Introduction

The measurements of intraocular pressure (IOP) plays a significant role in screening, detection and treating patients with glaucoma ***(Garcia Resua et al., 2005)***.

Tonometry is the objective measurement of IOP. It begains by ***Maklakoff, (1885)*** and his tonometer which developed later on by Imbert and Fick and their law, which state that the weight on a fluid filled sphere (F) divided by the area (A) flattened by that weight equal to the pressure within this sphere (P). P=F/A ***(Imbert, 1885; Fick, 1888)***.

Later on Maklakoff tonometer was replaced by Schoitz tonometer, which was developed in 1905. Schoitz tonometer is an indentation tonometer ***(Schoitz, 1905)***.

In 1955 Goldmann applanation tonometer was developed based on Imbert-Fick law. Since that time (GAT) is considered to be the gold standard in tonometry ***(Goldmann, 1955)***. Perkins applanation tonometer was developed in 1965. it is the hand held version of GAT, using its same principles in measurement ***(Perkins, 1965)***.

The GAT despite being the most reliable tonometer, there are numerous sources of errors, that may influence its validity, so other new tonometers begin to appear to avoid these errors ***(Stuckey, 2004)***.

The advent of non contact tonometers (NCT) allowed measurement of IOP without corneal contact, but still use the fundamental principles of applanation tonomtery, at which corneal flattening is done by a puff of pressurized air in time interval, that is proportional to IOP, but these form of tonometers have reliability within low to middle range only, many different form of NCT have been developed as the portable pulsair 3000 (Keeler) ***(Porges and Ophir, 2000)***.

With the evaluation of the portable tonometers Tonopen tonometer take its position as a hand held, digital, battery operated and not requiring sterilization. It is more accurate than GAT in irregular and oedematous corneas because of its smaller contact diameter ***(Bandyopadhyay et al., 2002)***. Among these portable tonometers, self tonometers begin to be used in order to make a self monitoring of IOP as ocuton tonometer and proview phosphene tonometer ***(Marchini et al., 2002)***.

Transplapebral tonometer also a portable, digital tonometer, measure IOP through the eyelids without contact with cornea. It can be used easily by patients' relatives in home ***(Van der Jaget and Jansonius, 2005)***.

Recently the new tonometers try to overcome the several eye variable, such as axial length, curvature, rigidity and corneal thickness. Rebnound tonomtere is one of these tonometer which based on bringing amagnetized probe in contact with the eye and detecting the deceleration caused by the eye on the probe with sensing coil, the motion parameters of the probe vary according to eye pressure ***(Casa et al., 2006)***.

Then the Dynamic contour tonometer was introduced which removes the corneal biomechanical effect and the thinning of CCT with LASIK operation ***(Kotecha, 2005)*** its tip has a concave surface adapted to the contour of the cornea, without flattening it ***(Casa et al., 2006)***.

So, these recent tonometers provide IOP measurement correlated with conventional tonometers, and at the some time try to overcome other factors, which may affect it.

Aim of Work

Discuss the recent trends in tonometry and the new technique to overcome the sources of errors in conventional tonometers.

Physiology of Aqueous Formation

The eye ball is a globe with a rigid exoskeleton composed of the sclera and cornea and the soft inner contents comprising lens, vitreous, choroid, retina and the aqueous. The aqueous may be classified as a soft inner content but like water it is incompressible. It is the aqueous that governs the state of the globe: if there is too little the eye become soft, but, if too much the eye becomes hard. There is constant production of aqueous into the globe. There is a constant drainage of excess aqueous via the corneo-scleral meshwork ***(Stuckey, 2004)***.

Aqueous humor hydrodynamics:

In the healthy eye, flow of aqueous humor against resistance generates an intraocular pressure (IOP) of approximately 11-21mmHg, which is necessary for the proper shape and optical properties of the globe ***(Kaufman and Alim, 2003)***.

