Tonometry of the eye

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ABSTRACT AND INTRODUCTION

The fluid in the eye (*aqueous humor*) is at a pressure slightly higher than the ambient pressure. The relative pressure is largely determined by the equilibrium between the rate of formation of aqueous humor and the rate of its drainage from the eye. Physicians long ago determined that there is a significant correlation between this pressure (the *intra-ocular pressure*, IOP) and the likelihood that the patient will develop *glaucoma*, a serious eye disease potentially leading to almost total vision loss.

Thus there is great interest in measuring the IOP (a matter spoken of as *ocular tonometry*). In the usual clinical setting, there is no reasonable way to measure it directly (as, for example, with a hollow needle connected to a manometer). But many ingenious ways to measure the IOP indirectly have been developed over the years. Almost all of these instruments (called *tonometers*) depend on determining how the eye, at the cornea, displaces in reaction to an applied force.

In this article, I describe in some detail two of these tonometers, and mention the general principles of some others.

CAVEAT

I am not an eye care professional, nor do I have any formal training in the practice in that field nor in its own unique branch of optical science. The information in this article is my own interpretation of the results of extensive (mostly quite recent) research into the available literature, and of discussions with eye care professionals, through the prism of my own scientific and engineering background and outlook.

BACKGROUND

As interest in the inter-ocular pressure developed among physicians, it was common to make a qualitative determination of the IOP by *digital palpation* (no, *digital* does not mean with 1s and 0s, but rather is used with its original sense, referring to the finger)). The physician would gently press on the eye at the cornea, and would discern how “stiff” it seemed to be.

Later, various researchers developed instruments that would, in many cases, do essentially the same thing, in the interest of getting a quantitative indication of the IOP. These instruments are spoken of collectively as *tonometers*.

DEFINITIONS

Gauge pressure

The intraocular pressure mentioned in this article is the pressure with respect to the ambient (atmospheric) pressure (what would be called "gauge pressure" in the field of pneumatics or hydraulics), not the absolute pressure.

Unit of pressure

In this field, in the US, it is the custom to describe pressures with the unit *mm Hg* (millimeter of mercury), which refers to the height in millimeters of a mercury column that would exert the pressure of interest.

Unit of force

It is common in this field to speak of forces with the unit *gram*. Of course, the gram is properly a unit of mass, not force. So what is usually meant there is the (non-SI) unit *gram-force*, which is the force exerted by a mass of one gram under the influence of the "standard" gravitational acceleration. Nevertheless, here I will follow common practice and speak of forces in the unit *gram*.

THE GOLDMANN APPLANATION TONOMETER

Introduction

The Goldmann Applanation Tonometer (often, GAT) was developed by Hans Goldmann in about 1954, based on earlier work by Hjalmar Schiøtz of Norway and many others. Despite various limitations, it is unceasingly referred to as "the gold standard of tonometry".

The initial manufacturer of the GAT instrument, and today its most prominent manufacturer, is the Haag-Streit Company of Switzerland. The Haag-Streit GAT instruments are distributed in the US by Reichert, Inc., the noted manufacturer of ophthalmic instruments (successor in that regard to the American Optical Company).

The term "applanation"

The term *applanation* essentially means "the process of flattening". I have no information on the use of the term prior to its use by Goldmann. It is possible that he coined it. We can suspect that the root "plan" is intended to mean "plane" (thus, "flat").

It is not etymologically related to the similar-seeming term *aplanatic* (notice, for one thing, the single "p"), a term used in the field of optics to refer to a camera or telescope lens that is free from certain aberrations. There, the root "plan" does not have the meaning "flat", but rather comes from a Greek verb meaning "to wander". Thus an aplanatic lens is free from (the "a" meaning "without") "wandering", or what we might interpret as "waywardness".

Basic principle

The Goldmann Applanation Tonometer presses with a controlled force on the cornea of the eye with a flat-fronted object, while we observe through a special optical system the diameter of the flattened area. When that reaches a certain target diameter, the force being then applied is read and from that an estimate of the intra-optical pressure is deduced.

This principle comes from a principle established (independently) by Armand Imbert of France and Adolph Fick of Germany in about 1885. If we have a spherical body of fluid, at pressure P, surrounded by a "skin" of zero thickness, dry, perfectly spherical, perfectly elastic, and of zero stiffness, and we press against it with a flat probe with a certain force, F, leading to a flattened region of area A, then P is given by:

$$P = \frac{F}{A} \qquad (1)$$

(just as we might naïvely expect).

Complications

Recall that equation 1, upon which the working of the Goldmann Applanation Tonometer is based, is predicated on a sphere full of liquid bounded by a surface of zero thickness, dry, perfectly spherical, perfectly elastic, and of zero stiffness.

