



How should we measure intraocular pressure in the era of coronavirus disease 2019? Balancing infectious risk, cleaning requirements, and accuracy

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Purpose of review

Accurate and precise measurement of intraocular pressure (IOP) is a vitally important component of the ophthalmic examination. There are multiple methods of tonometry, each of which has considerations in light of the ongoing severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) pandemic. This review discusses these considerations and compares various tonometer methods with the gold standard of Goldmann applanation tonometry (GAT).

Recent findings

The SARS-CoV-2 virus may spread via droplets, microaerosols, or direct contact in the ophthalmology clinic. Tonometry poses a high risk of contamination. The accuracy and reliability of various methods of tonometry with single-use disposable equipment has been compared with Goldmann applanation tonometry.

Summary

Goldmann applanation tonometry with disposable applanation tips, Tono-pen, and iCare employ single use tips to decrease the risk of cross-contamination of infectious agents. Review of the literature demonstrates good correlation between these devices and GAT, although the published level of agreement between devices varies.

Keywords

coronavirus disease, glaucoma, iCare, intraocular pressure, tonometry, Tono-pen

INTRODUCTION

Intraocular pressure (IOP) measurement, also called tonometry, is vitally important in the evaluation and treatment of ocular disease. Glaucoma management in particular requires accurate and precise IOP measurement. There are multiple methods of tonometry in clinical use, and they generally involve either contact with the ocular surface or directing a column or puff of air at the ocular surface. Each of these methods have unique concerns regarding the risk for cross-contamination or the spread of infectious agents, which is of paramount concern in light of the ongoing severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) pandemic.

The SARS-CoV-2 virus has been variably found to be present on the conjunctiva and in the tears of COVID-19-positive patients both with and without conjunctivitis or other ocular involvement [1,2³,3,4⁵,5,6⁷,7,8⁹]. The cornea and conjunctiva express ACE2, the receptor for the SARS-CoV-2 virus, as well as TMPRSS2, a protease that facilitates viral entry into

cells [9,10]. Therefore, cross-contamination via contact tonometry, which by nature touches the ocular surface, could potentially spread the virus from one patient to another. SARS-CoV-2 can also spread via aerosols or droplets [11,12]. Noncontact tonometry (NCT), such as air-puff tonometry and the Ocular Response Analyzer (ORA, Reichert Technologies, Depew, New York, USA) can lead to the formation of droplets and microaerosols, especially when the

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KEY POINTS

- SARS-CoV-2 may be spread via droplets, aerosols, or fomites in the ophthalmology clinic.
- Single-use disposable applanation tips are increasingly being utilized for GAT to reduce risk of contamination with infectious agents.
- Tono-pen and iCare are alternative methods of tonometry and use single-use disposable tips for each patient.
- Studies have demonstrated good correlation of GAT using disposable applanation tips, iCare, and Tono-pen with traditional GAT, although some studies have found either overestimation or underestimation of IOP with these devices, particularly in patients with ocular hypertension or glaucoma.

natural tear film is increased as with the addition of eye drops in the clinical setting [13,14]. For this reason, NCT technologies will not be further included in this review.

This review will discuss the ways in which the importance of reliable intraocular pressure measurements can be balanced with infectious risk reduction. It will also provide a review of the literature to compare various methods of tonometry. Interpretation of literature comparing methods of measurements may include correlation or intraclass correlation values. Correlation measures the association between two variables and does not consider agreement between two variables. In other words, two methods of measurement may have high correlation but may not give similar values. On the other hand, intraclass correlation evaluates the correlation within a class of data (such as intraocular pressure) and accounts for differences in values. It therefore provides a better understanding of agreement or consistency between the two measurements [15,16]. Bland–Altman analysis can also evaluate the agreement between different methods of measurement and provide 95% limits of agreement (LoA), which are the values within which 95% of the two methods of measurement would fall [17].

GOLDMANN APPLANATION TONOMETRY

Goldmann applanation tonometry (GAT) is considered the gold standard method of tonometry. It is based on the Imbert–Fick principle and involves measuring the force required to flatten the corneal apex with a clear plastic tonometer tip. It requires corneal anesthesia [18]. Although considered the gold standard, there are numerous possible sources of error with GAT, including the concentration of fluorescein on the ocular surface, eye position, patient Valsalva

maneuver or accommodation, and contact of the tonometer tip with ocular adnexa, among other factors [19]. Numerous studies have looked at the repeatability of GAT measurements, and an analysis of the literature by Pearce and Maddess [20] found that the 95% LoA for same-session repeated measurements ranged from 2.3 to 5.7 mmHg.

