SYSTEMATIC / NARRATIVE REVIEW ARTICLE

Intraocular pressure measurements in paediatric glaucoma: A narrative review on accuracy, tolerability, and ease of use

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ABSTRACT

Introduction: Numerous tonometers are available to measure intraocular pressure (IOP) in children with glaucoma. This review aims to discuss IOP measurement techniques and principles and compare the accuracy, tolerability and ease of use of available tonometers in measuring IOP in paediatric glaucoma patients.

Materials and Methods: A review of observational studies was conducted to discuss the accuracy, tolerability and ease of use of tonometers in measuring IOP in children with glaucoma.

Results: Goldmann applanation tonometry (GAT) and its portable handheld versions remain the gold standard in measuring IOP. Tono-Pen (Reichert Ophthalmic Instruments, Depew, New York, USA) and rebound tonometer (RBT) both correlate well with GAT. Although both tonometers tend to overestimate IOP, Tono-Pen overestimates more than RBT. Overestimation is more remarkable in higher IOP and corneal pathologies (such as but not limited to scarred cornea and denser corneal opacity). RBT was better tolerated than other tonometers in children and was easier to use in children of all ages.

Conclusions: RBT is the preferred tonometer for measuring IOP in children with glaucoma, as it is less traumatic, time efficient and does not require fluorescein dye or anaesthesia. However, examiners should use a second tonometer to confirm elevated IOP readings from the RBT.

KEYWORDS:
Intraocular pressure, measurement, paediatric, glaucoma, tonometry

INTRODUCTION

Glaucoma can cause severe vision loss and blindness and can affect people of all ages, including children.[1] Diagnosing paediatric glaucoma is challenging, as perimetry examinations and optic disc evaluation in children are difficult due to a lack of cooperation.[2,3] Usually, raised intraocular pressure (IOP) is the most common feature of paediatric glaucoma and the most important risk factor in glaucoma progression and development.[4]

Precise and accurate IOP measurement depends on several factors, including but not limited to patient cooperation, the use of anaesthesia and the application of fluorescein dye.[5,6] These pose a challenge, as children tend to cry, hold their breath and squeeze their eyes during examination.[7,8] Furthermore, the use of anaesthesia may cause pain and the application of fluorescein may cause discomfort.[6]

This literature review aims to discuss IOP measurement techniques and principles, and compare the accuracy, tolerability and ease of use of available tonometers in measuring IOP in paediatric glaucoma patients.

MATERIALS AND METHODS

A comprehensive medical literature search was conducted on PubMed and through manual cross-referencing (n = 144). The search terms used alone or in combination were IOP measurement, tonometers, paediatric glaucoma, accuracy, tolerability and ease of use. The review included full-text observational studies in the English language published from inception to April 2022 that discussed the accuracy of various tonometers in measuring IOP in children with glaucoma, as well as studies that investigated the tolerability and ease of use of tonometers in children with glaucoma and healthy children (n = 26). The review also excluded studies that recruited adult subjects (n = 2). Two reviewers performed the search, assessment and data extraction processes. This narrative review includes 14 studies, with 10 focusing on the accuracy of tonometers and four examining the tolerability and ease of use in children (Figure 1).

IOP Measurement Techniques and Operating Principles

IOP is a dynamic equilibrium of aqueous humour production and outflow, which are nearly equal under normal conditions. IOP can be evaluated by transpalpebral, manometry and tonometry.[9] Tonometry is performed with tonometers. The purpose of tonometers is to obtain accurate IOP measurement with the least disturbance of the eyes. Based on its operating principles, tonometers can be classified into (1) applanation, (2) indentation, (3) applanation-indentation and (4) rebound tonometers (Table I).[9]

Goldmann applanation tonometry (GAT) remains the gold standard amongst other tonometers in measuring IOP.[5,10] Perkins applanation tonometer is one of the GAT's portable handheld versions, thus enabling IOP to be measured in both upright and supine positions. Its handheld design is ideal for babies, young children and bedridden children. General anaesthesia is required for IOP measurements with GAT and

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Table I: Operating principles of tonometers