But, not surprisingly, these conditions do not obtain in the case of a real human eye. The layer that bounds the eye (or, most importantly, the cornea, where the flattening is taking place) does not have zero thickness nor zero stiffness.

Another fly in the ointment is that in a normal eye the bounding surface is not dry. Rather, there is a layer of tears over the entire front of the eye. The surface tension of this liquid exerts a pressure on the eye, which becomes a component of the intra-ocular pressure not taken into account by the basic Imbert-Flick relationship.

Interestingly, the errors in determining the IOP caused by these two phenomena are in opposite directions. Goldmann, through extensive testing, ascertained that, over the population of hypothetical "normal" eyes, these two effects very nearly cancel out if we press on the cornea until the diameter of the flat region is in the range 2.7-4.0 mm.

So Goldmann chose, within that range, a standard flattening diameter of 3.06 mm for use by his instruments. Why that specific value? If we consider equation 1, once we get the units sorted out properly, we find that a force of 0.1 gram-force is required to produce a flat region 3.06 mm in diameter for an intra-ocular pressure of 1.0 mm Hg. How handy!

Ascertaining when the flat region has that diameter

To prepare for Goldmann tonometry, a drop of a liquid containing fluorescein dye is instilled into each eye. The light source in the slit lamp (used to illuminate the eye in the Goldmann technique) is set to use a "cobalt blue" filter. The wavelengths of the light through that filter (400-450 nm) cause that dye to fluoresce with a greenish-yellow color.

Because of surface tension considerations, the dye forms a meniscus just outside the edge of the flattened region. We see that in figure 1.

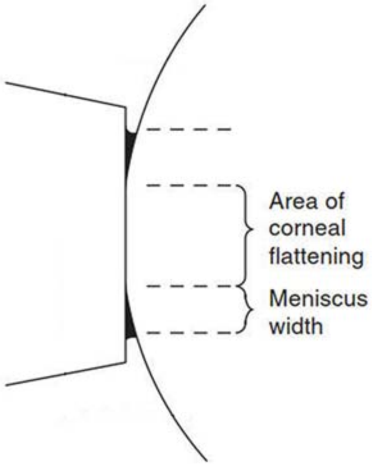

Figure 1. Meniscus around flattened region

Thus if we were to somehow view the cornea, we would see a greenish-yellow luminous ring from the dye in that meniscus. We wish to press on the cornea with our flat-faced prism until that luminous ring has an (inside) diameter of 3.06 mm.

The component that presses on the cornea is in fact an integrated dual prism. We see its general configuration in figure 2.

Figure 2. Goldmann prism

Note that this illustration is, for clarity, with the prism rotated 90° from its usual position in the instrument.

The flat, smooth left face of the prism is what presses on the cornea. The microscope looks from the right.

In fact, the "head" that consists of the prism in a housing is usually described as just the "prism".[1]

The prism divides the field of view in half (normally about a horizontal line) and effectively displaces the two parts of the view, as seen, laterally by 1.53 mm each (in opposite directions), for a separation of 3.06 mm. Each part of the view contains a semicircle of the fluorescent outline.[2]

If the diameter of the flattened area (and thus the inner diameter of the luminous cycle) is 3.06 mm, the inside of the right end of the upper semicircle will align with the inside of the left end of the lower semicircle.

We see that in figure 3 for the situation in which the flattened region in fact has our "reference" diameter, 3.06 mm. The black line represents the meniscus.

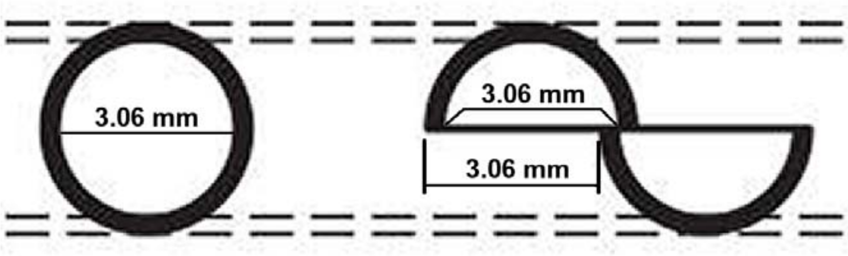

Figure 3. Meniscus ring split by prism

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[1] Or sometimes the "cone", from the typical overall shape of the "head".

[2] These are known technically as "mires", that word being often used in the field of ophthalmic instruments to mean some feature in the operator's view that is to be somehow aligned to make a measurement.

On the left we see the meniscus as it is, in particular when the diameter of the flattened region (the inside diameter of the meniscus) is exactly 3.06 mm; the cornea has been flattened to our “reference” diameter.

