Introduction

A precise assessment of the intra-ocular pressure (IOP) is crucial for diagnosis and decision making regarding treatment modalities in patients with glaucoma. Recent studies showed that a difference of only 1 mmHg in the mean IOP may be critical enough to determine the visual field prognosis in patients with glaucoma. The Goldmann applanation tonometer, which is current gold standard, has error in measurement of IOP after refractive surgery and in cases of thin corneas. New tonometers appeared in recent years like the Ocular response analyzer, Pascal dynamic contour tonometer,Tonopen and Transpalpebral tonometer which try to overcome these fallacies ***(Chihara, 2008)*****.**

Aim of the Review

The aim of this review is to collect information on recent methods of measuring the intra-ocular pressure.

Old Methods of Tonometry

Introduction

Tonometry refers to the indirect estimation of intraocular pressure by measuring resistance of the eye to indentation by an applied force. Intraocular pressure is estimated with a variety of instruments that mechanically deform the globe and relate intraocular pressure to either the force required to deform the eye or the area of eye deformed by the force.

Indentation Tonometers

Schiotz tonometer:

Description of the tonometer:

The Schiøtz tonometer is an indentation tonometer Fig (1) a, it consists of a plunger surrounded by a sleeve that is attached to a lever Fig.(1)c. The movement of the plunger in relation to the sleeve as it contacts the cornea deflects the lever causing its other end to move along a scale Fig.(1)b which indicates the IOP. However, the IOP that the Schiøtz tonometer measure is actually the eye pressure that results when the tonometer is in contact with the eye which is higher than the the actual IOP, So conversion table is provided with the tonometer ***(Morrison and Pollack, 2003).***

Fig. (1): Schiøtz indentation tonometer. A = Case, B = Scale, C = Concave foot with central plunger ***(Kniestedt, 2008)***.

Basic concept of Schiotz tonometer:

The original tonometer has a footplate concavity of 15mm radius of curvature and the footplate was of 11g weight. The plunger 3mm in diameter, and of 5.5g (which is the force of the lever resting on top of the plunger). We can use more weights 7.5, 10 or 15gm. The lever magnifies the plunger movement (20X). The plunger sinks into the corneal substance 0.05mm before it produced a bending deformation of the cornea Fig. (2). Because of this reason, displaced the zero of the tonometer scale. By using different weights the measured pressures fell on a curved line. This curve reflects the relation between pressure and the displaced volume. This slope line called "the coefficient of ocular rigidity" ***(Moses, 1986).***

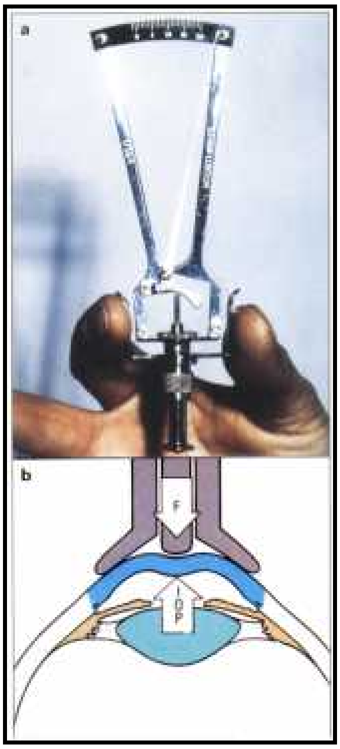


Fig. (2): Indentation principle of Schoitz tonometer ***(Kanski, 2004).***

Calibration of the Schiotz Tonometer:

Calibration can be simply done by placing the footplate of the instrument on the rounded metal stand (the artificial cornea) provided with the storage case. With the footplate resting on the stand, a correctly calibrated instrument will have a scale reading of zero ***(Alguire, 1990).***

Technique of the Schiotz Tonometer:

After a thorough explanation of the procedure, the patient is asked to lie on the examining table with eyes fixed upward on the ceiling. After applying a topical anesthetic to the cornea, such as 0.5% proparacaine, the examiner gently separates the eyelids with the thumb and index finger and applies the tonometer footplate directly on the cornea as shown in Fig. (3).

