Chapter 4

Tonometry

Felicia Ferreri, Rosa Minniti, Alessandra Polimeni,
Lucia Zavettieri, Giuseppina Ferreri,
Paolo Ferreri and Pasquale Aragona

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/58690

1. Introduction

Tonometry is a diagnostic method which, through the use of different tools, allows the evaluation of the pressure existing inside the human eye.

An elevated intraocular pressure (IOP) is the main risk factor for the development of glaucoma, an ocular disease, that if not properly treated, causes irreversible damage to the optic nerve, leading to blindness.

The aim of tonometry is to detect the IOP that is measured in millimeters of mercury (mmHg); it is performed through the interaction with the ocular structures and in particular with the cornea. The human cornea is a curved structure with an increasing thickness from the center to the periphery and with different radius of curvature in the anterior and posterior faces. From the histological point of view, the cornea has five layers, which, from inside out are:

1. Endothelium: the inner layer made from a layer of hexagonal cells that act as a barrier modulating the penetration of substances within the corneal structure from the aqueous humor;
2. Descemet's membrane: made by collagen;
3. Stroma: it is characterized by particular cells, keratocytes, and by collagen lamellae, arranged in parallel and covered with a mucopolysaccharide substance;
4. Bowman layer: a dense acellular cluster;
5. Epithelium: the outer layer made from non-keratinized cells.

Recently, it has been identified with the electron microscope, another layer, the layer of Dua, localized in the posterior stroma, close to the Descemet's membrane. [1] The cornea, is wetted in the most external part by the tear film that consists of two layers: the mucous-aqueous and the lipid layers. Cornea and tear film play a key-role in assessing the IOP; in fact, all the clinical instruments used to measure the IOP interact with these structures, being the value of IOP obtained studing the corneal deformation resultant from the strength applied on the anterior part of the eye. Therefore tonometry is based on the biomechanical characteristics of cornea, namely the elastic and viscoelastic characteristics, and thus IOP and corneal properties are closely interdependent [2].The ease of corneal deformability is called corneal hysteresis (CH), which is calculated as the difference in air pressures between force-in applanation (P1) and force-out applanation (P2), or (P1 – P2). Studies have shown that CH is altered in various disease.

Measurement of CH also provides a more complete characterization of the contribution of corneal resistance to intraocular pressure measurements than central corneal thickness (CCT) alone [3]. However, corneal hysteresis values can be produced by various combinations of corneal thickness, rigidity, intraocular pressure, and hydration. All these factor interfere with the evaluation of the IOP.

2. Tonometry

The history of the tonometry begins in 1622, when, for the first time, Richard Banister estimated the increase of intraocular pressure (IOP) by finger pressure on the bulb (digital eye pressure) and, for several centuries, this remained the only common and simple method to evaluate IOP.

In fact, in several studies, the digital eye pressure is described as a method to assess the IOP in uncooperative patients.

Nowadays, there is a rating scale for the digital eye pressure

Nt	Normal Tension
T+	Increased Tension
T+1	Appreciable tension
T+2	Manifests tension
T+3	Hardness wooden
T-	Hypotonia
T-1	Appreciable hypotonia
T-2	Manifested hypotonia
T-3	Bulb very soft

Afterwards, several instruments were created to obtain an IOP value, in terms of pressure brought to the cornea needed to achieve the applanation of its curvature.

The tonometry can be distinguished in base at the type of corneal deformation obtained in:

http://dx.doi.org/10.5772/58690

- Schiötz tonometry of known weight
- Applanation tonometry to force variable
- Applanation tonometry to force constant