On the right we see the image of the meniscus as seen through the prism system. The upper dimension of 3.06 mm is again the inside diameter of the meniscus; the lower dimension of 3.06 mm is the (fixed) offset between the two images from the prism system. Thus we see that for the desired flattening of the cornea, the alignment condition described above obtains.

That alignment condition having been attained by the adjustment of the pressure dial, the IOP is read directly from the dial.

In figure 4 we see drawings of what the images would be like for various settings of the pressure dial.

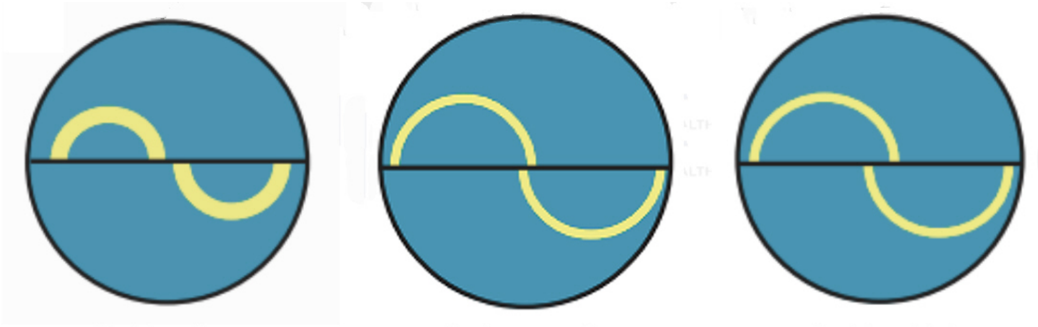
Set too low Set correctly Set too high

Figure 4. Mire alignment

Again note that the ideal setting is when the inside edges of the ends of the two mires align. That’s because it is the inside of the luminous meniscus that is at the edge of the flattened area.

Note that as the pressure dial is changed, the thickness of the mires changes. This is because for different amounts of displacement of the area being depressed, the angle of the corneal surface just outside that region changes, and thus the width of the meniscus (see figure 1).

Configuration and deployment of the tonometer

Before I discuss the actual configuration and deployment of the Goldmann Applanation Tonometer I must first introduce another instrument in the ophthalmologic arsenal with which the GAT often has a symbiotic relationship.

After the refractor, or “phoropter”, the most important instrument in an ophthalmological “lane” (an ophthalmologist’s “work station”) is the *slit lamp instrument* (usually called just a "slit lamp", and sometimes called a "slit lamp biomicroscope").

The apparatus is mounted on an articulated arm so that it can be moved to be properly aligned with the patient's head (and thus eyes). It has a frame with a chin rest and head rest to complete and maintain this alignment. The apparatus itself revolves around a variable-power binocular microscope, through which the ophthalmologist can examine the eye extensively.

But the component that gives this instrument its name is a special lamp mounted on a swing arm. It can be set to give beams of light of various configurations, but in the mode that gives it its name a *slit aperture* results in a beam that is essentially a thin vertical sheet of light. By swinging the lamp on its arm, the angle of arrival of the sheet of light at the eye can be varied. This whole arrangement allows the ophthalmologist to make many determinations of the geometry of all parts of the eye and to discern many properties that have to do with the health of the eye.

This process itself, though fascinating, is beyond the scope of this article. Rather, what is of importance to us is that the most common implementation of the Goldmann Applanation Tonometer is as an accessory mounted to the slit lamp instrument. In that way, the existing head frame will serve to properly locate the apparatus with respect to the patient's head (and thus one eye or the other), and the GAT optical system can be observed through the existing binocular microscope (usually through one eyepiece only). Additionally, the eye is illuminated (slightly from the side) by the slit lamp proper.

In figure 5 we see a typical GAT of one style (*e.g.*, Haag-Streit AT-900) mounted on a typical slit lamp instrument.

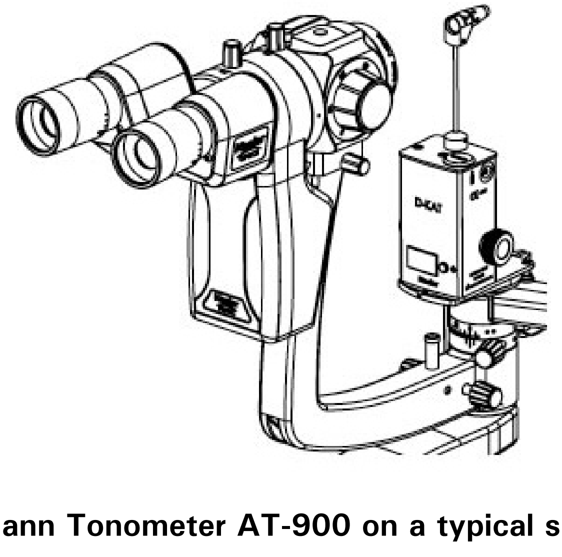

Figure 5. Goldmann Tonometer AT-900 on a typical slit lamp instrument

The arm that supports the slit lamp proper can be seen extending to the right just beneath the housing of the tonometer. In the actual use of the Goldmann instrument, it is swung to a position about 60° from the microscope axis to illuminate the cornea of the subject eye. When regular slit lamp examinations are made, the tonometer is swung out of the way.

