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Conventional Intraocular Pressure Measurement Techniques

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Abstract

Determining the intraocular pressure (IOP) is a part of routine ophthalmic examination. Elevated IOP is a risk factor for glaucoma, and reducing the IOP is the only way to halt or dampen glaucoma progression. Therefore, precise measurement of IOP is critical in glaucoma management. Tonometry is the procedure of determining IOP using various techniques. Various devices are available in the market for determining IOP. Each one works with different principles. Different methods have been introduced and some of them in development, but there is still no perfect clinical method for exact measurement of IOP. This chapter aims to explore various tonometry devices available in the market while explaining their working principles, features, advantages, and disadvantages. Clinicians must choose proper technique balancing the accuracy, convenience, and cost of the tonometers. Estimation values of tonometers should be used with clinical aspects of patients.

Keywords: tonometer, intraocular pressure, Goldmann applanation tonometer, Tono-Pen, Schiotz, rebound tonometer, pneumotonometer, manometry, noncontact tonometer

1. Introduction

Fluid pressure inside the eye is responsible for maintaining the shape of the globe as known as intraocular pressure (IOP). Since Bannister described the relation between blindness and firmness of the eye in the sixteenth century, IOP has been regarded as a vital parameter of the eye. Accurate measurement of IOP with proper technique is crucial in diagnosis and management of glaucoma and related conditions. Increased IOP is known to be associated with progressive optic nerve damage [1]. Currently, lowering IOP is the only way to control glaucoma and prevent optic nerve damage. Secretion of aqueous humor and regulation of outflow are critical in maintaining the normal IOP. Aqueous humor is produced in posterior chamber,

passes through the pupil into the anterior chamber, and leaves the eye via trabecular meshwork and uveo-scleral pathway. The balance between production and outflow determines the level of IOP, which is approximately 16 mmHg [2]. Age, surgery, trauma, medication, and various diseases may affect production or outflow of the aqueous humor and result in changes in IOP [3].

Tonometers are the instruments used for obtaining IOP. Measurements of an ideal tonometer should be accurate, reproducible, and repeatable. It should be portable, easy to use, simply calibrated, and standardized. Despite all the technological advances since sixteenth century, we still do not have a perfect method to measure IOP in clinical practice. Most of the currently available tonometers are used over cornea, which is only available and accessible structure for estimating IOP. All current clinical measurement techniques are affected by ocular and non-ocular factors and provide us with an estimate of the IOP [4].

Perceiving the working principles of tonometers and the factors affecting their measurement results would help examiners to choose the most proper technique.

The “conventional” tonometers covered in this chapter include:

1. Indentation tonometry: Schiøtz tonometer
2. Applanation tonometry: Goldmann applanation tonometer
3. Noncontact tonometer
4. Pneumotonometer
5. Mackay-Marg tonometer and Tono-Pen tonometry
6. Transpalpebral tonometry
7. Manometry

2. Indentation tonometry: Schiøtz tonometer

Schiøtz tonometer works with “*indentation*” principle, which implies that higher IOP requires higher weight or force to indent. It measures the depth of corneal indentation by a plunger carrying a known weight. The body of the tonometer consists of a curved footplate that rests on the cornea and a known weighted plunger moving freely within a shaft in the footplate. When measuring the IOP, the subject must be positioned in supine position and topical anesthetic drops should be applied. After placing the footplate on the cornea perpendicularly, the plunger moves in an amount depending on the IOP. Movement of the plunger is indirectly proportional to the IOP. A scale on the plunger gives a reading of the movement amount (**Figure 1**). The reading is converted to IOP in mmHg using a conversion table.

This is a mechanical method hence not very reliable in all cases. Conversion Table assumes an average coefficient of ocular rigidity. Therefore, in case of a change in ocular rigidity, blood volume alteration during the measurement and alterations in corneal properties such as steep

