 6 and 32 mm Hg to mimic a physiologic range of IOP plus 10 mm Hg above normal. The IOP set point ranged from 1) 6-9 mm Hg, 2) 10-12 mm Hg, 3) 16-18 mm Hg, 4) 19-22 mm Hg, 5) 27-32 mm Hg. One investigator performed IOP reading using each tonometer device consecutively and called out the readings while the second investigator recorded the pressure measurement from the manometer to ensure stable IOP and transcribed the dictated readings from the first investigator. The measurements for each device were immediately repeated at every set IOP point and recorded. This was repeated for a second cadaveric eye so that two IOP measurements were obtained from each eye in this fashion.

Statistical Analysis Mean differences between the gold standard manometer and each of the four tonometers, and their respective standard deviations (SD) were calculated. Linear regression analysis with general estimating equations to account for the fact that multiple measurements were obtained from each eye were used for statistical comparisons. Sub-analyses of eyes with IOP readings between 10-30 mm Hg and 10-21 mm Hg were performed to evaluate the tonometers' performance at the most clinically relevant IOP ranges. Actual mean differences and mean absolute differences, defined as the absolute value of difference between the two measurements, were calculated between manometry and tonometry data. In addition, IOP readings obtained with each tonometer were

Table 1 Measurement differences between each tonometer and manometer readings at IOP range of 10-50 mm Hg

Measurements	Perkins	iCare 200	iCare Home	Tonopen
Difference from manometer				
Mean±SD	-1.0±5.0	5.3±2.2	3.5±2.4	4.6±4.0
Median	-0.2	5.5	3.2	5.2
P	0.45	<0.0001	0.0004	<0.0001
Absolute difference from manometer				
Mean±SD	4.0±3.1	5.3±2.2	3.7±2.2	5.4±2.8
Median	3.4	5.5	3.2	5.4
P	<0.0001	<0.0001	<0.0001	<0.0001

IOP: Intraocular pressure.

Table 2 Measurement differences between each tonometer and manometer readings at different clinically relevant IOP ranges

Measurements	Perkins	iCare 200	iCare Home	Tonopen
IOP 10-30 mm Hg				
Difference from manometer				
Mean±SD	1.1±2.7	5.8±2.2	3.6±2.4	4.2±2.1
Median	0.8	5.3	3.2	4.8
Absolute difference from manometer				
Mean±SD	2.2±1.8	5.8±2.2	3.6±2.4	4.2±2.1
Median	1.8	5.3	3.2	4.8
IOP 10-21 mm Hg				
Difference from manometer				
Mean±SD	-0.4±1.5	6.3±2.1	4.5±2.5	5.4±1.3
Median	0.2	5.6	4.5	5.3
Absolute difference from manometer				
Mean±SD	1.2±0.9	6.3±2.1	4.5±2.5	5.4±1.3
Median	0.9	5.6	4.5	5.3

IOP: Intraocular pressure.

plotted against their respective manometer readings. A trend line with a slope of one was incorporated, which equals complete agreement between manometry and tonometry readings. To measure repeatability, the actual mean differences and mean absolute differences between the two readings sets, and Pearson's correlation coefficients were also obtained between the two reading sets for each tonometer.

RESULTS

The mean (±SD) pressure difference between Perkins tonometry, iCare 200, iCare Home, and Tonopen compared to manometer readings are demonstrated in Table 1 for all 26 measurements. In addition, sub-analyses of clinically relevant IOPs were analyzed for IOP readings between 10-30 mm Hg (12 measurements) and 10-21 mm Hg (8 measurements), data shown in Table 2.

Perkins tonometry readings demonstrated the greatest variability while both forms of rebound tonometry had much lower variability. Tonopen readings also demonstrated considerable variability between manometry measurement differences. Regarding repeatability, Pearson's correlation coefficient was 1 for both iCare 200 and iCare Home. Both the Perkins tonometer and Tonopen demonstrated high repeatability as well, but slightly lower Pearson's correlation coefficient of 0.96 and 0.94, respectively. Perkins tonometer demonstrated much lower mean differences from manometer IOP reading than either form of rebound tonometer or Tonopen (Table 1, Figures 1, 2). Absolute differences between the manometer were similar for all tonometers when including all IOPs (Table 1 and Figure 1) but were smallest for Perkins tonometer for clinically relevant IOP ranges (Table 2).