In this style of tonometer the *prism* that presses on the cornea is atop a vertical *prism arm*[3]. The torque is provided on the prism arm by a torsion hairspring which is tensioned by the IOP dial. This is a straightforward mechanism, but is somewhat susceptible to drift of calibration over time as the properties of the hairspring change with age.

A more elaborate (and I think earlier) form of the GAT (*e.g.*, Haag-Streit AT-870) is seen in figure 6.

Figure 6. Goldmann Tonometer AT-870

In this style, the *prism* that presses on the cornea (seen at the bottom) is on a more complicated-looking *prism arm*. The arm can be swung up to clear the area when regular slit lamp examinations are done. There are two rubber-coated prongs on the far side of the housing between which the flat "extension" of the prism arm can be placed when the arm is "parked".

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[3] Often called in the product literature the "feeler arm", or sometimes "cone arm"...

We see this in figure 7.

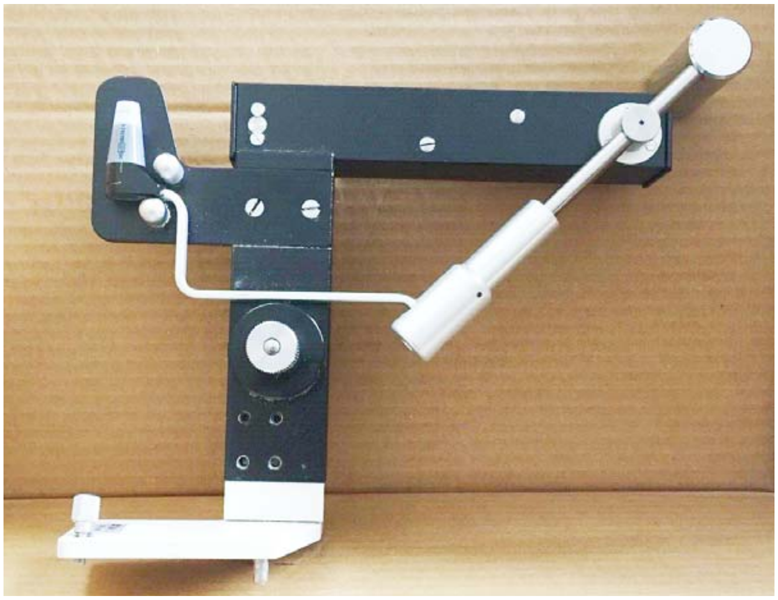

Figure 7. AT-870 tonometer with prism arm parked

The flat "extension" of the prism arm can be rotated about the cylindrical portion's axis to put it in the configuration we see and allow it to be moved between the two prongs.

Note that since the prism contains no electrical components, no wire leads are needed in the prism arm.

In this style of the instrument, the force of the prism on the cornea is controlled by an ingenious mechanism that does not rely on any spring for its operation, but which depends solely on gravity and the well-predictable geometry of the mechanism. In this way, the likelihood of a drift in the calibration of the instrument is minimized. Nevertheless, as we will see shortly, there is provision for adjusting the calibration, and a clever calibration scheme is used.

The operation of this mechanism is discussed in Appendix A, and the calibration procedures for both styles are discussed in Appendix B .

The effect of astigmatism

If the eye being examined is subject to substantial astigmatism, the geometry of the mires may be distorted with the result that a proper measurement cannot be obtained. To deal with this, the prism can be rotated so that the axis of division and offset of the image is rotated to nullify the effect of the astigmatism. The details of this are beyond the scope of this article.

Impact on the patient

Of course, while the Goldman prism presses on the cornea, the patient's reflexes would cause the patient to recoil, disrupting the measurement process. To avert this, a drop of a topical anesthetic (perhaps lidocaine) is instilled in the eye before the procedure. In common practice, for convenience a medication containing both the fluoroscein dye and the topical anesthetic is often used.

Sanitary considerations

In the past, prevention of the transfer of infection from one patient to another via the tip of the prism was averted by wiping the prism tip with a disinfecting wipe after the work for one patient is completed Today, more stringent measures are usually used. One approach is that the prism tip is covered with a cap with a thin transparent window (the actual prisms need to be made with this in mind). The cap is disposable, and is discarded and replaced after the work on one patient is complete.

In other cases, the prism assembly itself is easily replaceable within the prism housing, and is replaced after each patient.