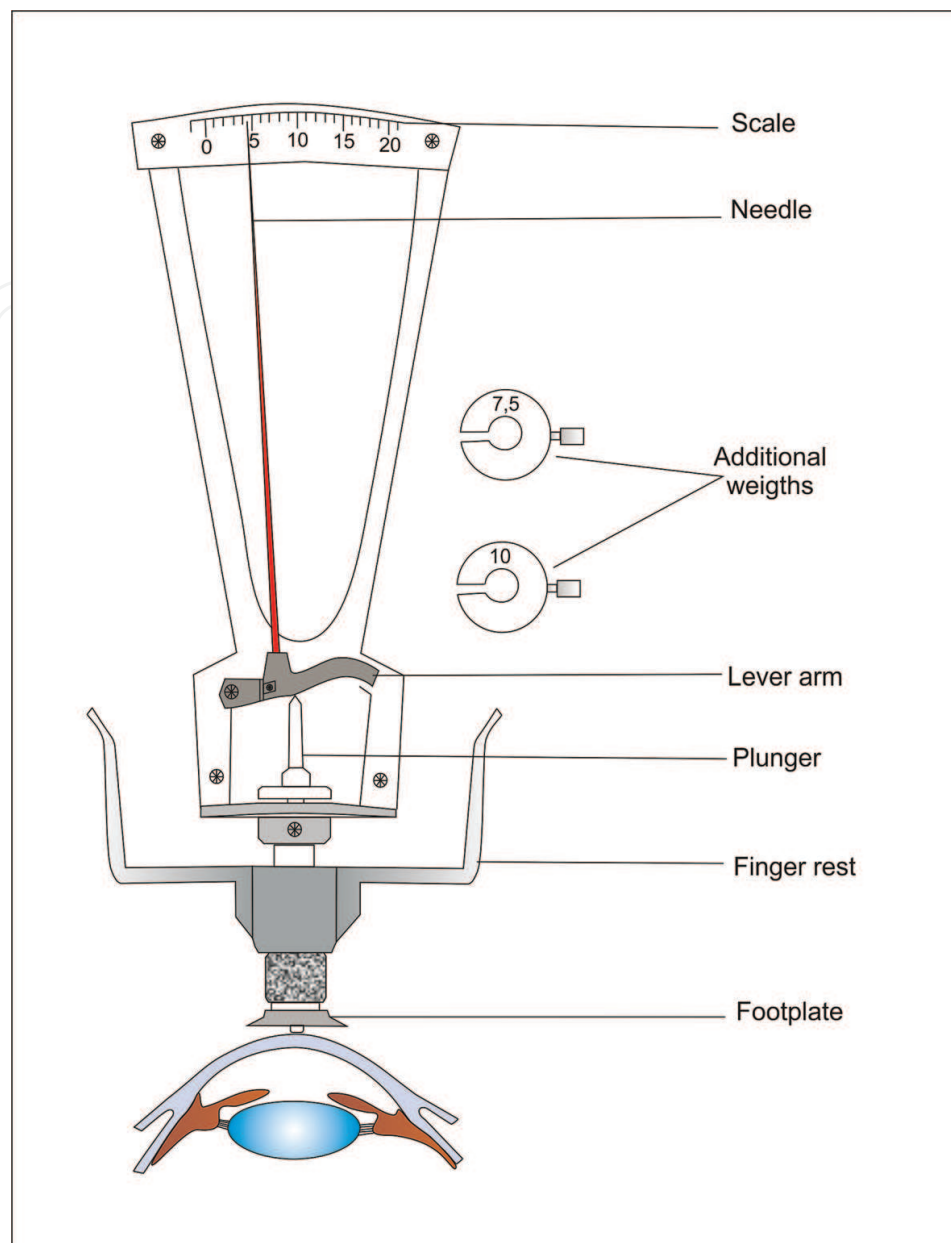


Figure 1. A schematic representation of Schiøtz tonometer.

and thicker cornea can cause faulty IOP measurement results. Footplate must be sterilized either with alcohol swap or soaking with 1:1000 merthiolate solution. Schiøtz tonometer is considered obsolete in many centers in the developed world but still is an important tool on peripheral centers across the developing nations.

3. Applanation tonometry: Goldmann applanation tonometer

Goldmann applanation tonometer (GAT) is the most widely used method and regarded as the reference standard. It was introduced in the mid-1950s and works based on the “Imbert-Fick

principle,” which states that the pressure (P) inside a sphere equals the force (F) necessary to flatten its surface divided by the area (A) of flattening, $P = F/A$ [5]. According to Imbert-Fick principle, eye must be perfectly sphere, dry, perfectly flexible, and indefinitely thin. But cornea is aspheric, wet with tear film, not perfectly flexible or thin. To overcome these limitations, Imbert-Fick law was modified. The tip to flatten the cornea was calculated, and a tip with a fixed area with a diameter of 3.06 mm (7.35 mm²) to minimize the impact of ocular rigidity and surface tension of the tear film was chosen. GAT measures the required force to flatten an area of the cornea of 3.06 mm diameter (**Figure 2**). The force in grams required for applanating this specific area multiplied by 10 equals the IOP in mmHg.

