

BENCH TO BEDSIDE



WHAT IS THE REAL IOP?

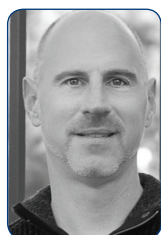
Laboratory studies may help us better understand our clinical dilemmas.

BY DAN EISENBERG, MD

It is not uncommon for a patient to experience glaucomatous progression despite apparently “normal” or seemingly controlled IOP. The opposite may occur as well: a patient whose IOP is higher than average never seems to develop glaucomatous optic neuropathy. Importantly, the measured IOP, such as that obtained with a Goldmann applanation tonometer (GAT), may not be as “true” as the eye care provider thinks. This creates concern in both the doctor and the patient. We asked three investigators three questions regarding this complex issue with the hope of better understanding “true” IOP.

In the second installment of this three-part series, Dr. Eisenberg addresses the challenges surrounding IOP measurements. In addition, he discusses the pros and cons of various tonometers and why the pneumotonometer is his go-to device for measuring IOP.

—Ronald L. Fellman, MD, and Davinder S. Grover, MD, MPH, section editors



The standard for IOP measurement continues to be the GAT. Please explain how this device works and why it may not be the best way to measure IOP.

The GAT belongs in the constant-area applanation family of tonometers. It works by flattening a defined area of the central cornea using a variable force. The amount of pressure needed to flatten the area is used to estimate the IOP by a linear formula. Several important issues present challenges when using this instrument. First, the primary calibration curve used to generate the formula was based on normal cadaver eyes with normal corneal thickness in a normal range of IOP. This means that the GAT works best on the eyes that need it the least. Deviations from normalcy such as corneal abnormalities, extremes of corneal thickness, and extremes of IOP—especially on the higher end—are outside the bounds of the formula and cause large underestimations of true IOP. This problem has been demonstrated in manometric studies using the direct measurement of IOP via direct cannulation.¹

The best situation for the GAT exists in a laboratory with a cadaver eye and controlled manometric IOP. Real clinical measurements add operator error, operator experience, heartbeat pulsation, respiratory pulsation, patient movement, physician movement, and variable fluorescein concentrations, among other potential sources of error.²

The endpoint of measurement is subjective and prone to operator bias. Studies using the GAT require a masked observer

to read the result independent from the operator because of this bias. Putting it all together provides a picture of a relatively poor method of measuring pressure in glaucomatous eyes. The GAT is a good tonometer for normal eyes, but this is mostly irrelevant. The instrument has also been shown to grossly underestimate IOP in young children and after LASIK and PRK. It is unusable in severely obese patients or those with neck restrictions. It cannot be used after penetrating keratoplasty or in the presence of nystagmus, severe corneal scarring, or keratoprosthesis. The GAT is most unreliable when it is most needed.

We are learning that corneal biomechanics may affect IOP measurements and may be related to the risk that glaucoma will develop and progress. Can corneal hysteresis help us better understand IOP measurement and the eye’s response to elevated IOP? Please explain corneal hysteresis. Will cornea-correlated IOP measured with the Ocular Response Analyzer G3 (ORA; Reichert), which takes corneal biomechanics into consideration, become the new standard for IOP measurement?

Hysteresis is a term used in electronics to describe the difference between activation and deactivation of a relay switch. As voltage is increased, the relay will switch on. As voltage is decreased, the relay will switch off, but it will do so at a lower voltage than the initial on voltage. The gap between the on and off voltages is the hysteresis of the relay. The ORA and other air-puff tonometers belong to the category of dynamic

applanation. They employ a variable force and measure a constant area, similar to the GAT, but do so rapidly with accelerated air. The mathematics may be similar in that the force of air required to flatten a defined area is used to estimate the IOP, but there is no other similarity to the static Goldmann method. The dynamic system allows the determination of two time points of flattening: the first during initial posterior movement of the cornea and the second on the rebound to normal shape. The difference in estimated IOP between the two time points is considered to be the corneal hysteresis. It is not the same concept as electrical hysteresis but more of a thematic analog, because nothing is turned on or off, and the corneal movement is continuous. The theory is that this hysteresis value somehow relates to the intrinsic corneal structure, and this may also be related to the risk of glaucomatous progression.

The challenge of corneal hysteresis results from the inherent properties of the cornea, which is like a non-Newtonian fluid. Some have called it “viscoelastic,” which is a good description. The field of rheology—the science and study of the flow of complex fluids like viscoelastics—likely applies more to the dynamic measurement of the cornea than static tonometry physics. A typical measurement with a rheometer produces response curves because the results change as the conditions change, creating a nonlinear 3-D space of results. A cornea has several features that might alter hysteresis such as hydration status, thickness, curvature, and IOP. The shape of the force-time curve of the air puff could also change the hysteresis results.

A large correlation study found that corneal hysteresis is influenced by age, corneal thickness, and IOP.³ This presents a problem for measuring and interpreting a result, because so many different factors interact. It does not seem reasonable to represent all of these factors with a single hysteresis number, and it certainly makes it difficult to understand a single hysteresis number, given the many unreported variables. It may not even be possible to measure all the relevant factors that alter corneal hysteresis. I am open to research on the topic. I would caution colleagues, however, that any evaluation of corneal hysteresis should consider controls for known covariates of corneal hysteresis, and even that is likely a gross oversimplification.

I remain unconvinced at this time that hysteresis is of value in the management of glaucoma. There are also no manometric studies of the IOP measurement by the ORA instrument to my knowledge. Without in vivo manometry, there cannot be a definite answer regarding accuracy. Studies of tonometer versus tonometer are unacceptable in determining instruments’ accuracy because of the confounding effect of each device’s errors.

Until we have the best way to measure IOP, how do we obtain the most accurate IOP?

There are more than 3 decades of literature on the Model 30 Pneumatonometer (Reichert), which provides a user-independent reading. The device uses an airflow resistor to

measure a constant area with variable force, similar to the GAT, but the operator’s skill does not change the outcome, unlike with the GAT. The Model 30 can accurately estimate IOP in children, people with nystagmus, and patients who are either seated or supine. It avoids the chest compression artifact that can occur with obesity, is unaffected by LASIK or refractive surgery, can estimate IOP after keratoplasty surgery, and can estimate IOP through a soft contact lens. It is the only commercially available method that can applanate the sclera to obtain a reasonably accurate estimate of the IOP, which is useful in situations with severe corneal scarring and postkeratoprosthesis.⁴

The only reasons not to use the instrument are its cost and the need for electricity. The device does overestimate IOP in cases of single-digit pressures, and it also underestimates very high IOP, but much less so than the GAT.¹ I have used pneumatonometry exclusively in my practice for the past 18 years.

The Pascal Dynamic Contour Tonometer (Zeimer Ophthalmic Systems) would be my second choice and is also more accurate than the GAT.⁵ Like the Model 30, the Pascal provides a user-independent reading. Unlike the GAT or the Model 30, it uses a constant force and measures a variable area via a high-precision pressure transducer. This is a modern descendant of the Maklokov tonometer. The Pascal is limited to slit-lamp position with a reasonably normal cornea. The device cannot work through a contact lens or with nystagmus, severe corneal scarring, a corneal transplant, or keratoprosthesis, but it has been shown to be uninfluenced by LASIK.⁶ ■

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