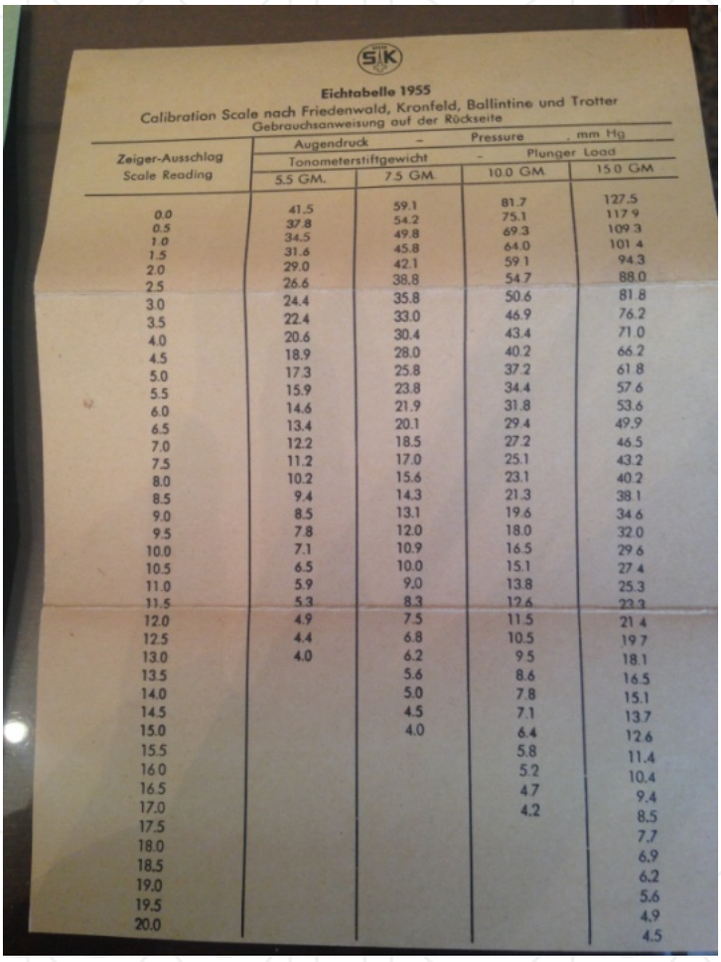
2.1. Schiötz tonometry of known weight

It was the first tonometer able to give reproducible results, simple and inexpensive to be used in clinical practice,being invented in 1905 by the Norwegian ophthalmologist Hjalmar Schiötz. Schiötz tonometry studies lOP by measuring the indentation of the cornea produced by a known weight applied on the corneal surface. It also measures the facility of aqueous outflow calculating the rate at which the pressure declines with time, being this related to the ease with which the aqueous leaves the eye. The decline in lOP over time can be used to determine outflow facility in micronL/min/mmHg through a series of mathematical calculations.

The Schiötz tonometer (Fig.1) is constituted by a piston, applied directly to the cornea, that moves vertically within a scale. The test is performed with the patient in the supine position. Although the test can be performed in an examination chair that reclines. The right position of the base of the scale applied on the cornea allows, to the piston and the weights fitted, to slide, until the intraocular pressure opposes to the applied force; this is indicated on the linear scale on the instrument and the resulting value is converted to millimeters of mercury by a table called "nomogram of Friedenwald" (Fig.2). Each unit of the scale indicates 1/20 mm of the cornea and evaluate the extent of the corneal deformation caused by a weighted force applied from the outside [4].The Schiötz tonometer does not require the use of the slit lamp, it is simple to use, but the IOP value obtained can be biased since repeated measurements may reduce the IOP value while the supine position is known to increase IOP [5].

Figure 1. Schiötz tonometer of known weight

The values of IOP obtained with this tool depend on several factors: the elastic properties of the eye, aqueous humor formation and removal, scleral rigidity [6],, high myopia and ocular blood volume changes. Others factors may cause an erroneous result: calibration problems, patient position, squeezing of the eyelids during the measurement, just to name a few although these errors affect the outcome of other tonometers also to some extent. These problems reduce the accuracy and reproducibility of the Schiötz tonometry for an individual patient [7]. In general, Schiötz tonometer finds its best use as a research tool for the investigation of pharmacokinetics and is rarely used clinically.



Eichtabelle 1955
Calibration Scale nach Friedenwald, Kronfeld, Ballintine und Trotter
Gebrauchsanweisung auf der Rückseite

Zeiger-Ausschlag Scale Reading	Augendruck – Tonometerstiftgewicht 5.5 GM.	7.5 GM.	Pressure – Plunger Load, mm Hg 10.0 GM.	15.0 GM.
0.0	41.5	59.1	81.7	127.5
0.5	37.8	54.2	75.1	117.9
1.0	34.5	49.8	69.3	109.3
1.5	31.6	45.8	64.0	101.4
2.0	29.0	42.1	59.1	94.3
2.5	26.6	38.8	54.7	88.0
3.0	24.4	35.8	50.6	81.8
3.5	22.4	33.0	46.9	76.2
4.0	20.6	30.4	43.4	71.0
4.5	18.9	28.0	40.2	66.2
5.0	17.3	25.8	37.2	61.8
5.5	15.9	23.8	34.4	57.6
6.0	14.6	21.9	31.8	53.6
6.5	13.4	20.1	29.4	49.9
7.0	12.2	18.5	27.2	46.5
7.5	11.2	17.0	25.1	43.2
8.0	10.2	15.6	23.1	40.2
8.5	9.4	14.3	21.3	38.1
9.0	8.5	13.1	19.6	34.6
9.5	7.8	12.0	18.0	32.0
10.0	7.1	10.9	16.5	29.6
10.5	6.5	10.0	15.1	27.4
11.0	5.9	9.0	13.8	25.3
11.5	5.3	8.3	12.6	23.3
12.0	4.9	7.5	11.5	21.4
12.5	4.4	6.8	10.5	19.7
13.0	4.0	6.2	9.5	18.1
13.5		5.6	8.6	16.5
14.0		5.0	7.8	15.1
14.5		4.5	7.1	13.7
15.0		4.0	6.4	12.6
15.5			5.8	11.4
16.0			5.2	10.4
16.5			4.7	9.4
17.0			4.2	8.5
17.5				7.7
18.0				6.9
18.5				6.2
19.0				5.6
19.5				4.9
20.0				4.5

Figure 2. Nomogram of Friedenwald

2.2. Applanation tonometry to force variable

There are different type of Applanation tonometry to force variable

- Goldmann Tonometer
- Perkins Tonometer
- Draeger Tonometer

- Mackay-Marg Tonometer
- Tonopen
- Pneumatic applanation tonometer.