In this method, the instrument is mounted on a slit lamp and the examiner looks at the center of the plastic prism tip, through the slit lamp microscope (**Figure 3**). Then, with the forward movement of the microscope, the tip is contacted slightly to the cornea. Local anesthetic and fluorescein drops are applied before the measurement. Fluorescein dye highlights the tear film when a cobalt blue light is used. Internal prisms of the tip divide the fluorescein meniscus into the superior and inferior arc. When the internal edges of arcs are aligned properly by adjusting the tension knob, a circular area of cornea in 3.06 mm diameter has been flattened at the apex, and examiner can read the IOP from the scale on the adjusting knob directly in mmHg by multiplying 10. After the procedure, it must be disinfected properly. Tip of the tonometer can be disinfected by 70% isopropyl alcohol wipes or soaking 3% hydrogen peroxide solution. The GAT provides an average of IOP between diastolic and systolic pressure.

According to the inventors, optimal IOP measurement can be achieved if the central corneal thickness is approximately 0.5 mm with a well-calibrated GAT [6]. Ehlers et al. reported that GAT most accurately measures intracameral IOP if the central corneal thickness was 520 μm. Variations in corneal thickness and elastic properties have a significant effect on applanation readings of GAT [7, 8]. Thicker corneas can cause overestimation of IOP, and thinner corneas

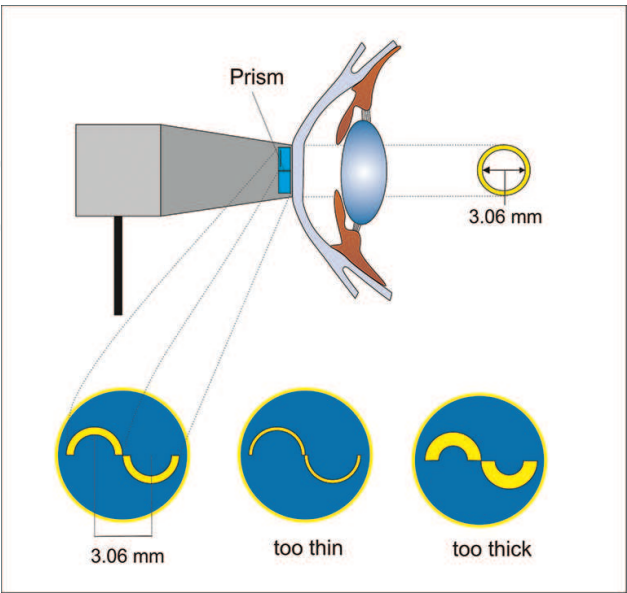


Figure 2. A schematic representation of IOP measurement with Goldman applanation tonometer.