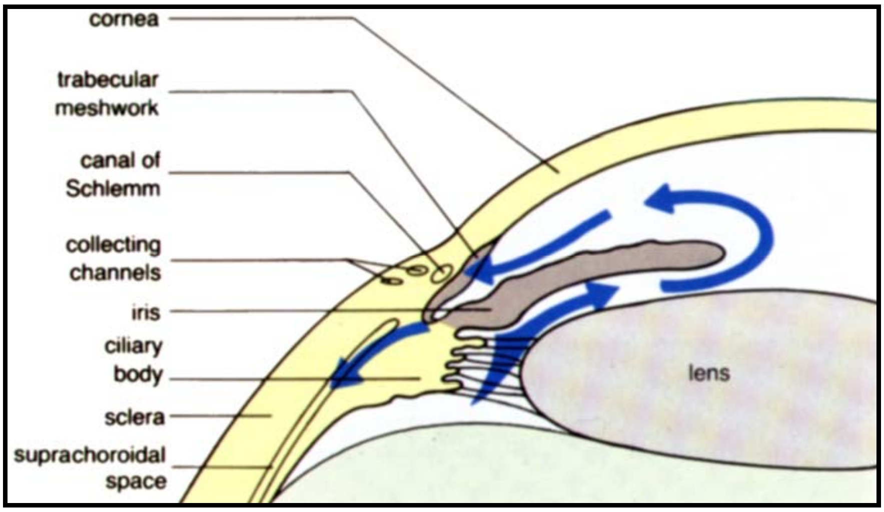


Fig. (1): Bulk flow of aqueous through the eye begins in the region of the ciliary epithelium, flows past the equator of the lens through the posterior chamber and the pupil to reach anterior chamber. It enters the canal of schlemm by the trabecular meshwork. Then passes into collector channels and aqueous veins to reach the episcleral veins ***(Hitchings, 1994)***.

The circulating aqueous humor nourishes the cornea and lens as these structures and the trabecular meshwork (TM) is devoid of blood vessels.

Aqueous humor journey Fig. (1):

Aqueous humor is secreted by the ciliary epithelium lining the ciliary processes (CPs) and enters the posterior chamber. The aqueous humor then flows around the lens and through the pupil into the anterior chamber (AC). Convection flow of aqueous humor exists in the AC-downward close to the cornea, where the temperature is cooler, then upward near the lens, where the temperature is warmer.

Aqueous humor leaves the eye by passive bulk flow via two pathways at the AC angle:

1. Through the TM, across the inner wall of Schlemm canal into its lumen, and then to collector channels, aqueous vein, and the episcleral venous circulation.
2. Across the iris root, the uveal meshwork, and the anterior face of the ciliary muscle, through the connective tissue between the muscle bundles through the supra choridial space and out through the sclera.

(Kaufman and Alim, 2003)

In the healthy human eye: the importance of the uveoscleral pathway has not been well quantified. In elderly eyes (60 years), the uveoscleral pathway accounts for 10% of total aqueous humor drainage, whereas in young individuals (20-30 years) it may account for more then 30% ***(Gobelt and Kaufman, 2000)***.

Aqueous humor formation and composition:

Physiology of aqueous humor formation:

Three physiologic processes contribute to the formation and chemical composition of the aqueous humor:

1. Diffusion.
2. Ultrafiltration (and the related dialysis).
3. Active secretion.

(Kaufman and Alim, 2003)

The first two processes are passive and hence require no active cellular participation.

Diffusion:

Solutes cross cell membranes down a concentration gradients; at which substances with high-lipid-solubility can easily penetrate biologic membranes and move readily in this way.

***Ultrafiltration*:**

Most of blood plasma cross the fenestrated ciliary capillary endothelia into the ciliary stroma. It can be increased by augmentation of the hydrostatic driving force.

Active secretion:

Active transport of sodium into the posterior chamber by the non-pigmented ciliary epithelium results in water movement from the stromal pool into the posterior chamber.

Active secretion accounts for perhaps 80% to 90% of total aqueous humor formation. So, any alter of systemic blood pressure have a little effect on aqueous formation ***(Wilson et al., 1993)***.

Active secretion is essentially pressure insensitive at near physiologic IOP. However, the ultrafiltration component of aqueous humor formation is sensitive to changes in IOP, it decreases with the increasing IOP. This diminished the increase of IOP due to over formation of aqueous humor. The rate of aqueous humor formation and drainage is approximately 1.0% to 1.5% of the AC volume per minute, in which the aqueous humor formation rate is approximately 2.5μL/min ***(Kaufman and Alim, 2003)***.

