The story of physicians’ attempts to assess intraocular pressure (IOP) goes back many centuries. Mechanical instruments designed for this purpose were introduced in the latter part of the 19th century but did not gain traction until the introduction of the Schiøtz tonometer in 1905. This report reviews details about this instrument, its inventor, and its role in glaucoma treatment.

In the 5th century BC, Hippocrates, the father of medicine, taught that experienced doctors were aware that the laying on of hands could relieve pain, induce healing, and be informative to the physician.1,2 In a similar manner, palpation of the eye seems to have been used in cases of ocular disease. Palpation of the eye through the lids to determine the globe’s hardness or softness probably preceded any concept of glaucoma as a disease.3

In ancient Greece, glaukos was sometimes used to describe diseased eyes in which the pupil or iris appeared light blue, grey, or green.4 Galen associated the glaukos with a hard crystalline lens, and later authors such as Celsus and Avicenna advocated palpation of the eye to determine if the intraocular humors had hardened and to estimate maturity of the cataract before couching.5 An English eye physician, Richard Banister, in his Breviary of 1622,4 generally is credited as the first to appreciate that elevation of IOP is recognizable by the globe’s resistance to palpation and, if present, is a distinct sign of ocular disease.5 Thirty-four years later, Felix Platter observed that the glaucomatous eye was hard.6 However, it was almost 200 years later when Sir William Bowman suggested to physicians at the meeting of the British Medical Association in 1826 to use digital tonometry in the diagnosis of ocular disease,7 and 26 years after that Bowman noted, “I have long paid special attention to the subject of the tension of the globe … and have found it possible and practically useful to distinguish nine degrees of tension.”7

The first attempts at developing tonometry using a mechanical instrument apparently were made by Albrecht von Graefe. Graefe (Fig 1) mentioned his initial trials with instrumental tonometry (Fig 2) in a letter to Frans Cornelis Donders in 1862, but apparently his instruments advanced only to the prototype stage.8 The earliest impression tonometers that actually were built and found their way into clinical use were developed in Donders’ clinic in Utrecht between 1863 and 1868.9–12 The foot plate was applied to the sclera after determination of the scleral curvature, and the IOP was estimated according to the depth of the indentation. More refined variations of the Donders’ tonometer followed from Priestley Smith in 1879 and 188713 and Layerat in 1885.14

The introduction of cocaine corneal anesthesia in 1884 by Karl Koller15,16 allowed tonometers to be applied directly to the cornea. Using this better-defined and anatomically more uniform site led to more consistent measurements. A fundamental source of error in all these early tonometers was noted by Adolf Weber16 in 1867: the indention of the sclera and cornea displaced a sufficient quantity of intraocular fluid to alter the pressure it was intended to measure. To address this problem, Weber designed the first applation tonometer, designed to measure the IOP with only minimal fluid displacement. The leaders in the glaucoma field at this time failed to appreciate the concept of a perfect appplanation point without fluid displacement, and Weber’s tonometer did not gain wide acceptance. A few years later, in 1885, C. L. Maklakoff,17 who was unaware of Weber’s work, introduced a more advanced tonometer designed on the application concept. It is generally considered to be the first reasonably accurate instrument produced before 1900.

Armand Imbert18 in France and Adolf Eugen Fick19 in Germany each independently provided critical research results regarding the design of an improved applanation tonometer. They showed that when the application of the tonometer produces a flat surface, forces cancel each other, and the reading of the tonometer equals the IOP. This proved critical to Hans Goldmann20 as he developed the Goldmann tonometer, and he termed this the Imbert– Fick law. Fick himself designed a tonometer, but it did not gain popularity.

Approximately 15 tonometers were described in the literature before the beginning of the 20th century. The Maklakoff improved model of 1892 (Fig 3), although complicated and difficult to use, continued to be used in Russia and Eastern Europe until the end of the 20th century.21 Apart from that instrument, none of the others met the requirements of a reliable and clinically useful instrument, and none found their way into the practice of ophthalmology. As the 20th century dawned, digital tonometry, as propounded by Bowman, remained as the unrivaled standard method of determining IOP.

In 1905, Hjalmar Schiøtz (1850–1927; Fig 4), a Norwegian ophthalmologist, inventor, and innovator, introduced his indentation tonometer (Fig 5).22 A half century later, in an article published posthumously in 1957, Jonas S. Friedenwald23 (Fig 6) wrote: “It is difficult after the lapse of so many years to gain a clear idea of the magnitude and solidity of Hjalmar Schiøtz’s contribution. During these years, the Schiøtz tonometer became the ‘gold standard’ for the measurement of intraocular...
pressure.” It was simple, rugged, and, for an indentation tonometer, remarkably precise, and rapidly gained the epithet of “the first clinically useful tonometer.” The instrument has a relatively flat foot plate measuring 15 mm in radius curved to match the average human corneal curvature. It deforms most corneas to a uniform, somewhat flattened state that becomes the plane of reference for the indentation.