Tonometers are considered semicritical items in the Centers for Disease Control and Prevention (CDC) guidelines for infection control as they come into contact with mucous membranes. As such, they require high-level chemical disinfection. The CDC recommendation is that tonometer tips be wiped clean and then disinfected by soaking in either 5000 ppm chlorine or 70% ethyl alcohol for 5–10 min [21]. The Ophthalmic Technology Assessment Committee of the American Academy of Ophthalmology published a report on the disinfection of tonometers in 2017 [22] and recommends the use of sodium hypochlorite (dilute bleach) at concentrations of 1 : 10 and 1 : 20. Alcohols including ethyl alcohol and isopropyl alcohol are not recommended as they are not effective against bacterial spores. It is notable that none of these methods of disinfection can prevent transmission of prions [22]. Although effective at eradicating most infectious agents, the disinfection process can also cause damage to the tonometer tips either through exposure to the disinfecting agent or through immersion in water, which is used to clean the tip after disinfection. The tonometer tip can become cracked, leading to an irregular surface, which can damage the cornea directly by causing trauma or via retained disinfectant agent leading to chemical injury. Furthermore, the rough surface may preclude thorough disinfection and allow for microbes to persist on the surface [23]. The manufacturer recommends that the reusable tonometer tip be replaced after 100 cycles of disinfection with dilute bleach, or whenever damaged [22].

In response to these inherent limitations in disinfecting tonometer tips, the use of single use tonometer tips has become increasingly common [24**]. In 1996, Maldonado *et al.* [25] described the use of a single-use sterile silicone shield over the tonometer tip. This technique led to an average overestimation of the intraocular pressure of 1.9 mmHg with higher variability in results, and these shields are no longer produced.

Several single-use disposable applanation prisms are available as alternatives to reusable applanation tips. Examples include the Tonosafe (Haag-Streit AG, Koeniz, Switzerland), Luneau Tonojet (Luneau Technology, Chartres, France), and Tonoclear (Keeler Malvern, PA, USA). Several studies evaluating the difference between reusable GAT tips and Tonosafe tips found a mean IOP difference in the

Table 1. Bland–Altman limits of agreement for Goldmann applanation tonometry versus Goldmann applanation tonometry with disposable tips, Tono-pen, and iCare