2.3. Goldmann applanation tonometer (GAT) (Fig.3)

This instrument is based on an interesting physical principle: the "Imbert –Flick principle", which states that the pressure inside an ideal, dry, infinitely thin, and a perfect sphere is equal to that applied to obtain the applanation of its surface. However, the human eye is not an ideal sphere, since it is not thin-walled and dry, and this produces two confounding forces:

- a force produced by the corneal rigidity (because the cornea is not infinitely thin and is usually toriodal),which is directed towards the outside of the globe;
- a force produced by the surface tension of the tear film (because the eye is not dry), which is directed towards the globe.

Goldmann estimated that a circular area of flattening, of the size of 3.06 mm of diameter applied on the cornea, is sufficient to avoid the influence of sclera and corneal rigidity and surface tension, allowing a realistic measurement of the IOP. The applanating force required to flatten this area, is directly proportional to the intraocular pressure. Specifically, the force (measured in dynes) multiplied by 10 is equal to the intraocular pressure (measured in millimeters of mercury).

The GAT is mounted on the slit lamp to produce a magnified image, and when it touches the tear film and the cornea, a circle appears as to the observer. Staining the ocular surface with fluorescein and using a cobalt blue light in the slit lamp allow obtaining a better observation of the tear film(Fig.4). The final image looks like two semicircles of exactly 3.06 mm in diameter, displaced by the presence of a prism in the head of the instrument, giving the applanation pressure when the half circles just overlap at the central end. The semicircles move with the ocular pulse, and the endpoint is reached when the inner edges of the semicircles touch each other at the midpoint of their excursion(Fig.5). At this point, the IOP value is reported, in millimeters of mercury, on the instrument dial used to modulate the pressure. This measurement is safe, easy to use and relatively accurate in most clinical situations [8].

The GAT remains the gold-standard to assess the IOP, because it is relatively unaffected by ocular rigidity.

An excessive amount of fluorescein results in wide mires and an inaccurately high reading, whereas an inadequate amount of fluorescein leads to artificially low readings.

Marked corneal astigmatism causes an elliptical fluorescein pattern, and the clinician should rotate the prism to obtain an accurate reading [9].

The accuracy of GAT is reduced in certain situations

- Corneal edema: the increased corneal thickness gives falsely high values.

- Soft corneal lens: give falsely low values.
- Scleral rigidity modifications: in the scleral buckling procedures the IOP may appear inappropriately low [10].
- The central corneal thickness (CCT): The IOP value is most accurate with a CCT of 520 micron [11].

Applanation tonometry measurements are not accurate, if CCT is increased or decreased compared to the reference values. Increased CCT may give an artificially high IOP measurement; decreased CCT, an artificially low reading [12].

Figure 3. GAT

However, because the relationship of measured IOP and CCT is not linear, it is important to remember that the biomechanical properties of an individual cornea may vary, resulting in changes of the relative stiffness or rigidity of the cornea and altering the measurement. Currently, there is no validated correction factor for the effect of CCT on the GAT [13].

The GAT has some disadvantages [14]:

http://dx.doi.org/10.5772/58690

- The IOP assessment is subjective
- It 's always required the sitting position of the patient
- It is possible to transmit infections if the prism head is not disinfected before each measurement
- The pulsations of the eye can lead to excessive movements of the semicircles
- The amplitude of the semicircles, after application of fluorescein, can influence the readings of IOP
- Repeated or prolonged contact between the cornea and the tonometer may damage the corneal epithelium, resulting in a not reliable assessment of IOP
- The characteristics of the cornea (thickness, astigmatism, corneal surface regularity, viscoelastic properties) may make it difficult or incorrect the reading of the IOP values
- Excessive pressure on the eye, caused by squeezing of the eyes of the patient or by the force applied by the operator on the lid to keep the eyelids open, may induce incorrect readings
- Possible incorrect results due to an altered calibration of the tonometer

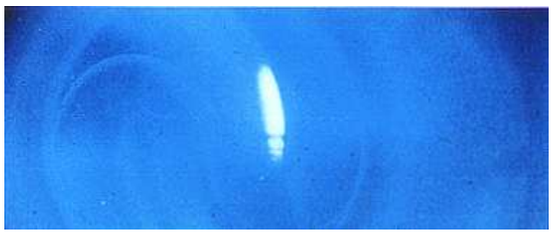


Figure 4. Semicircles

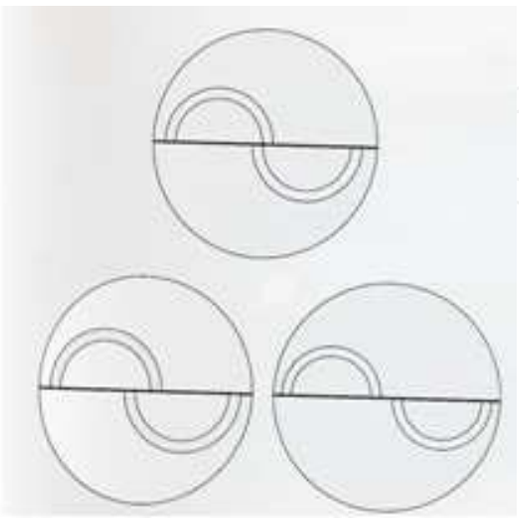


Figure 5. Semicircles readings

2.4. Perkins tonometer

The Perkins tonometer (Fig. 6) is a counterbalanced applanation tonometer that is portable and can be used with the patient either upright or supine [15].

