TONOMETRY THROUGH TIME

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10.14434/hindsight.v54i2.37207

ABSTRACT
The significance of intraocular pressure (IOP) was first noted in the 10th century. Instrumentation to measure IOP was first developed in the 19th century and has continued to develop over time. We now have anesthetics to aid in measuring intraocular pressure by indentation, applanation, or a combination of both indentation and applanation. In addition, non-contact and rebound tonometers are available and require no anesthetic. This article discusses the development, design and use of these instruments over a historical timeline.

KEYWORDS
Glaucoma, intraocular pressure, tonometry, Maklakoff, Schiotz, Goldmann, Mackay-Marg

INTRODUCTION AND HISTORY OF INTRAOCULAR PRESSURE/GLAUCOMA

The relevance of an eye’s intraocular pressure (IOP) and the techniques used to measure the IOP have changed significantly since it was first mentioned in the 10th century by an Arabic surgeon, At-Tabari. He was first to document a sudden increase of pressure in the eye. Although At-Tabari did not realize it at the time, this is thought to be the first mention of acute closed angle glaucoma. During this time others were evaluating IOP by reporting “firmness in the eye.”

Early glaucoma was first described by the Greeks as a blind eye with an “unreactive pupil and a blue-green cast to the pupil.” Today the association between glaucoma and IOP is well established, however, it was not until 1622 in the first ophthalmic book “Breviary” where an English oculist, Richard Banister, documented that chronic glaucoma may be related to high IOP. He noted a blind eye with an immobile pupil that was rock-hard when palpated.

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Documented IOP continued and was acknowledged again in the 1700’s by Platner of Leipzig. However, it took until the 19th century to be mentioned more frequently in European writings. In 1826, Sir William Bowman was the first in the British Medical Association to suggest the use of digital palpation or transpalpebral tonometry to diagnose ocular disease. Although first mentioned in 1622 by Richard Banister, IOP measurement was not taken seriously until the mid 19th century when it was accepted that elevated eye pressure was the primary factor for glaucoma and IOP became routinely assessed.

HISTORY OF TONOMETRY

The measurement of intraocular pressure, tonometry, is calculated by the resistance of the eye to indentation by an applied force. It can be estimated using a variety of instruments that deform the globe and measure the IOP. Thus, tonometers are classified by how the force is applied to deform the eye. These include indentation, applanation, a combination of both indentation and applanation or non-contact tonometers.

The first instrument developed for measuring IOP was created by von Graefe in 1863. A weight-loaded plunger was applied to the sclera and the degree of indentation was measured. In 1865, Donders invented a spring loaded indentation tonometer and the first applanation tonometer was developed by Adolph Weber in 1867. However, even with the invention of multiple devices, digital palpation was still considered the best method of determining a patient’s IOP in 1872.

UTILIZATION OF LOCAL ANESTHETICS

The use of cocaine as a topical anesthetic rapidly changed the practice of ophthalmology, not only for surgical procedures but for the accuracy of tonometry measurements. Prior to the use of cocaine, Richardson ether spray was the only local anesthesia method available and was ineffective and rarely used.

General
anesthesia could be utilized (ether or nitrous oxide); however, side effects of coughing and vomiting were common and would often damage the surgical eye. 

Research on the anesthetic properties of cocaine was known many years before Carl Koller’s discovery of its use as an oculans anesthetic in the summer of 1884. This discovery allowed patients to be more comfortable during removal of foreign bodies and pterygiums, strabismus and cataract surgeries, and IOP measurements. The use of cocaine as a corneal anesthetic opened the way for the development of more accurate tonometers due to the ability of directly applying the tonometer to the cornea.

Cocaine, as with most corneal anesthetics, can cause corneal epithelial damage. When used multiple times, it can result in corneal irregularities, erosions, or corneal pitting. Today, topical cocaine has limited use in ophthalmology, but remains historically important in the aid and development of tonometry and the management of glaucoma.