Authors and year	Instrument	N (eyes)	Mean IOP, instrument (mmHg, \pm SD)	Mean IOP, GAT (mmHg, \pm SD)	Mean difference, instrument – GAT (mmHg, \pm SD)	95% Limits of agreement ^a (mmHg)
Kotecha <i>et al.</i> [37], 2016	GAT – retest variability	100	15.5 \pm 5.2	15.8 \pm 4.6	-0.2 \pm 2.5	-5.1, 4.7
Wang <i>et al.</i> [38], 2013	GAT – retest variability	Intraoperator: 52 Interoperator: 52	-	-	-0.10 \pm 2.2 0.50 \pm 1.7	-4.44, 4.24 -2.78, 3.78
Desai <i>et al.</i> [27], 2001	GAT, tonosafe tip	197	19.5 \pm 6.5	19.1 \pm 6.6	0.44 \pm 1.54	-2.6, 3.5
Salvi <i>et al.</i> [28], 2005	GAT, tonosafe tip	400	15.8 \pm 5.4	15.9 \pm 5.4	-0.1 \pm 1.0	-2.1, 1.9
Eldaly [32], 2016	GAT, tonojet tip	104	17.8 \pm 10.5	20.5 \pm 11.7	-2.7 \pm 2.4	-2.0, 7.4
Salvetat <i>et al.</i> [39], 2007	Tono-pen XL	101	20.3 \pm 6.9	20.8 \pm 6.1	-0.5 \pm 4.5	-6.0, 7.0
Kato <i>et al.</i> [40], 2018	Tono-pen XL	60	13.7 \pm 4.1	14.0 \pm 2.8	0.27 \pm 4.16	-7.9, 8.4
Blumberg <i>et al.</i> [36 ^{***}], 2021	Tono-pen XL	600	15.5 \pm 0.6	15.4 \pm 0.7	0.15 \pm 0.4	Not provided
Bhartiya <i>et al.</i> [41], 2011	Tono-pen AVIA	50 glaucoma 130 control	30.9 \pm 10.5 15.1 \pm 3.4	31.4 \pm 8.5 15.0 \pm 3.0	Not provided	-7.7, 8.7 -5.1, -4.8
Kutzscher <i>et al.</i> [42], 2019	Tono-pen AVIA	321	20.5 [95% CI 19.9–21.3]	17.3 [95% CI 16.6–18.0]	3.2 [95% CI -2.7 to 3.8]	-6.1, -12.6
Brusini <i>et al.</i> [43], 2006	iCare TA01i	178	18.4 \pm 5.2	19.4 \pm 5.4	-1.0 \pm 3.5	-7.0, 6.6
Iliev <i>et al.</i> [44], 2006	iCare TA01i	47 right eyes 54 left eyes	17.0 \pm 4.49 18.0 \pm 6.76	16.3 \pm 4.0 16.7 \pm 6.9	0.70 \pm 2.38 1.29 \pm 1.92	Combined right and left eyes: -3.2, 5.2
Munkwitz <i>et al.</i> [45], 2008	iCare TA01i	75	21.59 \pm 9.17	20.80 \pm 9.38	0.79 \pm 4.73	-8.67, 10.25
Vandewalle <i>et al.</i> [46], 2009	iCare TA01i	93	15.7 \pm 5.7 ^a	15.1 \pm 4.8 ^a	2.5 \pm 2.3 ^a	-5.9, 7.1
Salim <i>et al.</i> [47], 2013	iCare TA01i	65	16.93 \pm 5.67	14.48 \pm 4.34	2.45 \pm 4.24	-1.79, 6.69
Sinha <i>et al.</i> [48], 2015	iCare TA01i	185	16.67 \pm 4.87	16.79 \pm 4.87	0.1 \pm 6.02	-5.8, 6.05
Kato <i>et al.</i> [40], 2018	iCare TA01i	60	11.6 \pm 2.5	14.0 \pm 2.8	2.46 \pm 2.10	-1.66, 5.59
Kutzscher <i>et al.</i> [42], 2019	iCare TA01i	321	16.9 [95% CI 16.2–17.6]	17.3 [95% CI 16.6–18.0]	-0.4 [95% CI -0.9 to 0.0]	-8.4, 7.6
Kim <i>et al.</i> [49], 2013	iCare PRO	172	15.6 \pm 3.0	13.6 \pm 3.3	1.92 \pm 3.29	-4.52, 8.37
Kato <i>et al.</i> [40], 2018	iCare PRO	60	12.6 \pm 2.2	14.0 \pm 2.8	1.42 \pm 2.35	-3.20, 6.04
Nakakura <i>et al.</i> [50], 2021	iCare PRO	145	13.3 \pm 3.2	14.5 \pm 2.9	Not provided	-3.72, 6.21

GAT, Goldmann applanation tonometry; IOP, intraocular pressure; mmHg, millimeters of mercury; SD, standard deviation.

^aPublished data.

range of 0.1–0.5 mmHg [26–31]. Studies comparing the Luneau Tonojet to reusable tip GAT found a mean IOP difference of 0.4–2.35 mmHg [26,32,33].

There are several important considerations in the use of disposable tips. Eldaly [32] found that surface irregularities were relatively common in the Luneau prisms. In their study, they inspected the prisms prior to use and found that 14 of 189 disposable tips had to be discarded because of the presence of surface irregularities. Baddon *et al.* [33] found that in 28 of the 140 eyes included in the study, the tonometer endpoint was difficult to assess with Luneau prisms because of excessively thick rings. The menisci endpoint was deemed to be of acceptable quality in 80% of the Luneau tip readings and 100% of the GAT readings. These difficulties may account for the higher mean difference in IOP readings noted between Luneau Tonojet prisms and GAT compared with the difference between Tonosafe prisms and GAT. Clinicians should exercise caution when using disposable lenses and consider discarding tips which do not allow for a clear reading.