It is similar to the GAT in using a split-image device and fluorescein stained ocular surface. However, the values of IOP are not well correlated with that obtained by Goldmann tonometer [16].

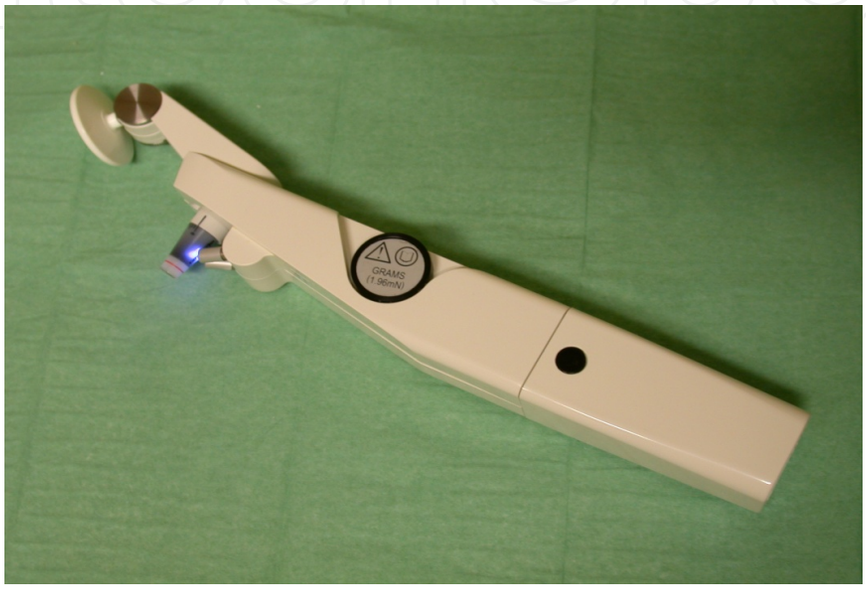


Figure 6. Perkins tonometer

2.5. Draeger tonometer

Portable version, supplied with an electric motor, able to change the applied force.

Less common and more difficult to use

2.6. Mackay-Marg tonometer

The Mackay-Marg model(Fig.7), made in 1959, was the first electronic tonometer and can be said to combine the principles of applanation and indentation. It uses a free-floating transducer to detect the transmitted pressure. An outer ring that flattens the adjacent cornea, reducing its influence on the IOP measurement, surrounds the transducer. The mobile tip that protrudes from a probe has a diameter of applanation of 1.5 mm on the corneal surface and, therefore, it is less affected by corneal thickness and corneal curvature. This device can be used in children and non-cooperative patients because of their portability and ease of use, in irregular and edematous corneas, even in the presence of LAC [17]; it gives values slightly higher compared to those obtained with the GAT [18].

http://dx.doi.org/10.5772/58690

Figure 7. MACKAY-MARG TONOMETER

3. Tonopen (Fig.:8)

It is based on the principle of the MACKAY-MARG tonometer. The values of IOP are converted into an electronic signal that is processed by a microprocessor. The area of applanation is smaller than that of GAT [19].

The instrument performs 4-10 measurements and calculates the average value, giving even higher percentages of reliability for values of 24 mmHg or higher, with a good correlation with the GAT [20].

The values below to 24 mm Hg are overestimated of about 2 mmHg compared to those of GAT.

The advantages of Tonopen are:

- It can be used in irregular corneas
- it allows to perform tonometry on patients in any position
- Easy to use

The disadvantages are that in presence of important corneal irregularities it gives unreliable results.