Operating Principles	Explanation	Tonometers (Production year)
Applanation	Operated based on the Imbert-Fick Law (P= F/A), which states that the pressure inside a thin-walled sphere is equal to the force needed to flatten its surface divided by the area of the flattening.[9,10] Can be divided into non-contact tonometers (no physical contact between the eye and tonometer, such as (pneumotonometer, air-puff tonometry, and Ocular Response Analyzer [ORA]).) and contact tonometers (GAT and Perkins tonometer).[10] Most widely used and reliable tonometers.	Goldmann applanation tonometer [GAT] (Haag Streit and Reliance Medical Products, Mason, Ohio, USA) (1955) Perkins tonometer (Haag Streit and Reliance Medical Products, Mason, Ohio, USA) (1965) Pneumotonometer (Reichert, Buffalo, New York, USA) (1969) Air-puff tonometer (1973) ORA (Reichert Ophthalmic Instruments, Depew, New York, USA) (2005)
Indentation	Operated based on the basic principle that a known force will indent a fluid- or gas-filled object to a greater extent if the internal pressure is low, as opposed to high. The force can be provided digitally or by a known weight.[9] Although it is no longer used in developed countries, it is still widely used in developing countries.[10]	Schiøtz tonometer (1905) Bailliart tonometer (1923) Maurice electrical tonometer (1958) Mueller electronic tonometer (1960)
Applanation-Indentation	Operated based on the principle of applanation and indentation.[9,10]	Tono-Pen (Reichert Ophthalmic Instruments, Depew, New York, USA) (1989) Corvis ST (Oculus, Wezlar, Germany) (2011)
Rebound	Analysis of motion parameters of a bouncing probe from the tonometer caused by an electrical pulse generator that creates a magnetic field after impact with the cornea. When the probe makes contact with the cornea, it bounces back to the instrument, causing a voltage change. The solenoid inside the tonometer detects voltage changes. The greater the IOP, the shorter the time the probe is in contact with the cornea and the faster it returns to the tonometer.[3] One of the most commonly used tonometers in clinical practice today.	Icare tonometer (Icare Finland Oy, Helsinki, Finland) (1997)

handheld applanation tonometers. There have been no studies that compare the accuracy of handheld applanation tonometry and GAT, however, in adults, the IOP measurements obtained with handheld applanation tonometer are closely comparable to those obtained with GAT.[18,19]

The applanation principle is also used in non-contact tonometry (NCT), in which the cornea is flattened with a puff of air.[3,10] NCT eliminates the possibility of contamination because it does not make contact with the cornea, thus ideal for cooperative children at increased risk of infection.[2,10] Another notable advantage is that NCT does not require topical anaesthesia's instillation.[3,10] NCT is available in handheld and stationary models.[3] Only a few studies investigated the accuracy of NCT, especially in children with glaucoma. Chan et al. in 2015 discovered that in the eyes of children with anterior segment pathology, including those with congenital glaucoma, the mean IOP measured by NCT was 3.9 mmHg lower than the IOP measured by Icare (Icare Finland Oy, Helsinki, Finland) rebound tonometry (RBT), and this difference became more significant at higher levels of IOP. The authors did, however, mention the possibility of IOP variation in their cohort due to stress on the cornea when measuring IOP with NCT to RBT, thus resulting in the lower IOP measurement with NCT.[20] More robust studies on the accuracy of NCT in children with glaucoma are warranted.

Tono-Pen is a battery-powered tonometer that operates on the principles of applanation and indentation. Tono-Pen is equipped with a disposable latex cap to reduce cross-infection. A more recent tonometer, Icare RBT, is a lightweight, portable handheld instrument with a disposable probe. Unlike Tono-Pen, RBT does not require topical anaesthesia.[3,10] RBT has high reproducibility, both intraobserver and interobserver.[4,21] IOP measurements with Tono-Pen and RBT correlate well with GAT, although both tonometers tend to overestimate the IOP. Studies have consistently shown that the IOP measured by RBT is higher than GAT (Table II).[4,7,12,13,17] When comparing the accuracy of RBT and Tono-Pen, numerous studies have found that the overestimation by Tono-Pen is greater than RBT.[5,14–16]