**TONOMETRY POST ANESTHETICS**

**Maklakoff Applanation Tonometry**

Utilizing the new local corneal anesthetic, Alexei Maklakoff was able to design the most accurate and “practical tonometer” at that time in 1885. This corneal applanation tonometer was preferred due to its clinical usefulness and reliability.

The Maklakoff tonometer was updated in 1967 as the Posner-Inglima tonometer. The principal design is the same; however, the Posner-Inglima tonometer is made of plastic and is disposable. The patient is placed in a supine position and a dumbbell shaped device with an ink covered footplate is lowered onto the cornea. When the footplate comes into contact with the cornea, ink is then transferred from the footplate to the cornea. The plate is removed and applied to a paper leaving a light area of ink where the footplate applanated the cornea and dark area where it did not come in contact with the cornea. A chart is then referenced comparing the area of applanation which is converted using the Imbert-Fick formula to the patient’s IOP. This design was used in Russia and Eastern Europe even in recent years.

Eye movement can cause the applanation area to be larger than it should be, causing the calculation of the IOP to appear lower. Therefore, lower IOP readings and poor repeatability can occur due to eye movement.

**Schiotz Indentation Tonometry**

Hjalmar Schiotz, a Norwegian ophthalmologist, developed a transcorneal indentation tonometer in 1905. It became the most widely used tonometer in the world at that time. The design continued to be refined for years and much of our knowledge about IOP in normal and glaucomatous eyes was obtained using the Schiotz tonometer.

Indentation tonometry involves having a force or weight indent the eye then measuring the eye’s hardness or softness. The Schiotz design consists of a weighted plunger with variable weights between 5-15g. Initially, the test is performed with a 5.5g weight. The weight floats in a barrel which has a 15mm footplate that fits loosely over the cornea. The plunger has an attached lever and when the barrel moves up and down, a needle across the scale will move.

To perform Schiotz tonometry, the patient is placed in a supine position. Once the footplate is placed on the eye, the weight sinks into the cornea giving you the indirect proportional pressure of the eye. As the depth of the plunger increases into the eye, the scale will move. Each 0.5mm increase indicates a one unit increase on the scale. If the measurement is less than 4, extra weights must be added for an additional reading.

The device’s positive features include portability and an all metal design that allows for easy sterilization. Negative features include the risk of a corneal abrasion if eye movement occurs during testing. Also, the possibility of aqueous humor displacement can occur which can increase the IOP above the baseline readings.

The Schiotz tonometer must also be calibrated before each reading. For calibration, a steel block is used, and the reading must be zero. If out of calibration, it has to be sent to the manufacturer. Proper training and familiarity with the instrument allow for more accurate measurements.

The Schiotz tonometer does not take into account scleral rigidity which could affect the IOP. Myopic eyes tend to have a low rigidity and IOP can be underestimated. Hyperopic eyes have higher rigidity and IOP can be overestimated. Patients with a history of corneal disease or ocular surgery may also have inaccurate readings.

In 1954, the calibration scale and Schiotz conversion tables were improved. The Schiotz tonometer was used throughout most of the 20th century and is still used in parts of the world today. Its popularity decreased once Hans Goldmann developed the Goldmann tonometer.

**Goldmann Applanation Tonometry**

Hans Goldmann felt the Schiotz tonometer needed improvement. He was frustrated by the influence of friction by the mechanical parts of the instrument, and the problems with calibration. He attempted improvements but was unsuccessful. He reviewed and considered the theory of applanation and was influenced by Weber, Maklakoff and Fick in his design of the Goldmann Tonometer.

The Goldmann Tonometer came into use in 1955 and was the most accurate measurement of IOP at the time. It is still used throughout the world today. The Goldmann Tonometer has a knob on the side of the device that controls the spring force of the tonometer. The applanation tip is cylindrical in shape and sits on top of a rod. There is a doubling prism present within the tip. The diameter of the tonometer tip is 3.06mm; this was chosen due to the tear surface tension and corneal elasticity. The tear surface tension will pull the tonometer tip towards the eye and the corneal elasticity will push the tonometer tip away from the eye. With a diameter of 3.06mm, these opposing forces are nearly equal and will cancel each other out. Fluorescein dye and a cobalt blue light are required for measurement. The blue light activates the fluorescein dye into a yellow-green color. When applanation occurs, due to the doubling prism in the tip, a superior and inferior meniscus is formed at the perimeter of the flattened cornea.
measure the exact amount of pressure, the inner margins of the meniscus should just touch.