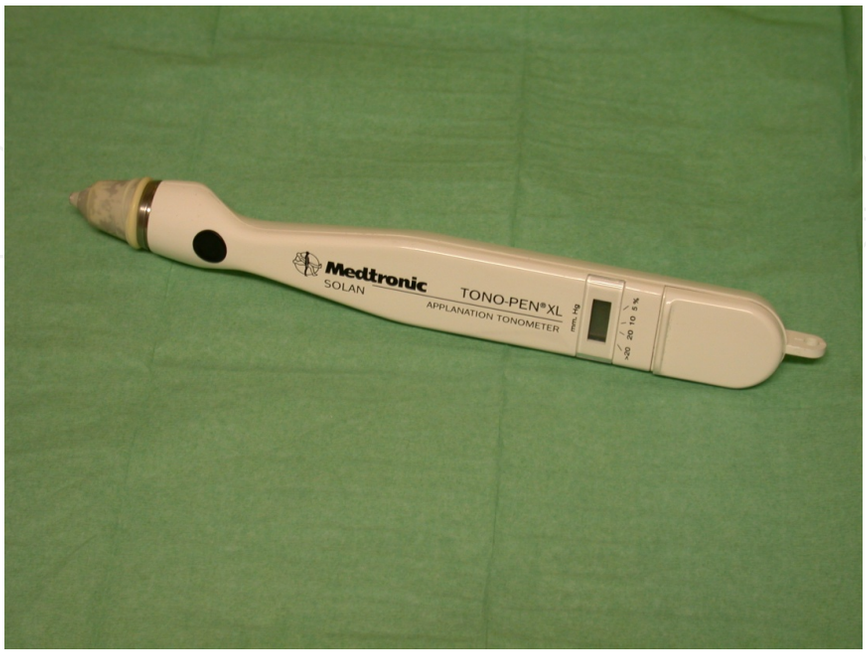


Figure 8. Tonopen

4. Pneumatic applanation tonometer (Fig.9)

The pneumatic tonometer, or pneumotonometer, has a pressure-sensing device that consists of a gas-filled chamber covered by a Silastic diaphragm. The gas in the chamber escapes through an exhaust vent.

As the diaphragm touches the cornea, the gas vent decreases in size and the pressure in the chamber rises.

Because this instrument perform an applanation on only a small area of the cornea, it is especially useful in the presence of corneal scars or edema [21].

The Ocular Blood Flow Analyzer (BFA) is a particular pneumotonometer. It performs the measurements of the IOP, 200 times per second and it records, with great precision, the amplitude of the eye pulse. It is based on the combination of a pneumatic system and an electronic system. A piston is moved by an air-flow until arriving in contact with the cornea, the force required to obtain the cornea applanation is given by the compressed air.

The air can freely exit the tool when far away from the cornea while when the probe is placed on the eye the airflow will be hampered to exit, so creating a proportional pressure. The IOP value is given as the force necessary to obtain the cornea applanation; the values are higher

http://dx.doi.org/10.5772/58690

than that obtained by the GAT [22]. Furthermore it is known that its values are influenced by physiological variations in central corneal thickness ([23] and corneal curvature [24] and the values are also not reliable if the cornea is significantly pathological

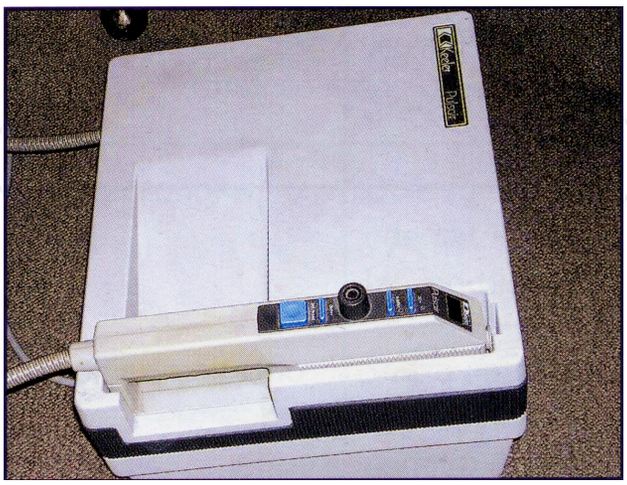


Figure 9. Pneumatic Applanation Tonometer.

5. Applanation tonometry to force variable

5.1. The Non-Contact Tonometries (NCT)

These instruments are based on two processes:

The applanation is obtained by a jet of compressed air that it is properly positioned on the cornea and checked optically ;

The applanation time is assessed by the maximum reflection of a beam incident at an angle of 45° and the speed with which it is obtained corresponds to the IOP.

The influence of corneal thickness is variable. There would be an overestimation for hypotension and underestimation for hypertension [25]

The instruments are often used in large-scale glaucoma-screening programs or by nonmedical health care providers.

5.2. Pascal dynamic contour tonometer (PDCT) (Fig. 10)

This tool entered the market recently and is based on the method of dynamic tonometry. While for the static tonometry, the tool deforms the corneal surface, and this deformation is correlated with the IOP, the dynamic tonometry is based not on the deformation itself, but on the fact that the instrument puts the applanation force on the cornea with a well-defined speed. The relationship between the time and the speed with which the deformation is achieved correlates with the value of IOP. The static IOP assessment is replaced by the concept of dynamic corneal

deformation speed and inertial mass. The profiled tip of the tonometer, called SensorTip, has a radius of curvature of 10.5 mm and the contact surface has a diameter of 7.5 mm which determines a line profile with the corneal surface and the tear film. The tip is mounted on a movable arm (cantilever) which is placed on the cornea giving a force equivalent to a gram and constantly kept by a spring mechanism.

A piezo-electric tip with a diameter of 1.2 mm is placed on the center of the contact surface, generates an electrical signal proportional to the IOP.

In conclusion, the PDCT eliminates most of the systematic errors due to individual changes of corneal characteristics, which, instead, influence all types of applanation tonometers. The advantage of measuring the real pressure in combination with the ability to record the dynamic fluctuations of the pressure gives the opportunity to diagnose and classify different types of glaucoma [26]

Indeed, it is important to underline that with the PDCT tonometer is possible to obtain an accurate definition of the pressure fluctuation due to the heartbeat (ocular pulse amplitude-OPA)

In fact, the PDCT seems to be the most accurate method for measuring the ocular pulse amplitude.