Patent

It is considered that the definitive US patent on the Goldmann Applanation Tonometer is US 3,070,997, issued January 1, 1963 to Franz Papritz, Hans Goldmann, and Theodor Schmidt, assignors to Haag-Streit, A.G., of Switzerland. It describes an implementation of the GAT instrument conceptually like that of the Haag-Streit AT-870 tonometer, but rather different in detail.

THE PERKINS APPLANATION TONOMETER

The Perkins applanation tonometer is essentially a Goldmann Applanation Tonometer implemented as a small hand-held instrument. It is especially attractive for use with recumbent patients. It includes an LED-based blue-filtered light source and a forehead rest to assist holding it in the proper position with respect to the eye being examined.

We see a typical one in figure 8.

Figure 8. Perkins tonometer

The LED light source is in the two “spigots” below the prism head, and the light is re-distributed toward the eye via the transparent ring seen around the prism tip.

The entire prism assembly is replaceable for sanitary purposes.

THE iCare REBOUND TONOMETER

Introduction

The ICare rebound Tonometer is a convenient hand-held tonometer, made by Icare Finland Oy of Vantaa, Finland (formerly Tiolat Oy). We see the basic model, Model IC100, in figure 9.

Figure 9. iCare IC100 rebound tonometer

Principle and operation

In the instrument, a thin probe wire, magnetized at its “rear” end, carries a small plastic ball (1.8 mm diameter) at its tip. It resides in the “nose” of the instrument in a solenoid electromagnet. The attraction between the magnetized rear and of the wire and a ferromagnetic portion of the solenoid assembly holds the wire (somewhat weakly) in place so it will not fall out of the instrument pending the taking of a measurement.

When a measurement is to be taken, the electromagnet is energized, which drives the probe wire toward the cornea of the subject’s eye. The movement of the probe wire induces a voltage in in a secondary coil on the electromagnet, which phenomenon is used to observe the velocity of the wire.

When the ball hits the cornea, as it displaces the cornea, the reaction force causes the probe wire to decelerate, eventually coming to zero velocity and then to rebound from the eye. This velocity behavior is observed as described earlier, and as rebound begins, the electromagnet is energized in the opposite polarity, which smartly draws the wire back to its starting position.

The electromagnet is then de-energized, but the wire is again held (weakly) in place.

The reaction force can be computed from that velocity profile.

There has been determined a known relationship between the IOP, the mass of the wire and its velocity as it hits the cornea, and the reaction force on the tip of the wire. The IOP is calculated from those values.

In one mode, six measurements are automatically made in rapid succession. The highest and lowest are discarded, and the mean of the remaining four is reported as the IOP. The standard deviation is also calculated and reported, and if it is too great, the result is marked as questionable.

Sanitary provisions

The probe wire is small, light, and relatively inexpensive. When the work for one patient is complete, the probe wire can be easily withdrawn against the modest magnetic retaining force and discarded, and a new (sterile) one put in its place for use on the next patient. It will be held in place by the modest magnetic force so it will not fall out of the instrument.

Other features

At the top of the instrument is an adjustable forehead post used to control the distance of the instrument from the patient’s head (and thus to the eye under measurement). Figure 10 shows this in operation.

Figure 10. iCare IC100 in use

The instrument judges whether it is at an appropriate distance from the eye and whether it is properly centered on the eye. The instrument nose emits a circle of light to help in this aiming. It is red if proper centration has not yet been attained and green if it has.

In the figure we see a reported IOP value of 18 mm Hg. (For reference, typically an IOP of over 22 mm Hg is considered worrisome with respect to concern over glaucoma.)

Since the contact of the ball on the probe wire with the cornea is fleeting and of low energy, the patient hardly notices it (if at all), and so it is not normally necessary to use a topical anesthetic to prepare for testing with this instrument.

But what about kitties and puppies?

A special version of the instrument, the TonoVet, is for use with dogs, cats, rabbits or horses, for whom we are also concerned with the risk of glaucoma. In figure 11 we see this instrument in use.

Figure 11. iCare TonoVet veterinary rebound tonometer

The forehead rest with which this instrument is provided is usually not relevant in this context.

Use on recumbent patients

One might at first think that an advantage of this instrument is that it could be handily used on a recumbent patient (perhaps in bed in hospital), but in fact, if the axis of the instrument is not nearly horizontal, the force of gravity on the wire corrupts the measurement.

But that effect could be compensated for it we knew the angle of the instrument axis from the horizontal when each measurement is taken. An advanced model of the instrument, the IC200, has an attitude sensor to determine that angle, and makes the necessary compensation so that the instrument can be used on a recumbent patient. We see it in use in figure 12.