Fig. (3): Schiøtz tonometer in use ***(Ramos et al.,2008).***

The instrument must be held perpendicular to the eye to allow the plunger to move freely, indenting the cornea. The degree of indentation is measured by movement of a needle on a scale. Fine oscillations of the needle represent ocular pulsations, indicating free movement of the plunger and good technique. The midpoint of the needle excursion is taken as the pressure measurement. Since the Schiøtz tonometer does not measure pressure directly, conversion tables, supplied with the instrument, are used to translate scale readings into estimates of intra- ocular pressure ***(Alguire, 1990)***.

Sources of error in indentation tonometry:

The accuracy of indentation tonometer depends on the assumption that all eyes respond in the same way to the external forces of indentation, which is not the case.

1. **Ocular rigidity**: because conversion tables are based on an average coefficient of the ocular rigidity (K), eyes that deviates significantly from this (K) value, give false IOP measurement ***(Allingham et al., 2005)***.

2. **Blood volume alteration:** the variable expulsion of the intraocular blood during indentation tonometry influence IOP measurement. Blood volume in the eye increases with the systolic pulse and decreases during diastole. When the blood volume in the choroid increases, eye pressure increases as well ***(Allingham et al., 2005)***.

3. **Corneal influences:** either a steeper or thicker corneas causes a greater displacement of fluid during indentation tonometry, which leads to falsely high IOP ***(Allingham et al., 2005)***.

4. **Refractive errors:** including hyperopia and myopia increase and decrease scleral rigidity respectively.

5. **Corneal disease and past ocular operations:** alter the resistance to indentation and are an additional source of measurement error ***(Alguire, 1990)***.

Sterilization of the Schiotz tonometer:

Because Schiøtz tonometer come into contact with the cornea and tear film, it must be properly disinfected to prevent cross- infection with HIV and other infectious pathogens. The Centers for Disease Control and Prevention (CDC) recommends that all eye contact devices be disinfected by a 5- to 10- min soak in one of following disinfectants: 3% hydrogen peroxide, 1:10 sodium hypochlorite (household bleach), or 70% isopropyl alcohol. The effects of CDC- recommended disinfectants on the structural integrity of Schiøtz tonometers; was demonstrated in a showed that soaking in 1:10 sodium hypochlorite and 3% hydrogen peroxide damaged Schiøtz tonometers and rendered them inoperable. Alcohol caused minor damage to the tonometer and was the safest of the CDC disinfectants ***(Chronister, 1997)***.

Applanation – Fixed Area Tonometers

Goldmann Tonometer:

Description of the tonometer:

The Goldmann applanation tonometer is mounted on the slit lamp and consists of a strain gauge connected by a lever to a plastic tip. When the tip face contacts the cornea, a biprism in the tip splits the view of the tear film meniscus into two semicircles. Rotating a dial attached to the gauge varies the force against the cornea and alters the alignment of the semicircles (Fig. 4) ***(Morrison and Pollack, 2003)***.

Fig. (4): Goldmann Tonometer ***(Kanski, 2004)***

Basic concept of Goldmann Tonometer:

The Goldmann applanation tonometer is based on Imbert- ficks law which states that an external force against a sphere (w) equals the pressure in the sphere (p) times the area flattened by the external force (A) (Fig. 5) ***(Allingham et al., 2005).***

So $W = p \times A$

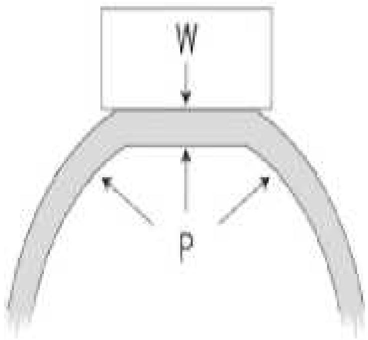


Fig. (5): Basic principal of applanation tonometer ***(Stuckey, 2004).***

So, for applanation of an area 2.5 to 4.0mm, the corneal bending force and the tear meniscus surface tension force are equal. As they are opposite in sign they cancel each other. The applanation diameter selected was 3.06mm because at this diameter the force applied in gram multiplied by (10) gives a direct readout in mmHg (which is equivalent to the pressure of a column of mercury 1mmHg) ***(Moses, 1986)***.

Calibration of the Goldmann Tonometer

* It is possible to check the calibration of the tonometer; this should be done every six months. Calibration is done at dial positions 0, 2, and 6 (equivalent to 0, 20, and 60 mmHg).

* Insert the prism in the holder and place the tonometer on the slit lamp.