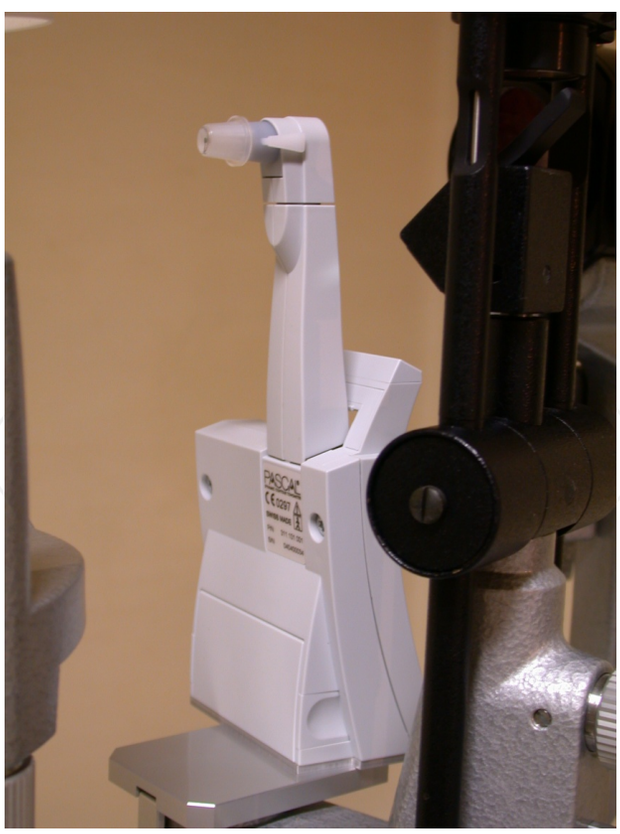


Figure 10. PDCT

http://dx.doi.org/10.5772/58690

5.3. Icare rebound tonometers (Fig.11)

The rebound technology is based on the rebound measuring principle, in which a very light-weight probe is used to make a momentary contact with the cornea.

In the rebound technology, motion parameters of the probe are recorded during the measurement. An induction based coil system is used for measuring the motion parameters. An advanced algorithm, combined with the state of the art software, analyzes deceleration and the contact time of the probe while it touches the cornea. Deceleration and the contact time of the probe change as a function of IOP. In simple terms, the higher the IOP, the faster the probe decelerates and the shorter the contact time.

The Icare rebound tonometer does not require any maintenance calibration, the anaesthesia is not needed since the touch of the probe is so gentle that the measurement is barely noticed by the patient [27].

Figure 11. Icare

5.4. The self-tonometers (Fig.13)

The Proview phosphene tonometer is based on an entoptic phenomenon called phosphene (flash of light); that is a feeling of light obtained from the retina by non-luminous stimuli. It looks like a pen, but inside it is present in a small, flat probe, an internal spring and a graduated scale for the values of IOP.

The patient can measure the IOP several times a day, with a device safe, easy to use and inexpensive. The measurement is carried out through the upper lid, does not require either anesthesia or fluorescein stain, it is portable, does not require batteries or electrical outlets.

The patient puts the instrument on the upper eyelid, at the root of the nose, and he presses until he sees a phosphene, and the IOP is recorded.

There is not a corneal applanation, and then tonometry can be performed on the abnormal corneas or after ocular surgery [28].

The Proview may be useful for perform a self-tonometry, but it needs to be calibrated with the GAT to have a good correlation between the values obtained by the two instruments [29]

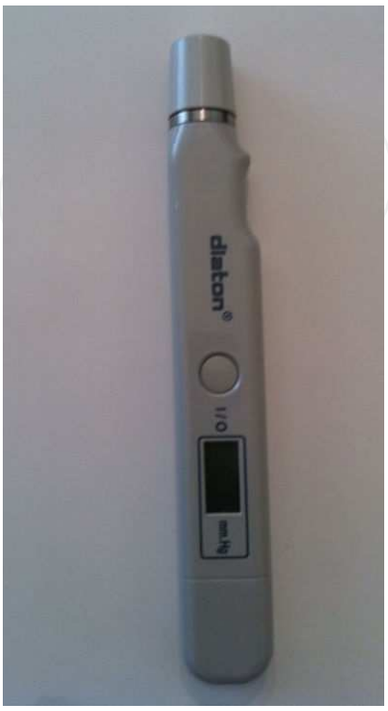


Figure 12. Self Tonometer

5.5. iCare tonometer

This tool is ideal for all patients treated with anti-glaucoma medications.

iCare tonometer is used in the diagnosis, follow-up and screening of intraocular pressure.