The Schiøtz tonometer functions in the following manner, accordingly to Kniestadt et al8: “Gravity provides a known force on a weighted metal plunger. The plunger rides inside a metal cylinder attached to a foot plate. The top of the plunger rides along a curved lever that attaches to a pointer, which in turn rides along a scale. For each 0.05 mm that the plunger sinks below the level of the footplate, the pointer moves up 1 scale unit. Thus, the lower the IOP, the farther into the cornea the plunger sinks and the higher the scale reading....” “...The scale measuring the amount of indentation is linear. The relation between the amount of indentation and intraocular pressure is ... logarithmic, so that the higher IOP values are compressed toward the lower end of the scale.”8,23 The original calibrations between the scale readings and the IOP were carried out in conjunction with manometry readings in artificial eyes and cadavers. Schiøtz’s brother, a physicist, helped him to convert the tonometer readings into millimeters of mercury of IOP.24

Hjalmar August Schiøtz was a major figure in late 19th- and early 20th-century ophthalmology in his native Norway and in Europe. He was less well recognized in England and the United States because he published almost exclusively in Norwegian and German. He attended medical school in Oslo and trained in ophthalmology with Karl Ferdinand von Arlt and Ernst Fuchs in Vienna. He spent the subsequent 2 years working with Louis Emile Javal at the Sorbonne ophthalmologic laboratory, where they constructed an early keratometer known as the Javal-Schiøtz ophthalmometer.
Schiøtz returned to Norway and in 1881 introduced the concept of asepsis to Norway at the Rikshospitalet in Oslo, which included disinfection of instruments by boiling in water and the use of white coats when performing surgery. In 1882, Schiøtz presented an ophthalmoscope (Fig 7) of his own design that featured 2 moveable mirrors, allowing the instrument to be used for either direct or indirect ophthalmology without requiring removal and replacement of either mirror, as was previously the case. Also in 1882, he invented an instrument to measure colored halos in narrow-angle glaucoma. Three years later, in 1885, he presented his new self-monitoring perimeter, and in 1888, he demonstrated a prism apparatus to investigate and measure muscle balance between the 2 eyes. In 1916, he produced a blink lantern to diagnose color vision abnormalities in seamen and to train personnel. His medical thesis in 1883 was titled “On Some Optical Corneal Characteristics,” and he was later one of the earliest performers of refractive corneal surgery.

Schiøtz was a gifted craftsman who built prototype models of his inventions in his home workshop. In 1915, he became the first Norwegian professor of ophthalmology and was a founder and first president of the Norwegian Ophthalmological Association. Schiøtz was an austere, sensitive individual who was haunted by depression and despised showmanship and publicity. Although he was an admired public figure in Norway and was regarded warmly by students and patients, he had little interaction with his international colleagues. His many inventions were well received during his lifetime, but since his death in 1928, only his tonometer has endured. Although now beyond its zenith, it remains widely used throughout the world. Starting
in 1910, clinical studies with titles such as “Glaucoma Therapy under the Guidance of the Schiøtz Tonometer” began to appear with increasing frequency.\textsuperscript{15} Much of our present basic knowledge of IOP in the normal eye and in the glaucomatous eye was gained using the Schiøtz tonometer.\textsuperscript{12}

Until his death in 1928, Schiøtz continued to refine both the tonometer calibration process and the mechanism of the tonometer itself (Fig 8).\textsuperscript{24} The Schiøtz tonometer was manufactured by Andreas Jensen Krogh (1849–1938), owner of a firm that produced mathematical and surgical instruments in Norway (Fig 5).\textsuperscript{24} The moderate price of the tonometer no doubt contributed to its popularity.

Starting in about 1937, Jonas S. Friedenwald (Fig 6), Johns Hopkins’ great ophthalmologist and visual scientist with wide-ranging interests, at the request of the American Academy of Ophthalmology and Otolaryngology, began making contributions to the theory and practice of tonometry.\textsuperscript{25} In particular, he improved the accuracy of the calibration scale for the Schiøtz tonometer.\textsuperscript{26} Working with Robert A. Moses and others, he offered improved conversion tables in 1954 and again posthumously in 1957\textsuperscript{23} that prolonged the time during which the Schiøtz tonometer was the unrivalled standard for diagnosing and treating glaucoma patients. Friedenwald also designed electronic versions of the Schiøtz tonometer. Although the problems inherent in impression tonometry were minimized and compensated for by these efforts, the basic flaws of impression tonometers could not be eliminated: the displacement of aqueous elevating the IOP; the variability of the cornea’s thickness, rigidity, curvature, and elastic properties; as well as the increased pressure, introduced by squeezing the lids.\textsuperscript{8}

In 1955, Hans Goldmann,\textsuperscript{27} a Swiss ophthalmologist from the University of Bern, published his concept for an applanation tonometer and developed the Goldmann tonometer, which replaced the Schiøtz as the gold standard against which all others are judged to the present day. Its limitations are that it is not portable, requires anesthesia and sterilization, and needs to be calibrated and the apparent pressure can vary according to the corneal thickness. Despite being eclipsed by the Goldmann and other more recent tonometers, the Schiøtz tonometer nonetheless remains in wide use today and is manufactured in China, Pakistan, and India.

References


Footnotes and Financial Disclosures

Financial Disclosure(s): The author(s) have no proprietary or commercial interest in any materials discussed in this article.

Supported by Research to Prevent Blindness, Inc., New York, New York (unrestricted grant); and the National Eye Institute, National Institutes of Health, Bethesda, Maryland (Ophthalmology Core Facility grant no.: P30EY010572).

Correspondence:
Daniel M. Albert, MD, MS, Casey Eye Institute, 515 SW Campus Drive, Portland, OR 97239-4197. E-mail: albedan@ohsu.edu.