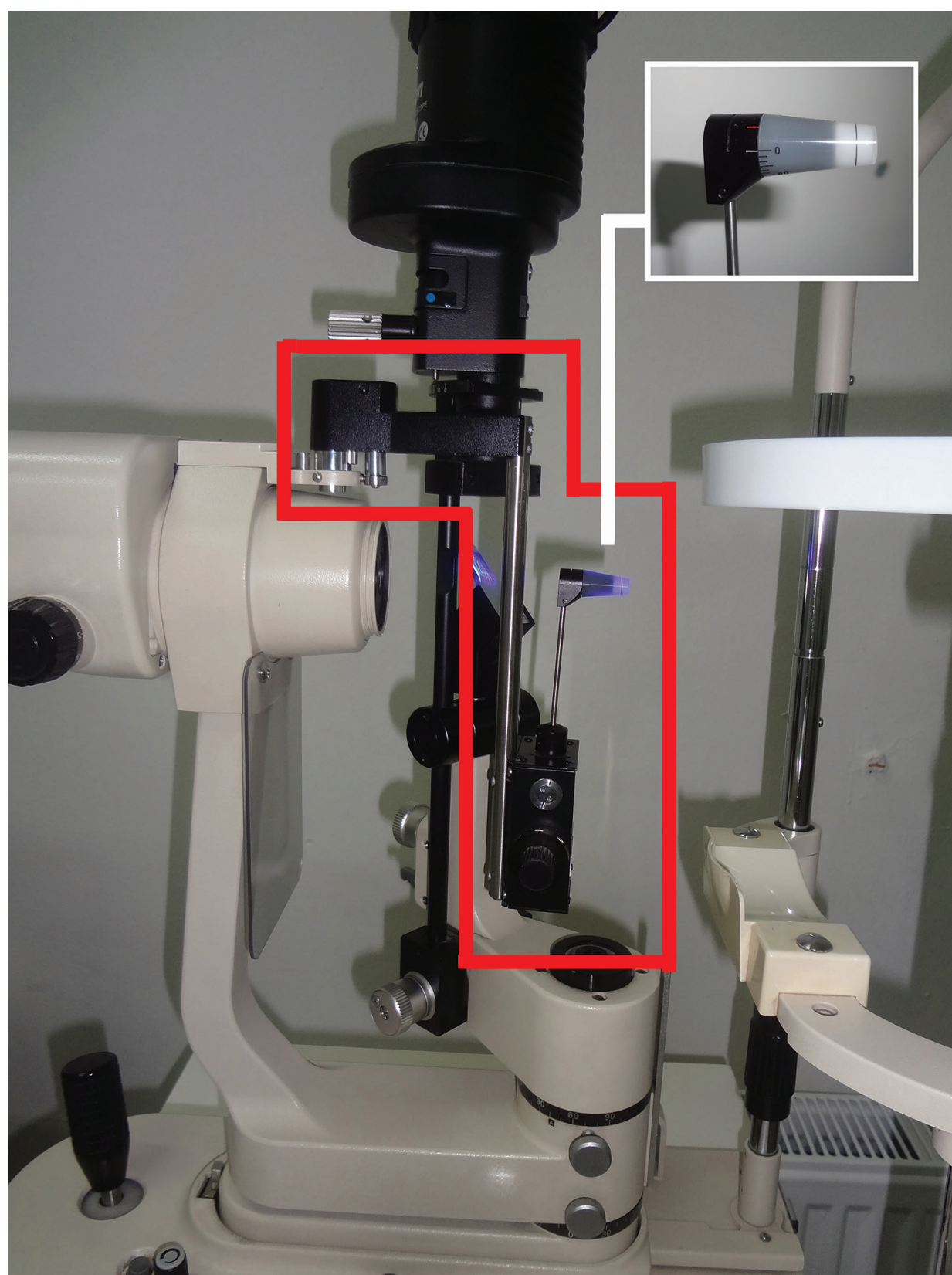


Figure 3. Goldman applanation tonometer, red line outlines tonometer mounted on a slit lamp, and white line magnifies tip of the tonometer.

can cause underestimation of IOP with GAT. Central corneal thickness greatly varies among the general population, and it should be corrected according to the thickness of the cornea [9]. Measurement of GAT may be affected by using excessive or insufficient amount of fluorescein, Valsalva's maneuver, corneal curvature, astigmatism, corneal scarring, eyelid squeezing, prior refractive surgery and indirect pressure on the globe [10]. High corneal curvature can be compensated by rotating tip to the axis of astigmatism. GAT must be calibrated by the user on a regular basis to maintain its accuracy. Despite these limitations, it is still popular and widely used due to low cost, simplicity and lack of consumables.

Goldman tonometry is not portable, and the subject must be in upright position. Handheld, portable version of GAT is called as Perkins tonometer. It is battery powered, uses GAT tip, and requires fluorescein dye. It has an internal mechanism and allows using either in supine or in upright position. Disinfection of the tip for both tonometers must be done properly. Wiping with alcohol solution does not kill all pathogens, and tip should be soaked in hydrogen peroxide or bleach solution at least 10 min and then should be washed.

4. Noncontact tonometer

Noncontact tonometry (NCT) also known as air puff tonometer works in a similar fashion as applanation tonometry, but it uses compressed air to flatten the corneal apex. It does not require direct contact with the cornea or topical anesthesia and can be used in uncooperative patients and children (**Figure 4**). No disinfection procedure is also required.

During the procedure, the device emits a column of air with gradually increasing intensity to the subject's cornea. Highly sensitive electro-optical sensors scan and detect the exact time of the corneal flattening and shut off the air pulse. Thereafter, the device records the value of force information at the moment of corneal flattening and calculates the IOP in mmHg.