Figure 12. iCare IC200 rebound tonometer and recumbent patient

Patent

It seems likely that the definitive US patent on the basic iCare rebound tonometer is US 6,093,147, issued July 25, 2000 to Antti Kontiola of Helsinki. Finland.

My own experience

I recently had an extensive ophthalmological examination in anticipation of having cataract surgery. When the ophthalmological technician, ready to determine my IOP, reached to pull over the slit lamp instrument in the lane we were in, she realized that the Goldman Applanation Tonometer with which is was normally equipped was gone (perhaps taken away for maintenance). “No problem” she said, and went off to fetch a lovely iCare IC100, with which she quickly made the needed measurement. (I came in at 12 mm Hg.)

It was this incident, by the way, that provoked the writing of this article.

OTHER TONOMETRY SYSTEMS

Introduction

Over the years many ocular tonometry systems have been developed and implemented in commercially-available instruments. Here I will describe briefly two of those systems.

Indentation tonometers

In an indentation tonometer, a probe with a rounded end is pressed against the cornea with a known force, causing an indentation to be made in the cornea. The instrument measures the travel of the probe beyond the point at which it would contact the (yet undisturbed) cornea to the point at which it settles having made the indentation in the cornea.

There has been established a relationship between the force applied and the depth of the indention and the intra-ocular pressure.

A practical tonometer based on this principle was first devised by Hjalmar Schiøtz of Norway in about 1905, and Schiøtz tonometers were widely used prior to the instruction of the Goldmann Applanation Tonometer. We see a typical Schiøtz tonometer in figure 13.

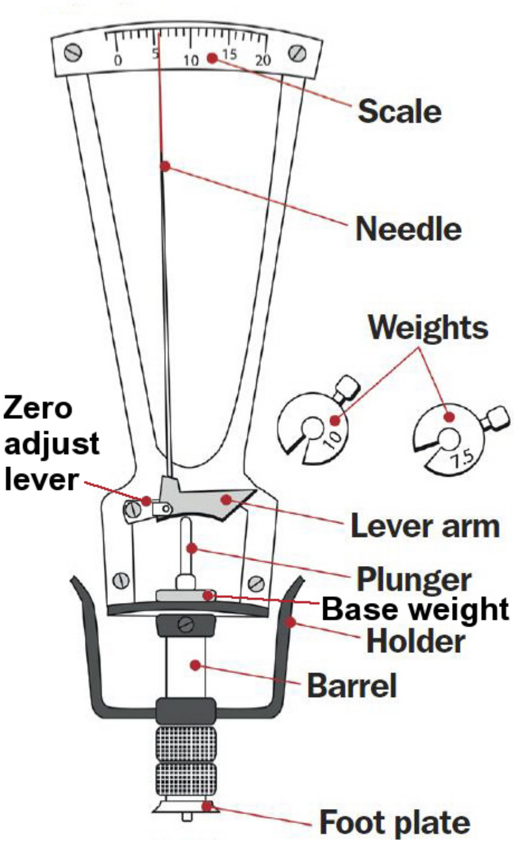

Figure 13. Schiøtz tonometer

The mechanism has a cylindrical *barrel* that slides freely in a cylinder on the *holder*, by which the practitioner holds and positions the instrument. The lower end of the barrel terminates in a concave *foot plate,* which will rest on the eye.

With the instrument "in the clear", the lower end of the plunger (essentially flat at its end) protrudes through the footplate. The weight of the plunger, including that of a base weight mounted to the plunger, plus the effect of the needle and its lever arm, makes the plunger have an effective weight (and thus force on the plunger) of 5.5 gm.

In use, with the patient supine, the instrument (still vertical) is positioned so the footplate is in contact with the front of the eye.

The cornea will push back on the protruding tip of the plunger. The amount by which the plunger still protrudes from the footplate, an indication of the depth of the indentation made in the cornea by the force of the plunger, is indicated by the needle on the scale, which is calibrated in arbitrary units. Each 0.05 mm of plunger travel leads to a difference of one unit on the scale.

Then a table is used to convert this reading to the IOP.

To allow the necessary range of IOP values to be covered, there are two supplementary weights that can be placed on the plunger so that the total effective plunger weight becomes 7.5 grams or 10.0 grams. Other columns of the table are used for these plunger weights.

When it became available, the Goldmann tonometer was more attractive than the Schiøtz instrument for general use because it did not require the patient to be supine during the procedure, and because the contact of the Goldmann prism on the eye was less obtrusive than the contact of the Schiøtz footplate and plunger.

To confirm and adjust the zero setting of the instrument, it is put in contact with a test pad, a metal “dummy eye”. Its configuration is such that the pointer should then read zero. If not, the pivot of the pointer can be shifted by moving the *zero adjustment lever* until a reading of zero is attained.