Aqueous humor drainage:

Fluids mechanics:

The tissues of the AC angle normally offer a certain resistance to fluid outflow. This resistance lead to accumulation of aqueous and the pressure inside the eye increase to overcome the resistance in the AC angle and allow the aqueous to pass out. This pressure is the IOP, which allow the aqueous to drain, with a rate equal to the rate of its formation. In the glaucomatous eye, this resistance is unusually high, resulting in elevated IOP (Fig. 2).

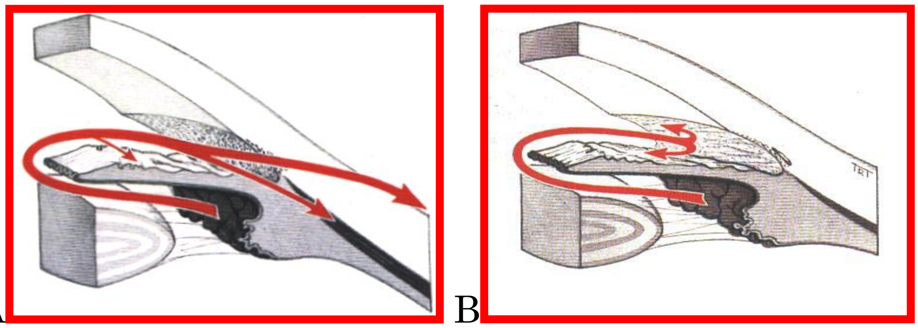
A  B

Fig. (2): Aqueous flow in normal eye (A) and in glaucomatous eye (B) ***(Kanski, 2004)***.

IOP thought to be one of the common risk factors in the development and progression of glaucoma ***(Sommer, 1996)***.

The simplest hydraulic model, represented by the classic Goldmann equation, views aqueous flow as passive, non-energy-dependent bulk fluid movement down a pressure gradient, with aqueous humor leaving the eye only via the trabecular route.

where

$$\Delta P = P_i - P_e \qquad \text{so that } F = C_{trab}\,(P_i - P_e)$$

ΔP = Pressure (mmHg)
P_i = IOP (humans = 16mmHg)
P_e = Episcleral venous pressure (human= 9mmHg).
F = Flow μl/min
C_{trab} = Facility of outflow via trabecular pathway (0.21μl/min).

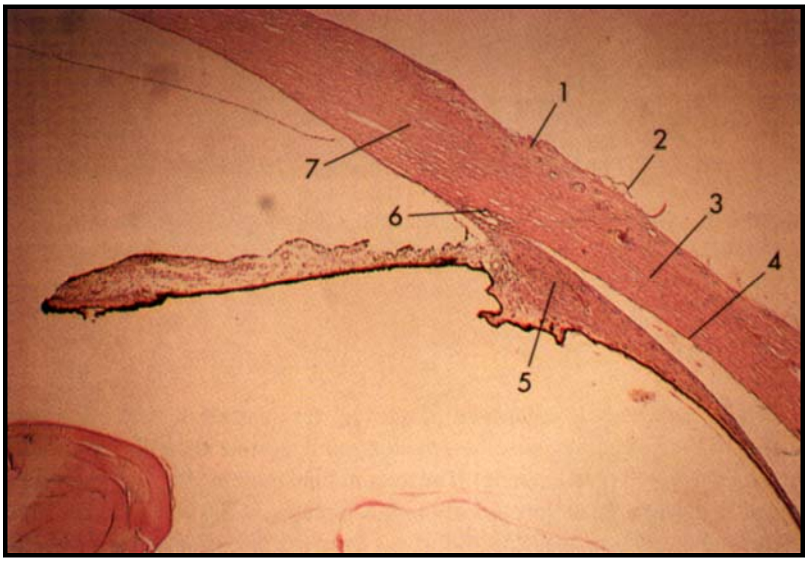


Fig. (3): Light micrograph of the anterior segment of the eye showing 1, Tenon's capsule; 2, episclera; 3, sclera; 4, lamina fusca; 5, ciliary body; 6, Schlemm's canal; and 7, peripheral cornea *(Becker and Shaffer, 1999)*.