Similar with GAT, NCT is also affected by corneal biomechanical factors such as ocular rigidity and central corneal thickness [11]. NCT measures IOP in a few milliseconds, and therefore, it may be affected by ocular pulse amplitude. A minimum of three measurements should be averaged to estimate the mean IOP. Modern NCT devices are advanced greatly than previous models and are well correlated with GAT measurements [12].

5. Pneumotonometer

The pneumotonometer was first invented by Durham et al. and modified by Langham and McCarthy [13]. It basically works like applanation tonometer; however, sensor of the device is air pressure. A slightly convex plunger with a 5-mm tip moves on a cushion of an air stream. The anesthetized cornea is intended by the tip and air pressure. When the tip and cornea are flat, pushing pressure equals the pressure in the eye. After measurement of IOP, the tip keeps indentation for 5–10 s more and provides real-time pressure monitoring of the eye during this period. The device measures the pressure in the system and displays or writes on graph paper for about 5 or 10 s.



Figure 4. External view of a noncontact tonometer.

Unit of the pneumotonometer is portable and does not need to be mounted on a slit lamp. Measurement procedure is easy to learn and requires less skill than GAT. On the other hand, the tip must be sanitized for each patient. Tip can be cleaned in 70% isopropyl alcohol for 5 min and disinfected in 3% hydrogen peroxide solution.

The pneumotonometer gives 1–3 mmHg higher reading in normal IOP range than GAT, but readings tend to be similar in glaucomatous eyes [14]. A manometry study showed that pneumotonometer overestimates IOP at 10, 20, and 30 mmHg set points [15]. However, another study showed that pneumotonometer consistently underestimated IOP in the range of 5–58 mmHg. Like other applanation tonometers, pneumotonometer is susceptible to corneal thickness changes and measurements are positively correlated with increasing thickness [16, 17].

6. Mackay-Marg tonometer and Tono-Pen tonometry

Mackay-Marg tonometer was first described in the 1950s by Mackay et al., which is an electronic applanation tonometry working with Imbert-Fick principle. It uses a free plunger and a strain gauge for measuring the force necessary to flatten the cornea. A newer version of the Mackay-Marg tonometer is Tono-Pen, which was introduced in the 1980s as a small handheld device. The device is portable, easy to use, and powered by a battery. Tip of the tonometer has an applanating surface and a microscopically small plunger protruding from the center of the applanating surface. When applanating surface contacted with the cornea, plunger takes the corneal resistance and IOP shows an increasing record. Strain gauge linked to the plunger measures the force change and converts to mmHg electronically (**Figure 5**).



Figure 5. A schematic representation describing the working principle of Tono-Pen.

Tono-Pen tonometry uses a very small area of the cornea, and IOP measurement can be achieved from any normal portion of the cornea. Therefore, it is especially handy in the presence of corneal scarring, corneal grafts, band keratopathy, or similar cases. As Tono-Pen is designed to estimate IOP from especially center part of the cornea, it is affected by changes in corneal thickness and tends to overestimate IOP compared to GAT [18]. Moreover, in case of measurement from the peripheral portion of the cornea, the device may estimate IOP higher than normal [19]. Excessive pressure application on the globe during the measurement procedure may cause higher IOP estimation than normal. In optimal conditions, Tono-Pen readings are well correlated with GAT measurements within normal IOP ranges [20]. Single-use disposable covers are available for the tip of the Tono-Pen. Tip should not be disinfected with solvent and cleaning solutions.

7. Transpalpebral tonometry

Several centuries ago, IOP was first evaluated by eye palpation through the eyelids. However, this method is subjective and uncertain. This device aims to perform this evaluation method (ballistic) by sensors in an automated fashion. It applies pressure on an area of 1.5 mm in diameter by a rod through the eyelid, and the eyelid acts as a transmissive part. The device can be used in supine or upward position and does not require corneal anesthesia. In supine position, patient is instructed to look up 45° superiorly and the device is placed appropriately on the cartilaginous part of the lid while keeping the tonometer vertically. Rod of the device falls automatically with gravity and after analyzing the momentary change of the rebound; IOP is estimated and displayed in mmHg. Sterilization is not required. The device does not have a guiding feature for proper placement, stabilization, and orientation. It has been reported that results seem to be affected by corneal thickness, especially thinner corneas [21]. Results of Diaton were showed high variability and poor agreement with GAT results. Hereby, the authors recommend this device only for screening purposes (**Figure 6** and **Table 1**) [22, 23].