There is no need for calibration of the actual non-zero reading since the force-applying system is based on the weights of the plunger and related mechanism, which should not be subject to variation over time, and the ratio between plunger movement and pointer deflection is a property of the dimensions of the mechanism, which again should not be subject to variation over time.

Non-contact (air puff) tonometers

In this type of instrument, a carefully controlled brief puff of air is directed at the cornea, causing it to momentarily flatten slightly. The degree of flattening is observed by a subsystem employing infra-red light. There has been established a relationship between the potency of the air puff, the degree of flattening, and the intra-ocular pressure.It might seem that this approach is highly attractive because of the lack of need for anesthesia of the eyes (and, in the case of the Goldmann tonometer, the need to apply fluorescent dye). Nevertheless, this type of instrument is seemingly less used today than the Goldmann Applanation Tonometer or the iCare rebound tonometer.

Appendix A

Mechanism of the Haag-Streit Goldmann Applanation Tonometers

AT-870 tonometer

Here. the prism is suspended on an arm (the *prism arm*) supported by a ball bearing so that the arm may, of itself, swing freely with little friction. A counterweight on the top of the prism arm is intended to balance out the weight of the prism arm proper and prism so that, absent any force on the prism arm, it will be in neutral equilibrium.

A "carriage" inside the housing is arranged to move vertically under control of a knob which carries a dial with markings for the indicated IOC. The carriage contains an L-shaped lever whose horizontal limb carries a weight and whose vertical limb presses, horizontally, on a *pressure pin* that bears on an arm inside the housing that is a proxy for the prism arm. We can think of it as being on the same shaft as the prism arm, but actually it is on a shaft at a different location but linked to the prism arm shaft. The result is to impose a torque on the prism arm which translates into a force of the prism against the cornea.

The force applied to the support arm by the pressure pin is constant (a function of the weight and the geometry of the L-shaped arm), but the radius of the proxy arm at which it is applied is determined by the height of the L-shaped arm. This is changed by the knob, which moves vertically the carriage supporting the L-shaped arm. Thus the torque on the proxy arm, and thus on the prism arm, and thus the force applied by the prism on the cornea, is varied as the knob is turned.

Since the shaft turned by the knob to move the carriage carries a dial, the force on the cornea can be read from the markings on that dial. Actually, the markings take into account the relationship between the force on the cornea needed to produce the "reference" flattening and the intra-ocular pressure, so the dial is actually marked in terms of the indicated IOP.

AT-900 tonometer

Here the torque is provided on the prism arm by a torsion hairspring which is tensioned by the IOP dial. This is a much-more straightforward mechanism, but is perhaps more susceptible to drift of calibration over time as the properties of the hairspring change with age. I do not have further details of the mechanism of the AT0900 tonometer.

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Appendix B

Calibration of the Haag-Streit AT-870 and AT-900 Goldmann Applanation Tonometers

The AT-870 style tonometer

Introduction

With this mechanism, to allow the calibration of the instrument to be brought very precisely to the proper state, the weight on the L-shaped arm may be, after loosening its mounting screw, moved along the length of its limb (the horizontal limb) of the L-shaped arm, thus varying the force that will be predictably applied by the pressure pin driven by the vertical limb of the L-shaped arm, and thus the torque applied to the proxy arm and thus ultimately on the prism arm for any given setting of the knob.

But how can we measure the force created on the prism for some setting of the knob, so we can see if we have that calibration adjustment is made properly?

First, for reference, figure 14 shows the top end of the *prism arm*.

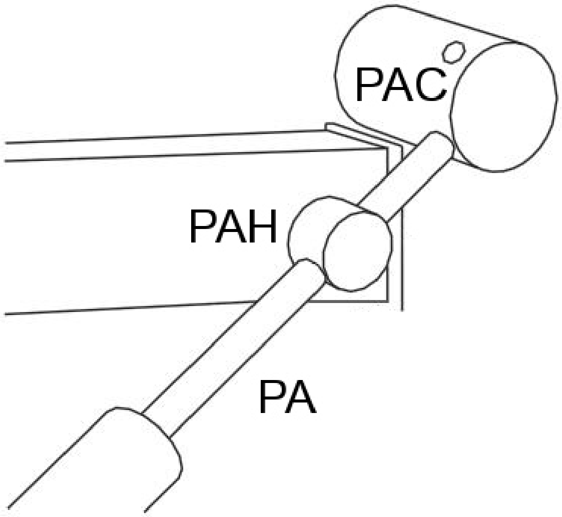

Figure 14. Top end of prism arm

PA is the *prism arm* itself and PAC is the *prism arm counterweight*. As mentioned earlier, it is intended to balance out the weight of the prism arm proper so that, absent any force on the prism arm, it will be in neutral equilibrium. It is held on the top end of the prism arm proper by a setscrew (we see the outside of its hole), and if that is loosened, the counterweight can be moved along the prism arm to perfect that balance.