Recently, some aqueous fluid has been detected passing through the tissue spaces of ciliary muscle bundle. These spaces, in turn, open into the suprachoridl space, from which fluid can pass through the scleral substance or perivascular scleral space to the episcleral tissue (Fig. 3).

Some fluids also may pass osmotically into the vortex veins by the high protein content in the blood of these vessels. These side pathways represent the uveoscleral pathway ***(Kaufman and Alim, 2003)***.

In steady-state conditions, C_u are so low compared with C_{trab}. Now the aqueous dynamics may be approximated for clinical purposes by the following equation:

$$F_{in} = F_{out} = C_{trab} (P_i - P_e) + F_u$$

F_{in} = Total aqueous humor inflow.
F_{out} = Total aqueous humor outflow.
F_u = Outflow via uveascleral pathway.
C_u = Facility of outflow via uvesoscleral pathway 0.02μl/min.
C_{trab} = Facility of outflow via trabecular pathway (0.21μl/min).

The drainage across the TM into SC (85% of total drainage) is pressure dependent, but drainage via the uveoscleral pathway is virtually independent of pressure at IOP levels greater than 10mmHg (15%).

The clinically significant increases in inflow occur only in situations involving breakdown of the blood aqueous barrier (BAB). The pressure sensitivity of the ultrafiltration component of aqueous secretion diminished the tendency for IOP to rise ***(Kaufman and Alim, 2003)***.

Historical Developments

The dynamic state of aqueous production and drainage, and any change of the rate of both of them, lead to increase of IOP: it has to be detected and measured by tonometry.

Historical developments:

Three factors affect the historical writing on tonometery:

1. The impossibility of measuring the pressure in the undisturbed globe.
2. The variable nature and flexibility of ocular coat.
3. The search for the original pressure (P) by minimal displacement of aqueous.

(Stuckey, 2004)

A century ago tonometry has been put on a firm bases by the application of sound physical principal by ***Maklakoff, (1885)*** and ***Imbert, (1885)***, than by ***Schiotz, (1905)***.

Tonometry only return to Fick's rational treatment through ***Goldmann, (1955)*** the Swiss ophthalmologist who has enhanced our understanding in tonometry ***(Moses, 1986)***.

Digital method is considered to be a rough and primitive way to detect IOP (Fig. 4) ***(Bedford, 1987)***.

Fig. (4): Digital method ***(Bedford, 1987)***.

The only accurate method to detect the "true" intracameral pressure is monometry. At which the eye is cannulated and connected to instrument, measure the pressure in (mmHg). This method is very invasive, and only used as an experimental way to detect and evaluate the performance of new tonometers.

In clinical practice it is necessary to estimate IOP through the wall of the eye, that is, without puncturing the globe. The wall of eye is under tension being induced by the IOP. Although the units of pressure and tension: are the same (force per unit area), but the meanings of the terms are not the same. Tension is a measure of the force stretching the wall of the eyeball;

while pressure is a measure of the force in the fluid confirmed within the eye.

Applanation tonometery:

The force of IOP on an area of cornea can be measured by flattening or applanating portion of the cornea. The force of IOP on the flattened area of cornea must be balanced by the force applied to the flattening surface. As the pressure equals force per unit area, the force applied to the applanating surface is known and the applanated area is known, then the pressure is known (Fig. 5).

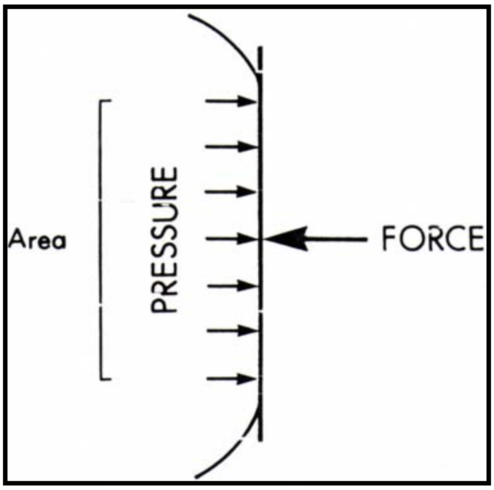


Fig. (5): Applanation tonometry *(Moses, 1986)*.

Yet, there are two factors which complicate this simple concept. The first factor is the force required to distort the cornea from its domed shape to a plane. This