Table II: Summary of accuracy from included studies

Author (Year)	Study population	Sample size	Tonometers used	Mean IOP measurements
Levy et al. (2005)[11]	PCG (IOP measured ~3 minutes after inhalation anaesthesia)	16 children (28 eyes)	Perkins tonometry and Tono-Pen XL	Perkins: 18 ± 6 mmHg Tono-Pen XL: 22 ± 8 mmHg
Martinez-de-la-Casa et al. (2009)[12]	PCG	47 children (47 eyes)	Perkins tonometry and RBT	Perkins: 19.1 ± 5.4 mmHg RBT: 22.1 ± 7.7 mmHg
Flemmons et al. (2011)[13]	Known or suspected glaucoma	71 children (71 eyes)	GAT and Icare	GAT: 18.7 ± 6.8 mmHg Icare: 21.1 ± 8.4 mmHg
Gandhi et al. (2012)[7]	Known or suspected glaucoma	60 children (60 eyes)	GAT and Icare ONE	GAT: 16.9 ± 5.7 mmHg Icare ONE: 19.0 ± 8.4 mmHg
Dahlmann-Noor et al. (2013)[4]	Glaucoma	102 children	GAT and RBT	GAT: 18 ± 6.45 mmHg RBT: 21.1 ± 8.19 mmHg (observer 1); 21.14 ± 8.41 mmHg (observer 2)
Dosunmu et al. (2014)[14]	Known or suspected glaucoma and healthy children	47 children (94 eyes)	GAT, Icare PRO and Tono-Pen	Sitting position GAT: 16.4 ± 4.2 mmHg Icare PRO: 17.5 ± 3.5 mmHg Tono-Pen: 18.0 ± 3.9 mmHg Supine position Icare PRO: 18.4 ± 4.5 mmHg Icare PRO: 18.8 ± 4.2 mmHg
McKee et al. (2015)[5]	Glaucoma with/without corneal pathology and healthy children (IOP measured immediately after inhalation anaesthesia)	50 children (100 eyes)	Icare PRO and Tono-Pen XL	Icare PRO: 16.7 ± 7.1 mmHg Tono-Pen XL: 16.9 ± 7.5 mmHg
AlHarkan et al. (2016)[15]	Glaucoma and other eye pathologies (IOP measured ~20 minutes after oral sedation)	28 children (52 eyes)	Icare PRO, Tono-Pen XL and Pneumotonometer	Glaucoma group Icare PRO: 17.6 ± 6 mmHg Tono-Pen XL: 20.5 ± 6.8 mmHg Pneumotonometer: 20 ± 6.4 mmHg Control group Icare PRO: 13.54 ± 3.07 mmHg Tono-Pen XL: 14.6 ± 3.3 mmHg Pneumotonometer: 15.25 ± 3.3 mmHg
Mendez-Hernandez et al. (2020)[16]	Glaucoma	46 children (91 eyes)	Perkins, Icare PRO, and Tono-Pen XL	Perkins: 17.99 ± 6.24 mmHg Icare PRO: 19.3 ± 6.10 mmHg Tono-Pen XL: 23.5 ± 10.65 mmHg
Angmo et al. (2021)[17]	Glaucoma (Patients were under general anaesthesia)	105 children (200 eyes)	Perkins and Icare IC200	Clear cornea Perkins: 15.05 ± 8.8 mmHg Icare IC200: 15.83 ± 10.4 mmHg Corneal haze Perkins: 19.1 ± 10.8 mmHg Icare IC200: 18.59 ± 10.74 mmHg Corneal haze Perkins: 23.71 ± 11.6 mmHg Icare IC200: 26.05 ± 15.09 mmHg

PCG = Primary congenital glaucoma; IOP: Intraocular pressure; RBT = Rebound tonometer; GAT = Goldmann applanation tonometer

Table III: Summary of tolerability of different tonometers in children from included studies

Author (Year)	Study population	Sample size (Age range)	Tonometers used	Tonometers used
Lundvall et al. (2011)[26]	Healthy children	39 children (3 to 18 months)	Icare	No child shows discomfort.
Rodrigues et al. (2014)[27]	Children with horizontal strabismus and healthy children	50 children (3 to 21 months)	Icare PRO and Perkins tonometry	Icare PRO is more tolerable than Perkins tonometry. Three infants (6%) were distressed and cried during examination with Icare PRO, compared to 31 infants (62%) with Perkins tonometry.
Sahin et al. (2007)[21]	Healthy children	152 children (7 to 15 years)	RBT (Icare) and GAT	RBT is more tolerable than GAT. Ten (6.6%) children felt slight pain and/or discomfort, and the remaining 142 (93.4%) children experienced no pain or discomfort.
Gandhi et al. (2012)[7]	Known or suspected glaucoma	60 children (5 to 17 years)	Icare ONE and GAT	Icare PRO is more tolerable than GAT. Forty parents (78%) rated Icare ONE as equal or more tolerated than GAT.