PAH is the *prism arm hub*, from which a short shaft runs into the ball bearing that supports the *prism arm*, and which is linked to the *prism arm proxy arm* inside the housing.

Calibration procedure

Now, on to the calibration procedure itself.

Firstly, we test that the "zero" of the instrument is correct. We set the dial so that it reads "0". Than, the prism arm should happily sit midway between its two stops.

If not, we adjust the position of the counterweight on the top end of the prism arm until that situation obtains.[4]

Next, we ascertain that the setting of the weight on the L-shaped lever is such that the dial correctly reads the indicated IOP.

To do this, we attach the hub of a *calibration rod* over the hub of the prism arm (at which the prism arm is suspended in its ball bearing). I suspect it is held in place by a friction clip of some sort. We see this in figure 15.

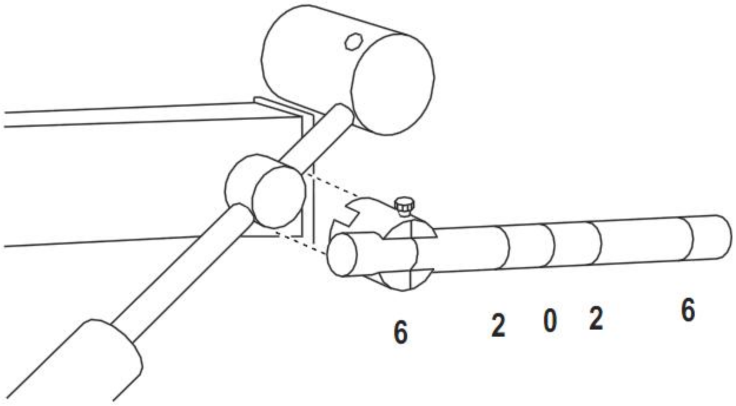

Figure 15. Calibration arm with type AT-870 tonometer

It has a a number of accurately-positioned engraved marks, and it can be moved through its hub until the desired mark aligns with a fiducial mark on its hub.

With the prism arm in the center of its (small) travel. the calibration arm will be horizontal.

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[4] Actually, in the formal procedure, the dial is set to two specified positions at equal small distances from the zero mark, at each of which the arm should rest against one stop or the other.

By setting the calibration arm in its hub to any of the marked positions, it can be made to impose several standardized torque values on the prism arm.

With the arm at a certain setting (there are marks for 2 and 6 mm Hg), we can adjust the position of the weight on the L-shaped arm until the IOP dial shows the matching value when set so that the prism arm hangs happily in mid-stroke.[5]

The mark "0" is to provide for setting the "zero balance" of the instrument with the calibration rod in place, if that best fits in with the calibration scenario.

The marks "2" and "6" on the right portion of the calibration rod are for use in the calibration of the AT-900 style tonometer.

The AT-900 style tonometer

Introduction

Here I have no information as to how to adjust the zero balance or calibration, only how to check them.

Checking the zero balance

Essentially, the dial is set to zero and we check to see that the prism arm is happily between its travel stops. (Actually . . .)

Checking the calibration

Again we use the calibration rod, this time with a different "hub", one with a short shaft which enters a test port on the unit and engages the shaft on which the prism arm pivots. We see this in Figure 16.

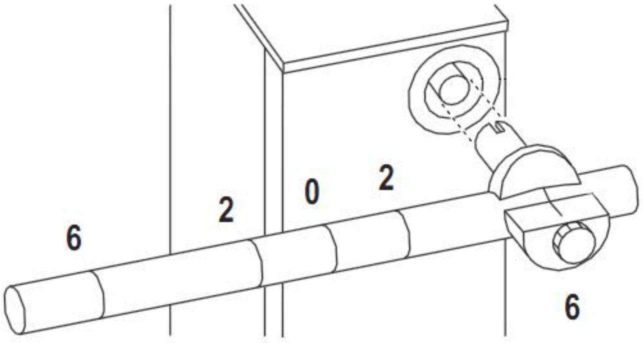

Figure 16. Calibration rod on AT-900 style tonometer

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[5] Again, in the formal procedure, the dial is set to two specified positions at equal small distances from the 2 or 6 mm Hg mark, at each of which the arm should rest against one stop or the other.

We set the rod so that the line marked 2 or 6 align with the fiducial mark on the test rod hub. We then set the IOP dial to the corresponding value and verify that the prism arm is happily between its travel stops. (Actually . . .)

The mark “0” is to provide for setting the “zero balance” of the instrument with the calibration rod in place, if that best fits in with the calibration scenario. The marks “2” and “6” on the left portion of the calibration rod are for use in the calibration of the AT-870 style tonometer.

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