The use of disposable tonometry tips carries with it a concern for increased cost (currently approximately \$1.30–1.40 USD each). Several studies have compared the cost of using disposable tips versus that of reusable GAT prisms. In general, when considering the need to disinfect the reusable tips and replace them as recommended, the cost of disposable tips is comparable with or less than that of reusable tips [28,30,31].

TONO-PEN

Tono-Pen (Reichert, Inc, Depew, New York, USA) is a hand-held portable Mackay-Marg-type applanation tonometer, which uses a strain gauge to measure the force needed to flatten the cornea [18]. It requires topical anesthesia. A disposable cover is used for each patient, making it an attractive option for infection-control purposes, and are relatively inexpensive (approximately \$0.50 USD). A study by Bao *et al.* [34] measured IOP with GAT and Tono-Pen in 989 eyes and found that the mean difference was 0.15 mmHg, with high correlation (0.76). However, the Tono-Pen overestimated the IOP compared with GAT at lower IOPs and underestimated the IOP at higher IOPs. Increased central cornea thickness was associated with a higher IOP reading by Tono-Pen, which has also been seen in other studies [35]. A study of 600 eyes in a university glaucoma clinic found that although mean IOP measurements were similar between GAT and Tono-Pen (correlation 0.76), there was difference in IOP of at least 3 mmHg in 34% of eyes. Among a subgroup of eyes with IOP greater than 21 by GAT, IOP by Tono-Pen was significantly lower

with a mean difference of -3.6 ± 1.7 mmHg. A separate subgroup analysis of 120 patients with primary open angle glaucoma also found that the IOP was lower with Tono-Pen than with GAT in this population. Furthermore, they found that Tono-Pen overestimated GAT at lower IOPs and underestimated GAT at higher IOPs [36¹¹]. A random distribution of IOP values in a large sample may mask these overestimations and under-estimations, leading to the overall lack of significant difference found between tonometry with GAT and Tono-Pen. Evaluating the level of agreement between two methods of measurement with Bland–Altman 95% limits of agreement (see Table 1) or with intraclass correlation can be useful in this situation.

REBOUND TONOMETRY (iCare)

iCare (iCare Finland Oy, Vaanta, Finland) is a portable hand-held rebound tonometer, which uses a solenoid to propel a single-use disposable magnetic probe toward the cornea. The movement of the probe generates a current, the magnitude of which depends upon the speed at which the probe bounces back from the eye, and which is used to determine the IOP [51]. This method does not require corneal anesthesia. The tips are intermediate in price (approximately \$0.72–0.84 USD) compared with disposable applanation tips and Tono-pen covers. There are several models of iCare devices available.

A meta-analysis of studies comparing GAT with iCare PRO found a meta-difference of -0.14 mmHg (95% confidence interval of -0.43 to 0.15 mmHg), which was not a statistically significant difference [52¹¹]. Notably, one of the six studies included in the analysis found that iCare gave significantly lower IOP readings whereas another found that iCare gave significantly higher IOP readings. Another study found that there was good agreement between GAT and iCare in patients with and without glaucoma, although at higher IOP levels (IOP >22 mmHg), RBT readings were lower than those for GAT [49]. Munkwitz *et al.* [45] found that in eyes with IOP of 23 and above, 28% had a difference of greater than 5 mmHg in the measurements taken with GAT versus iCare. These findings suggest that one should be cautious in interpreting tonometry with iCare in the setting of IOPs above 22 mmHg.

CONCLUSION

The SARS-CoV-2 pandemic has brought infection control to the forefront of clinical practice. Tonometry is essential to the practice of ophthalmology but carries the risk of spreading infectious agents. The gold standard GAT may be made safer by adopting

single use applanation tips. It should be cautioned that these tips may have more variability in the endpoint of tonometry, and if there is difficulty finding the endpoint, it may be better to discard the tip in question and repeat the measurement with a second tip. NCT with an air puff device or ORA presents a challenge because of the potential formation of droplets or aerosols and are best avoided if there is concern for infection with SARS-CoV-2. Tono-pen and iCare have the advantage of being handheld portable devices with single-use disposable tips or covers that come into contact with the eye. Overall, studies have demonstrated good correlation between these devices and GAT. Clinicians must balance the risk of microbial transmission with that of accurate and reproducible tonometry.

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Conflicts of interest

There are no conflicts of interest.

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- of special interest
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