Proper training is important for accurate measurement techniques. Inaccurate readings can be affected by too much or too little fluorescein in the tear film and pressure from a finger on the eye or eyelid. Patients with scarred corneas or large amounts of astigmatism can have inaccurate readings.

Sterilization of the tip has also been an issue. Most practices clean with an alcohol swab, while the manufacturer recommends bleach or hydrogen peroxide. Disposable tips have been produced but are not as accurate.

Non-Contact Tonometry (NCT)

Non-contact tonometers became commercially available through the work of Dr. Bernard Grolman, an optometrist, in the 1970’s. However, the idea was conceived much earlier in 1951 by Erich Zeiss. This tonometer was developed for usage when a topical anesthetic was unavailable or needed to be avoided.

Acrotonometry is the principal behind non-contact/air puff tonometry. The design uses an applanating force through a column of air with increasing pressure. When the cornea flattens from the air, a laser beam from the side reflects into a sensor and the air is stopped. The force is recorded from the moment of applanation and converted into millimeters of mercury. It is recommended that IOP value should be an average of 3-4 readings.

A newer version by Reichert measures the force until the cornea is indented and decreases the force of the air until the cornea is no longer indented. The difference between these two points is a measure of the corneal elasticity or hysteresis. This allows the IOP measurement to be independent of corneal thickness. There are many positive features of this device. No anesthesia is required, no sterilization is needed, it provides an objective measurement and is not dependent on user technique.
Mackay-Marg tonometer (combined indentation and applanation)

In 1959, optometrist Dr. Elwin Marg along with R. Stuart Mackay, an electrical engineer, introduced the Mackay-Marg tonometer. This design is a combination of indentation and applanation tonometry. The Mackay-Marg tonometer has a strain gauge, where a tiny plunger protrudes that allows for a 3.06mm applanation surface. When taking an IOP measurement, the cornea and the IOP present resistance to the plunger. The resistance on the plunger then puts force on the strain gauge. During the measurement process when applanation occurs, there is a small decrease in the force when the force is shared by the plunger and foot plate. This device is even accurate on those patients with corneal issues since the endpoint is mechanical and not optical. It is also accurate if more pressure is applied to the cornea than necessary and aqueous fluid is displaced. An increase in IOP can occur; however, it will not cause major errors. The Mackay-Marg tonometer is not in production; however, the currently popular tonopen is based on its design. The Tonopen takes an average of several readings depending on the model and gives an indicator of reliability in its final reading.

The advantage of the Tonopen is portability and ease of usage. It can be used in an upright or supine position and even through a bandage contact lens. However, it does require a disposable latex cover for each use.

Rebound Tonometry

This design was developed as early as 1931 and a modern modification occurred in 1967. This was developed originally for small animals since it was a rapid measurement. Accuracy of the original design was affected by the tear film layer and corneal biomechanics. It did not gain widespread usage. The newest version is the iCare device, which was first described in 1997. It was designed by Dr. Antti Kontiola. Due to the portability, ease of use and because no anesthetic is required, it is becoming more popular. Its measurements are comparable with the Tonopen and NCT. It may be useful for small children or anyone needing a quick IOP reading and are unable to use other devices.
SUMMARY

IOP elevation has been associated with glaucoma, a blinding condition, for over a millennium.1

Over the past 150 years our ability to measure IOP has improved and continues to improve, although the instruments we have provide an indirect measurement of IOP. Currently, there is no practical direct way of measuring IOP. With continued research, newer measurement techniques and more accurate devices will be created. Our understanding of the eye and glaucoma continues to be under much research. We look forward to the next 150 years of changes to come in this area of eyecare.

REFERENCES