GAT = Goldmann applanation tonometer; RBT = Rebound tonometer

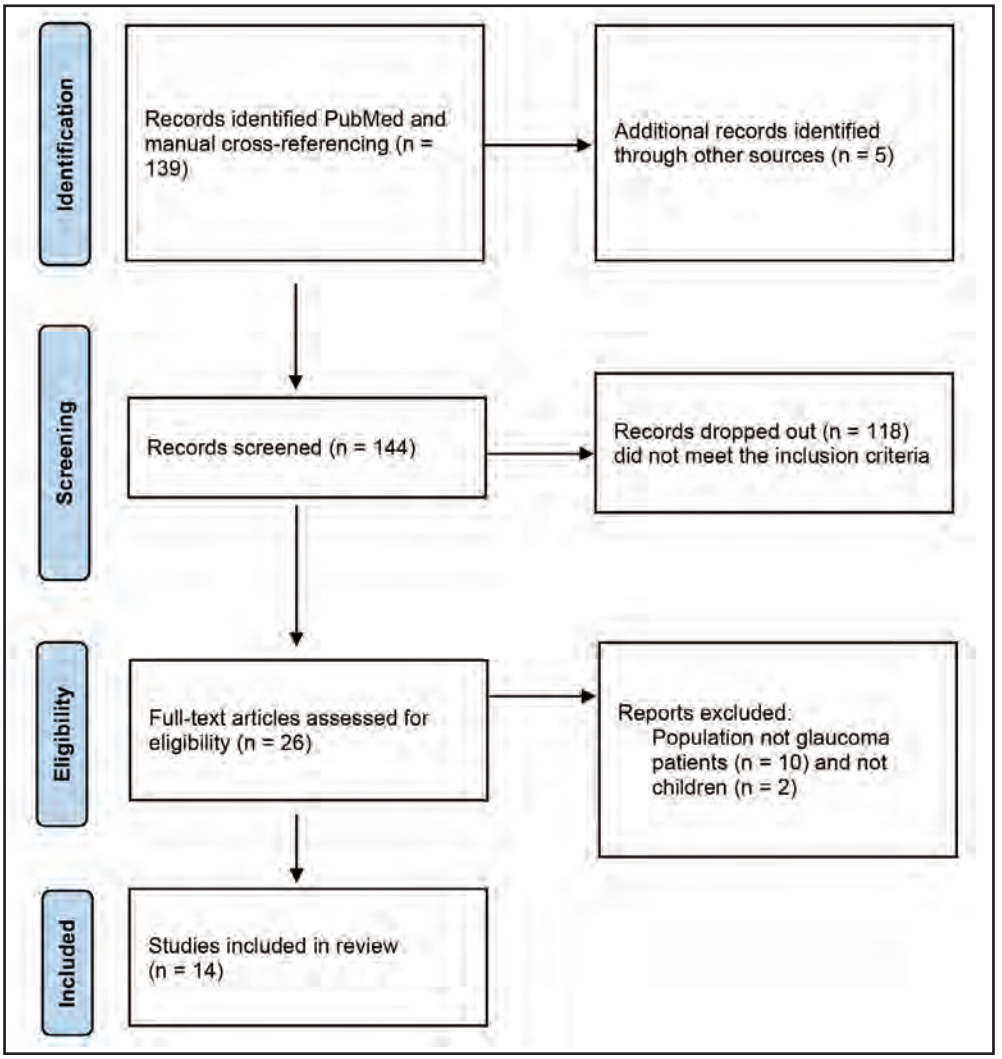

Fig. 1: Flow chart of the study selection process.

The mean difference between IOP readings with Tono-Pen and RBT is more significant in eyes with corneal oedema or abnormalities.[5,22] According to Levy et al., the overestimation with Tono-Pen is greater than with handheld applanation tonometry when the IOP exceeds 16 mmHg.[11] A study by Mendez-Hernandez found that the overestimation by Tono-Pen is even more remarkable if measurements by handheld applanation tonometry are greater than 20 mmHg.[16] When comparing RBT and handheld applanation tonometry, overestimation with RBT is more pronounced in eyes with an IOP of ≥19 mmHg and scarred cornea.[6,17] Angmo et al. discovered that the scarred cornea group (2.34 mmHg) had significantly higher IOP overestimation with RBT than the clear cornea group (0.78 mmHg).[17] These findings imply that RBT IOP values are less reliable in eyes with higher IOP and denser corneal opacity. Three case reports concluded that high IOP readings obtained with RBT should be interpreted with caution in cases of congenital corneal opacity with corneal fibrosis and that examiners should always consider the possibility of false-positive glaucoma diagnosis in these patients.[23] The accuracy of Tono-Pen over other tonometers in children with paediatric glaucoma presenting with oedematous cornea is still in question. However, several studies have stated that Tono-Pen is superior to GAT in adults with glaucoma and oedematous cornea.[10] Thus, more studies should be conducted to validate the accuracy of Tono-Pen in the oedematous cornea in children.