The iCare is an handheld tonometer, which is based on the impact-induction principle also known as rebound tonometry [31] The main advantages of this device include its quick and simple use, and that local anesthesia and slitlamp are not needed.

iCare tonometer has shown good reproducibility [31]and correlation with GAT and other tonometers in healthy and glaucomatous eyes. [31,32,33,34] Although iCare was designed not to be influenced by corneal properties, studies have shown that CCT and other corneal structural characteristics affect iCare IOP readings [32,33,34,35,36]

6. Sensory system lenses

This system consists of a soft contact lens attached to a micro-voltage detection unit connected to the external recording tool. It is still a prototype and several physiological parameters such as the tear film and eyelid movements need to be evaluated.

Another type of lens is the tonometric gonioscopic Smart Lens.

The values obtained are overestimated compared to those obtained with the Goldmann of approximately 4-5 mmHg.

6.1. The continuous measurement tonometry

Based on methods that allow evaluating the IOP through the application of a sensor to lens applied on the cornea, during the day, or to an intra-ocular lens (IOL). The latter system allows to obtain continuous values of IOP, without interference of the corneal thickness and curvature. This sensor, made of silicone, is applied on the IOL and has a plate shape divided into 4 parts where there are some cavities that generate a specific electrical voltage. The intraocular pressure fluctuations change the silicone structure and consequently the generate voltage. The chip present on the lens transforms the electric pulses into digital signals that are sent to a tool, called Photodisc, constituted by radio waves and a coil. The receiver is inserted in special glasses and is connected to a portable display. The values of IOP are sent to the photodisc and then displayed on the external display expressed in mmHg [37]

Conclusion Tonometry is the fastest, simple, and popular way to assess the IOP, which is the main risk factor for the glaucoma disease. The GAT is considered, the gold-standard for the assessment of IOP. Over the centuries it has been tried to develop accurate tonometers, searching for the true IOP value, and not altered from the biomechanical characteristics of the human eye. The way to the pursuit of the best tonometer is still long, but certainly the evolution of technology in ophthalmology will permit to develop more and more sophisticated and accurate tools to defeat the “thief of sight”: glaucoma.

Author details

Felicia Ferreri[1], Rosa Minniti[1], Alessandra Polimeni[1], Lucia Zavettieri[1], Giuseppina Ferreri[1], Paolo Ferreri[2] and Pasquale Aragona[1]

1 Institute of Ophthalmology, University of Messina, Italy

2 Institute of Ophthalmology, University of Bari, Italy

References

[1] Dua HS, Faraj LA, Said DG, Gray T, Lowe J. Human corneal anatomy redefined: a novel pre-Descemet's layer (Dua's layer). Ophthalmology. 2013 Sep;120(9):1778-85.

[2] Shah S, Laiquzzaman M, Bhojwani R, Mantry S, Cunliffe I: Assessment of the biomechanical properties of the cornea with the ocular response analyzer in normal and keratoconic eyes. Invest Ophthalmol Vis Sci 2007, 48(7):3026-3031.

[3] Touboul D, Roberts C, Kerautret J, Garra C, Maurice-Tison S, Saubusse E, Colin J: Correlations between corneal hysteresis, intraocular pressure, and corneal central pachymetry. Journal of cataract and refractive surgery 2008, 34(4):616-622.

[4] .Moses RA, Grodzki WJ. Theory and calibration of the Schiötz tonometer. VII. Experimental results of tonometric measurements: scale reading versus indentation volume. Invest Ophthalmol. 1971 Sep;10(9):716-23.

[5] Friedenwald Js.: Jun;52:543-7

[6] Pemberton JW.: Schiötz-applanation disparity following retinal detachment surgery.Arch Ophthalmol. 1969 Apr;81(4):534-7.

[7] Friedenwald Js.: Some problems in the calibration of tonometers. Am J Ophthalmol. 1948 Aug;31(8):935-44.

[8] Goldmann H, Schmidt T. Applanation tonometry. Ophthalmologica. 1957 Oct;134(4): 221-42.

[9] Holladay JT, Allison ME, Prager TC.Goldmann applanation tonometry in patients with regular corneal astigmatism. Am J Ophthalmol. 1983 Jul;96(1):90-3.

[10] Johnson MW, Han DP, Hoffman KE. The effect of scleral buckling on ocular rigidity. Ophthalmology. 1990 Feb;97(2):190-5.

[11] Ehlers N, Bramsen T, Sperling S.: Applanation tonometry and central corneal thickness. Acta Ophthalmol. 1975 Mar;53(1):34-43.

[12] Doughty MJ, Jonuscheit S.: Effect of central corneal thickness on Goldmann applanation tonometry measures-a different result with different pachymeters. Graefes Arch Clin Exp Ophthalmol. 2007 Nov;245(11):1603-10.

[13] Kohlhaas M, Boehm AG, Spoerl E, Pürsten A, Grein HJ, Pillunat LE :Effect of central corneal thickness, corneal curvature, and axial length on applanation tonometry. Arch Ophthalmol. 2006 Apr;124(4):471-6.