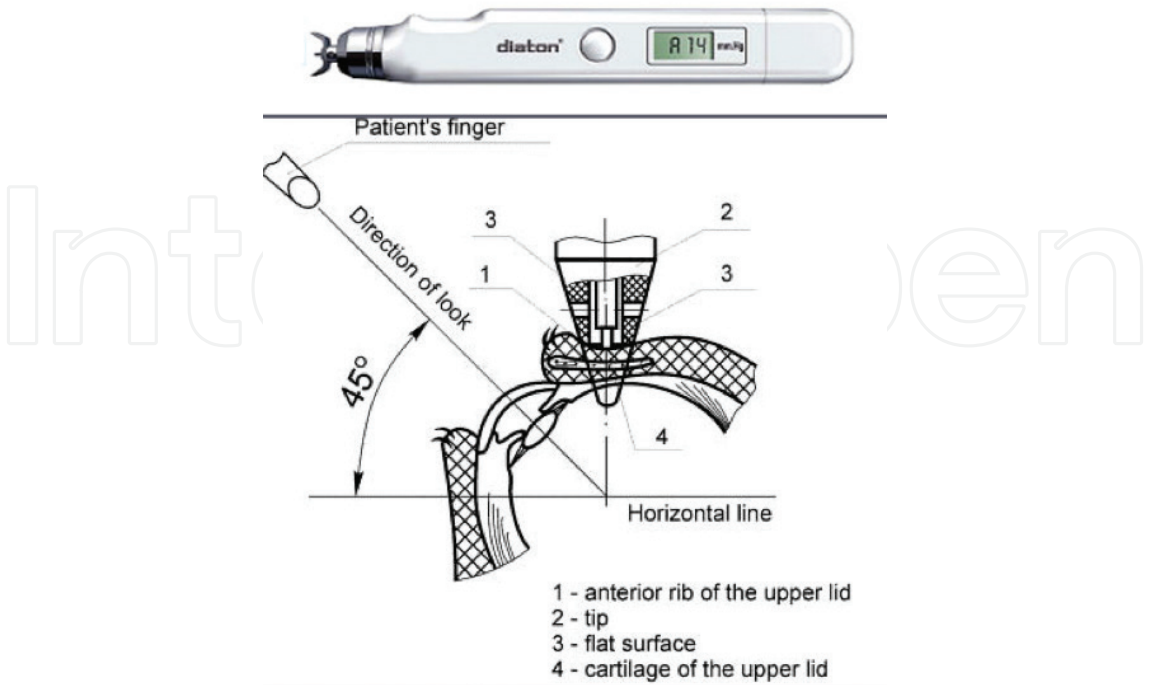


Figure 6. Diaton transpalpebral tonometer.

	Working principle	Brand name	Contact/noncontact
Conventional tonometers			
Goldmann applanation tonometer	Fixed area applanation	Goldman tonometer/perkins tonometer in various brands	Contact
Electronic applanation tonometer	Mackay-Marg applanation	Tono-Pen, Accupen	Contact
Noncontact tonometry	Air puff applanation	Various brands	Noncontact
Pneumatic tonometer	Fixed area applanation with air pressure	Reichert Model 30	Contact
Newer tonometers			
Ocular response analyzer	Bidirectional air puff	Reichert ocular response analyzer	Noncontact
Scheimpflug noncontact tonometer	Air puff; corneal analysis with Scheimpflug imaging	Oculus Corvis ST	Noncontact
Dynamic contour tonometer	Contour-matched piezoresistive sensor	Pascal DCT	Contact
Rebound tonometer	Ballistic probe	iCare Rebound tonometer	Contact
Transpalpebral tonometer	Ballistic probe through eyelid	Diaton	Contact (eyelid)

Table 1. Currently available tonometers in the market.

8. Manometry

Manometry is an invasive technique that precisely measures the real pressure inside the eye. Results of the manometry are the reference pressure for all other tonometers. It is especially used in laboratory conditions for continuous IOP measurement. It evaluates the effects of pharmacologic or physiologic manipulators and is useful in exploring the aqueous humor dynamics. It is also used for calibrating and validating the results of various types of tonometers on postmortem human eyes.

The ideal tonometer would be easy to use, portable, reliable, and comfortable for both the patient and physician. It should have low inter- and intraoperator variability and provide an IOP reading that is close to the manometric IOP of the individual. To date, no such tonometer exists. Till date, the gold standard for IOP measurements is Goldmann applanation tonometer.

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