DISCUSSION

Both the mean difference and mean absolute difference between manometer and tonometer were lowest for the Perkins tonometer followed by the iCare Home, Tonopen, and iCare 200. At a physiologic IOP range of 10-21 mm Hg, both the mean difference and mean absolute difference between manometer and tonometer readings were lowest for the Perkins followed by the iCare Home, Tonopen, and then iCare 200.

While the Perkins tonometer obtained readings that were most consistent with manometry, the readings demonstrated the greatest variability compared to all other methods of tonometry. Both forms of rebound tonometry and the Tonopen

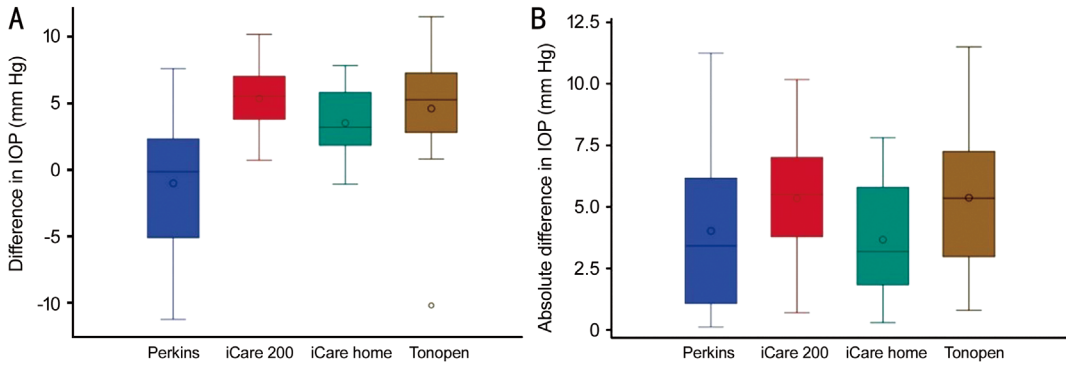

Figure 1 Actual and absolute difference between tonometer and manometer readings A: Difference between other tonometer readings and manometer by type of tonometer; B: Absolute difference between other tonometer readings and manometer by type of tonometer.

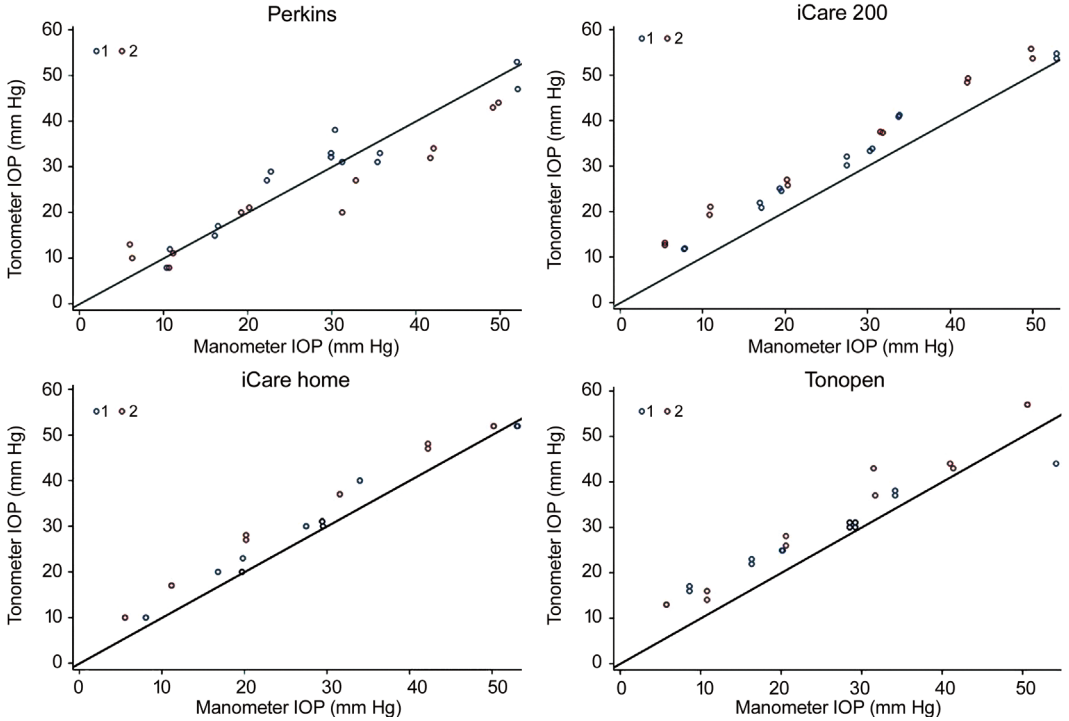

Figure 2 Plots of each tonometer with corresponding manometer IOP readings.