* At dial position 0, the feeler arm should be in free movement. If the dial is turned backwards a small way (to the equivalent of position -0.05), the arm should fall towards the examiner. If the dial is turned forwards a small way (to the equivalent of position +0.05) the arm should fall towards the patient.

* If the arm doesn't respond in the above way, the tonometer is inaccurate at dial position 1.

* To check dial positions 2 and 6, the check weight is used (this is normally found in the case with the tonometer

prisms or in the drawer of the slit lamp). There are five markings engraved on the bar. These represent 0 centrally, then 2 on either side, and 6 towards the edges.

* Line up the adjustable holder with index mark 2 on the weight. With the longer end of the bar facing you, put it into the slot on the side of the tonometer and push it all the way in Fig. (6).

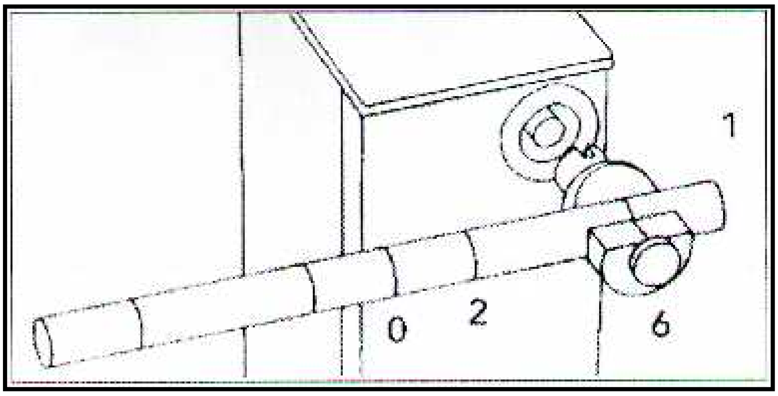


Fig. (6): calibration of Goldmann tonometer ***(Sandhu et al., 2005).***

* Repeat the above steps (for dial position 0), with the dial now at position 2. This time, turn the dial backwards to the equivalent of 1.95 and forwards to the equivalent of 2.05.

* To check dial position 6, move the weight bar to the end position. Repeat the steps at dial position 6, turning the dial backwards to the equivalent of 5.9 and forwards to the equivalent of 6.1.

* If the tonometer is inaccurate at any of these dial positions, it should be returned to the manufacturer for recalibration ***(Stevens et al.,2007)***.

Technique of Goldmann Tonometer:

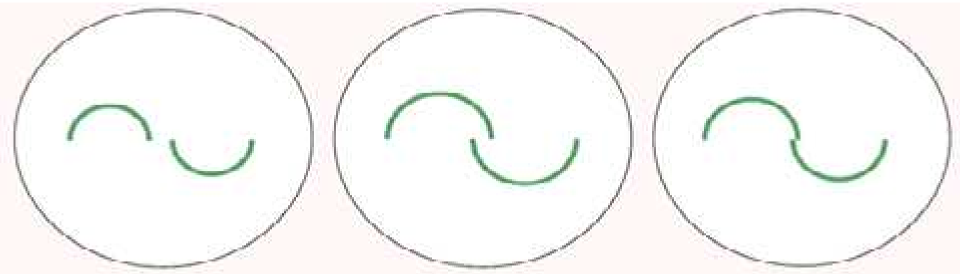
* Instil the local anaesthetic drops and then the fuorescein. Only a very small amount of fuorescein is needed.
* For measuring the IOP in the right eye, make sure the slit beam is shining onto the tonometer head from the patient's right side; for the left eye, the beam should come from the patient's left side.
* Move the filters so that the blue filter is used to produce a blue beam.
* Make sure the beam of light is as wide as possible, and that the light is as bright as possible. This makes visualising the fluorescein rings easier (with the slit diaphragm fully open).
* Ask the patient to look straight ahead, open both eyes wide, fix his or her gaze and keep perfectly still.
* With the thumb, gently hold up the patient's top eyelid, taking care not to put any pressure on the eye.
* Direct the blue light from the slit lamp onto the prism head.
* Make sure that the tonometer head is perpendicular to the eye.
* Move the tonometer forward slowly until the prism rests gently on the centre of the patient's cornea.
* With the other hand, turn the calibrated dial on the tonometer clockwise until the two fluorescein semi- circles in the prism head are seen to meet and form a horizontal ‘S’ shape. The correct end point is when the inner edges of the two fluorescein semi- circle images just touch (Fig. 7).