The notable challenge when measuring IOP in children with suspected or known glaucoma is the need for repetitive measurements. This has been shown to influence IOP readings in adults.[24] However, this is not true for children, as Dosunmu et al. found that the mean IOP difference between the initial and final (eighth) measurements with RBT was similar among the 20 eyes of 10 children recruited for the study. This could be because the RBT tip measures only 1 mm in diameter and makes only a small and brief contact with the cornea, hence, it does not appear to affect IOP.[25]

Another noteworthy challenge is the effect of body position during examinations and measured IOP. IOP measurements in infants are usually taken in supine positions, and it was questioned whether IOP measurements in older children in seated positions would be significantly different. Dosunmu et al. found that supine IOP readings with RBT and Tono-Pen were higher than seated readings in children. However, the IOP increases of 0.9 and 0.7 mmHg with RBT and Tono-Pen were considered insignificant and unlikely to change treatment plans in children with or without glaucoma.[14]

Tolerability and ease of use are two essential features of a tonometer, especially in children with paediatric glaucoma. As previously mentioned, GAT, handheld applanation tonometer, and Tono-Pen readings require topical anaesthetic drop and general anaesthesia which may be daunting to younger children.[3,13] The Tono-Pen has a relatively large tip that may intimidate children. Although no prior topical anaesthetic is required for IOP measurement with NCT, the puff of air may be frightening to children. With its small tip diameter, RBT's design is tolerable for children.[3]

Numerous studies have investigated the tolerability of various tonometers in infants and school-aged children without general anaesthesia (Table III). Lundvall et al. discovered that 39 healthy infants aged 3 to 18 months experienced no discomfort using RBT during or after an IOP examination.[26] A later study by Rodrigues et al. found that measurement with RBT was better tolerated in infants, causing distress and crying in only 6% of infants, compared to 62% with handheld applanation tonometer.[27]

In children between 5 to 17 years of age with known or suspected glaucoma in clinical settings, majority of patients' parents rated RBT as equally or more tolerable than GAT.[7] In a study by Sahin et al., school going children aged 7 to 15 years were asked to rate their level of discomfort during IOP measurements using RBT. According to their testimonies, 93.4% of the children experienced no pain or discomfort during IOP measurement with RBT, while the remaining children felt minor discomfort.[21]

In terms of ease of use, a survey of current paediatric tonometry practice in 2012 that included 144 paediatric ophthalmologists in the UK discovered that rebound tonometry (77.8%) is the most preferred method to measure IOP in children, followed by GAT/Perkins (44.4%), Tono-Pen (5.6%) and air-puff NCT (5.6%). 85.7% of participants rated rebound tonometry as 'very easy' and 'moderately easy'.[4] Another study found that examiners rated RBT higher than handheld applanation tonometer, regardless of the child' age.[12]

CONCLUSION

The primary goal of paediatric glaucoma diagnosis is to avoid irreversible eye damage that can lead to blindness. Goldmann applanation tonometry (GAT) is the gold standard for measuring intraocular pressure (IOP) but can only be used on older, cooperative children. Many newer tonometers have been developed, including handheld applanation tonometer (Perkins), rebound tonometer (RBT) (Icare), Tono-Pen, and air-puff non-contact tonometry (NCT) (in descending order of accuracy), each with distinct advantages over GAT. In children with suspected or known glaucoma, choosing the right tonometer is crucial, considering the accuracy, tolerability and ease of use. This review suggests that RBT is a better option than other tonometers in paediatric glaucoma patients because it is less traumatic, time-efficient and does not require anaesthesia or fluorescein dye. However, high readings with RBT, especially in patients with scarred cornea, should prompt the examiner to confirm findings with a second instrument. Further studies should be done in large, multi-centred cohorts to assess the accuracy of tonometers (and their various versions) in different anterior segment abnormalities in patients with paediatric glaucoma.

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