showed much lower variability. Of the four tonometers tested, the greatest repeatability was demonstrated with the iCare 200 and the iCare Home. Both the Perkins tonometer and Tonopen demonstrated high repeatability as well, but slightly lower compared to both iCare platforms. Comparing absolute differences, all four methods of tonometry obtained IOP readings that were significantly different compared to manometer but Perkins and iCare Home performed slightly better than the iCare200 and Tonopen.

Tonometry is an essential clinical tool necessary for the successful diagnosis and treatment of glaucoma. The current gold standard for tonometry remains Goldmann applanation tonometry. Both GAT and Perkins tonometry are methods of applanation tonometry with studies demonstrating good agreement between IOP readings obtained with GAT and Perkins tonometry[11]. Disadvantages of GAT include effect of CCT on accuracy of measurement, need for topical anesthetic and need for patient cooperation[8]. The Tonopen measures IOP through a combination of applanation and indentation tonometry[17]. While there are multiple sources of error with the use of a Tonopen, advantages include the ability of the device to read IOP in eyes with corneal pathology and the portable nature of the device[8,17-19]. Several studies comparing IOP measurements between GAT and Tonopen demonstrate a significant difference between readings, with some studies demonstrating that the Tonopen overestimates IOP[12,17] and others demonstrating an underestimation of IOP[19]. Rebound tonometry is the newest form of tonometry and has become increasingly popular due to the ease of use and lack of need for topical anesthetic. Unlike applanation and Tonopen devices, rebound tonometry does not require the use of a topical anesthetic and allows for supine IOP measurement and at-home readings. One disadvantage of rebound tonometry is the tendency to over-estimate pressure

in eyes with thick CCT or with corneal scarring compared to GAT[12]. Studies comparing IOP measurements with GAT and rebound also show variability between the two, again with some studies demonstrating an overestimation of IOP with rebound tonometry[20] and others demonstrating a lower IOP measurement with rebound tonometry[21].

Previous studies comparing IOP readings obtained with various devices demonstrated variable results. While several studies have shown a close correlation between GAT readings and those obtained with Tonopen[15] and rebound tonometry[16,22], others show significant variability between these devices[21,23]. Most of these studies comparing GAT with rebound tonometry demonstrate that rebound tonometry overestimates IOP to a similar amount obtained in our study. Even the studies that demonstrate good agreement between rebound tonometry, GAT and Tonopen note that greater variability exists at higher IOP and with variations in CCT[15-16,21]. Several studies have demonstrated a clear correlation between CCT and alterations in IOP readings with all forms of tonometry[24-29]. Tonnu *et al*[27] compared the effect of CCT on multiple methods of tonometry and noted that all methods of tonometry are significantly affected by CCT, however the effect is least with GAT. Some of the variability between tonometers in our study may be secondary to the increased CCT in the cadaveric eyes used during the study. However, it is worth nothing that in this study all tonometry measurements were performed in the same two eyes. Furthermore, readings from each IOP range were obtained in the same eye at the same set point range. As such, any effect from CCT was equal across all methods of tonometry. Still, the findings of this current study may not be generalizable to all CCTs. This highlights a limitation to our study which is the small sample size. However, it should be noted that several readings were obtained in each cadaveric eye which allowed for statistical analysis of the data.

In conclusion, this study uses cadaveric eyes to confirm that applanation tonometry is the most accurate method of tonometry, despite having a greater degree of variability. It also confirms that rebound tonometry tends to over-estimate IOP more than Perkins tonometer when compared to manometry readings. iCare Home performed well in comparison to iCare 200 and Tonopen and both methods of rebound tonometry showed good reproducibility compared to the other forms of tonometry.

ACKNOWLEDGEMENTS

Conflicts of Interest: Ertel MK, None; **Seibold LK,** None; **Patnaik JL,** None; **Kahook MY,** None.

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