* Note the reading on the dial and record it in the notes

* Withdraw the prism from the corneal surface and wipe its tip

* Repeat the procedure for the other eye

* Wipe the prism with a clean, dry swab and replace it in the receptacle containing the disinfectant ***(Stevens et al.,2007).***



High intraocular pressure before the end point is reached will result in this image. Continue to turn the calibrated dial on the tonometer clockwise to reach the correct end point.

Low intraocular pressure will result in this image. Turn the calibrated dial on the tonometer anticlock-wise to reach the correct end point.

This is the correct end point - the inner edges of the rings are just touching. This will give a correct reading of intraocular pressure.

Fig. (7): Applanation tonometry rings viewed through the Goldmann prism ***(Stevens et al.,2007).***

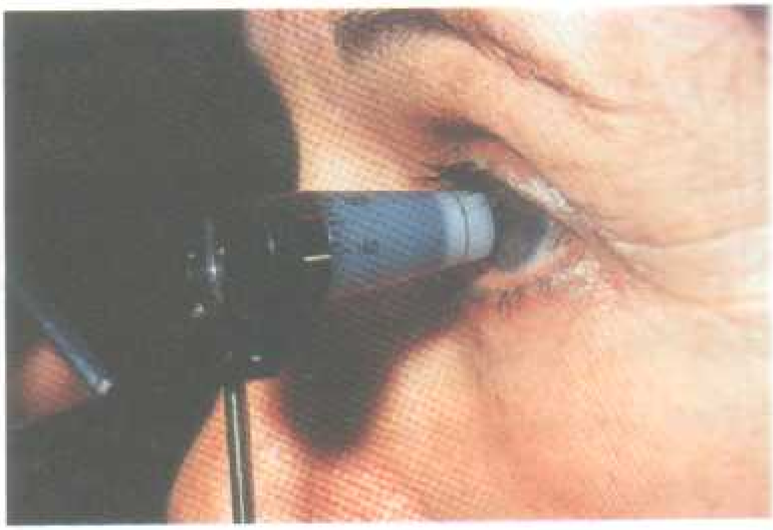


Fig. (8): Applanation tonometer in use ***(Kanski, 2008).***

Sources of error in Applanation Tonometry :

Insufficient dye will make the semicircles too thin and underestimates the pressure.

Repeated tonometry or prolonged contact may induce a decline in the intraocular pressure (IOP) often yields decreasing IOP measurement. It is due to pressure of the tonometer tip that increases aqueous drainage.

Change of Corneal curvature by 3 diopters increase in the corneal power, leads to approximately 1mmHg increase in IOP.

Corneal astigmatism causes under estimation of the IOP in with the rule astigmatism and over estimation with against the role astigmatism. There is a difference of 1mmHg for 4 diopters astigmatism ***(Allingham et al., 2005).*** To correct this defect we can rotate the doubling prism, so that the axis of least corneal curvature is opposite the red line on the prism holder. An alternate method to obtain accurate IOP measurement is to obtain two IOP measurements with the prism position 90° apart and to average this reading ***(Holladay et al.,1983).***

The Valsalva maneuver causes change in the IOP due to increasing of the episcleral venous pressure and consequently increase of IOP. ***(Whitacre, 1993).***

Vertical gaze (one semicircle larger than the other) will lead to a false high IOP ***(Whitacre, 1993).***

Corneal edema results in an overestimation of IOP measured by Goldmann applanation tonometer (GAT), at rate of 1.0mmHg for every 10µm, as corneal edema causes an alteration of corneal rigidity in addition to increase in central corneal thickness(CCT) ***(Allingham et al., 2005).***

Goldmann has constructed his tonometer based on a central corneal thickness of 500um and the accuracy of device will vary if CCT deviated from that value.

- ***Ehlers et al., (1975)*** proposed a relation between CCT and IOP and it is shown in the following table:

CCT in microns	IOP correction in mmHg
445	7
455	6
465	6
475	5
485	4
495	4
505	3
515	2
525	1
535	1
545	0
555	-1
565	-1
575	-2
585	-3
595	-4
605	-4
615	-5
625	-6
635	-6
645	-7

(Khan et al., 2008)