[14] Whitacre MM, Stein R.:Sources of error with use of Goldmann-type tonometers. Surv Ophthalmol. 1993 Jul-Aug;38(1):1-30

[15] Dunn JS, Brubaker RF: Perkins applanation tonometer. Clinical and laboratory evaluation. Arch Ophthalmol. 1973 Feb;89(2):149-51

[16] Arora R, Bellamy H, Austin M. Applanation tonometry: a comparison of the Perkins handheld and Goldmann slit lamp-mounted methods. Clin Ophthalmol. 2014 Mar 26;8:605-10.

[17] Kaufman HE, Wind CA, Waltman SR: Validity of Mackay-Marg electronic applanation tonometer in patients with scarred irregular corneas. Am J Ophthalmol. 1970 Jun;69(6):1003-7.

[18] Moses Ra, Marg E, Oechsli R. Evaluation of the basic validity and clinical usefulness of the Mackay-Marg tonometer.Invest Ophthalmol. 1962 Feb;1:78-85.

[19] Hessemer V, Rössler R, Jacobi KW: Tono-Pen, a new tonometer. Int Ophthalmol. 1989 Jan;13(1-2):51-

[20] Deuter CM, Schlote T, Hahn GA, Bende T, Derse M.: Measurement of intraocular pressure using the Tono-Pen in comparison with Goldmann applanation tonometry-a clinical study in 100 eyes. Klin Monbl Augenheilkd. 2002 Mar;219(3):138-42.

[21] West CE, Capella JA, Kaufman HE.Measurement of intraocular pressure with a pneumatic applanation tonometer. Am J Ophthalmol. 1972 Sep;74(3):505-9.

[22] Pianka O Geyer O : Comparison of the pneumatonometry with applanation tonometry. Inv Ophthalmology Vis Sci 1998; 39: 4309

[23] Doughty MJ, Zaman ML Human corneal thickness and its impact on intraocular pressure measures: a review and meta-analysis approach. Surv Ophthalmol. 2000 Mar-Apr;44(5):367-408.

[24] Gunvant P, Baskaran M, Vijaya L, Joseph IS, Watkins RJ, Nallapothula M, Broadway DC, O'Leary DJ.Effect of corneal parameters on measurements using the pulsatile ocular blood flow tonograph and Goldmann applanation tonometer.Br J Ophthalmol. 2004 Apr;88(4):518-22.

[25] Shields MB. The non-contact tonometer. Its value and limitations. Surv Ophthalmol. 1980 Jan-Feb;24(4):211-9.

[26] Ku JY, Danesh-Meyer HV, Craig JP, Gamble GD, McGhee CN. Comparison of intraocular pressure measured by Pascal dynamic contour tonometry and Goldmann applanation tonometry.Eye (Lond). 2006 Feb;20(2):191-8.

[27] Fernandes P1, Díaz-Rey JA, Queirós A, Gonzalez-Meijome JM, Jorge J. Comparison of the ICare rebound tonometer with the Goldmann tonometer in a normal population. Ophthalmic Physiol Opt. 2005 Sep;25(5):436-40

[28] Groenhoff S, Draeger J, Deutsch C, Wiezorrek R, Hock B.: Self-tonometry: technical aspects of calibration and clinical application. Int Ophthalmol. 1992 Sep;16(4-5): 299-303.

[29] Avarez TL Gollance SA The Proview Phosphene tonometer fails to measure ocular pressure accurately in clinical practice,Ophthalmology 2004 Jun;111(6):1077-85

[30] Witte V, Glass Ä, Beck R, Guthoff R.Evaluation of the self-tonometer Icare ONE in comparison to Goldmann applanation tonometry.Ophthalmologe. 2012 Oct;109(10): 1008-13.

[31] Kontiola AI. A new induction-based impact method for measuring intraocular pressure. Acta Ophthalmol Scand. 2000;78:142–145.

[32] Martinez-de-la-Casa JM, Garcia-Feijoo J, Castillo A, Garcia-Sanchez J. Reproducibility and clinical evaluation of rebound tonometry. Invest Ophthalmol Vis Sci. 2005;46:4578–4580.

[33] Nakamura M, Darhad U, Tatsumi Y, Fujioka M, Kusuhara A, Maeda H, et al. Agreement of rebound tonometer in measuring intraocular pressure with three types of applanation tonometers. Am J Ophthalmol. 2006;142:332–334.

[34] Martinez-de-la-Casa JM, Garcia-Feijoo J, Vico E, Fernandez-Vidal A, Benitez del Castillo JM, Wasfi M, et al. Effect of corneal thickness on dynamic contour, rebound, and Goldmann tonometry. Ophthalmology. 2006;113:2156–2162.

[35] Brusini P, Salvetat ML, Zeppieri M, Tosoni C, Parisi L. Comparison of ICare tonometer with Goldmann applanation tonometer in glaucoma patients. J Glaucoma. 2006;15:213–217.

[36] Chui W, Lam A, Chen D, Chiu R. The influence of corneal properties on rebound tonometry. Ophthalmology. 2008;115:80–84.

[37] Mottet B, Aptel F, Romanet JP, Hubanova R, Pépin JL, Chiquet C. 24-hour intraocular pressure rhythm in young healthy subjects evaluated with continuous monitoring using a contact lens sensor. Jama Ophthalmol 2013 Dec;131(12):1507-16