How Should We Measure IOP After LASIK?

New "smart" tonometers compensate for corneal biomechanics and offer alternatives to standard Goldmann applanation tonometry.

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Soon after the excimer laser was first utilized commercially for laser vision correction, an editorial was published predicting the future impact refractive corneal surgery might have.[1] This article identified three areas: (1) the measurement of IOP; (2) the calculation of IOL power; and (3) the identification of postsurgical corneas contaminating the eye bank donor pool. As we approach the 10th anniversary of the excimer laser's FDA labeling, these issues have come to the forefront of discussion and continue to challenge ophthalmologists today.

THE INFLUENCE OF CORNEAL BIOMECHANICS ON IOP MEASUREMENTS

Why is it important to understand corneal characteristics when determining a patient's risk for glaucoma? Many of the standard tests used to assess glaucoma risks, such as laser polarimetry and tonometry, are filtered through the optical[2] and biomechanical[3] properties of the cornea. The biomechanical properties (eg, pachymetry, hydration, viscoelasticity, etc.) can profoundly change following LASIK flap creation and/or laser ablation, which affects the measurement of IOP postoperatively.

Ophthalmologists have appreciated the positive relationship between central corneal pachymetry and IOP measurement for many years, and the Ocular Hypertension Treatment Study recently showed an inverse correlation between an individual's central corneal pachymetry and his risk of developing glaucomatous damage.[4] Some investigators have tried to "correct" the measurement of IOP using linear algorithms. However, the basis of any linear correction of IOP is unfounded, because the positive correlation between IOP measured with Goldmann applanation tonometry (Haag-Streit, Bern, Switzerland) and central pachymetry is very weak ($R^2 \approx 0.17$).

Corneal biomechanics reflects more than central pachymetry. For example, IOP, as measured by Goldmann applanation, generally drops following a number of surgeries (eg, RK and hyperopic LASIK) where there is little change in central pachymetry but profound changes in corneal rigidity. Conversely, patients with Fuchs' dystrophy generally have thick corneas, but they are less rigid and generally show lower Goldmann readings. Therefore, simplistic attempts at a linear "correction" of Goldmann tonometry based on central pachymetry could be in the wrong direction in select cases. The more accurate measurement of IOP will require instruments that perform dynamic, rather than static, applanation measurements and therefore assess and compensate for corneal biomechanics in this metric. These considerations become particularly important in patients who undergo corneal

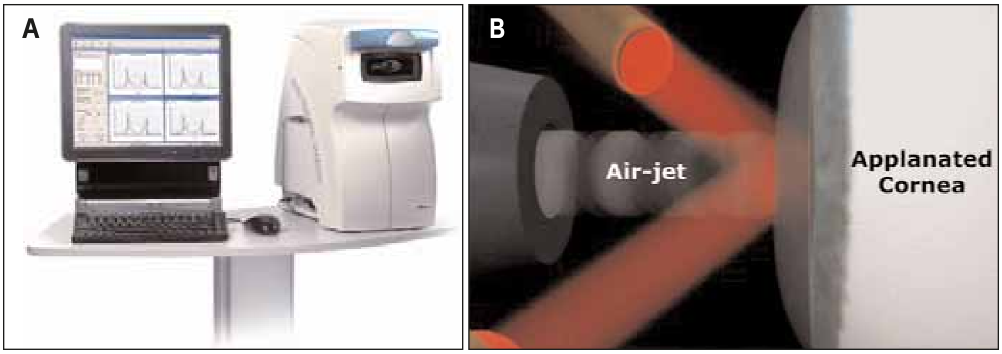

Figure 1. The Ocular Response Analyzer (A) uses a collimated air pulse to applanate the cornea, along with an infrared electro-optical detection system (B).

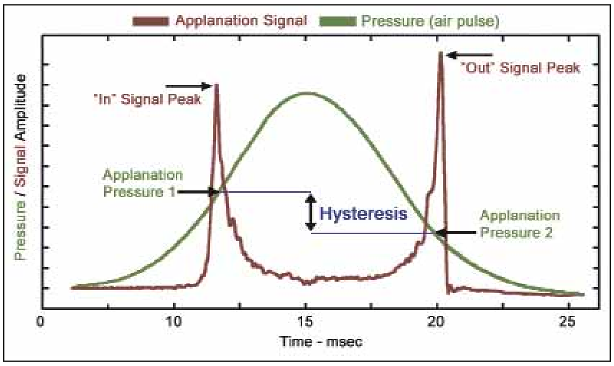

Figure 2. The difference in the pressure required to produce the "inward" applanation and "outward" applanation events is called *corneal hysteresis*.

surgery (eg, LASIK or penetrating keratoplasty) or who have corneal pathology (eg, keratoconus, pellucid marginal degeneration) where both corneal thickness and rigidity vary.

MEASURING IOP

Standard of Care and New Devices

Although generally considered the industry standard for measuring IOP since its introduction in 1955, Goldmann applanation tonometry relies upon a number of assumptions that are not universally valid (eg, that the corneal surface is infinitely thin and perfectly flexible). Another limitation to Goldmann tonometry, especially with respect to patients who have undergone LASIK, is that it is calibrated according to the assumption that all corneas are of a uniform thickness (ie, 500µm).

Two newer devices that have the potential to perform dynamic, rather than static, applanation measurements to compensate for individual corneal biomechanics are the Ocular Response Analyzer (Reichert, Inc., Buffalo, NY) and the Pascal Dynamic Contour Tonometer (SMT Swiss Microtechnology AG, Port, Switzerland). These devices may minimize the effects of corneal refractive surgery—where not only corneal thickness has changed, but corneal rigidity has been affected by flap creation and/or laser ablation—on IOP measurements.

The Ocular Response Analyzer

The Ocular Response Analyzer (Figure 1) delivers a metered collimated air pulse to the cornea, which results in a deformation through the initial applanation and beyond into concavity. The cornea then rebounds through a second applanation event. The inward and outward applanation events are recorded by a sensitive, infrared electro-optical detection system. Data are collected throughout the entire dynamic process and sent to a computer, which then creates a graph with two peaks representing corneal movement. Applanation is reached and specifically plotted along each peak.

The difference between the air-pulse pressures at the two applanation events is what is known as corneal hysteresis and is a reflection of the viscoelastic characteristics of the cornea (Figure 2). The instrument gives an IOP-G reading, which is closely correlated with Goldmann tonometry. A regression analysis of the IOP-G of nonglaucomatous, glaucomatous, and postrefractive populations of patients allows the conversion of IOP-G to IOP-CC, or cornea compensated Ocular Response Analyzer IOP. IOP-CC takes into account the differential effect of altered corneal biomechanics on the two applanation pressures and is less sensitive to the effects of corneal refractive surgery.

The Pascal Dynamic Contour Tonometer

The Pascal Dynamic Contour Tonometer (Figure 3) utilizes a curved tip to match the corneal surface, thereby minimizing corneal distortion. This device is based on Pascal's Law of Pressure, which states that pressure applied to a confined fluid is transmitted undiminished throughout the confining vessel of the system. The concave shape of the tip generates minimal corneal distortion and theoretically eliminates errors in measuring IOP induced by ocular rigidity when the cornea is applanated with a flat-tipped tonometer. The Pascal Dynamic Contour Tonometer is a slit-lamp–mounted device that is operated in a fashion similar to a Goldmann applanation tonometer. A microchip-enabled, solid-state sensor embedded within the tip records 100 IOP measurements per second and averages them over fluctuations in ocular pulse amplitude (ie, the range in IOP change during the cardiac cycle). Auditory

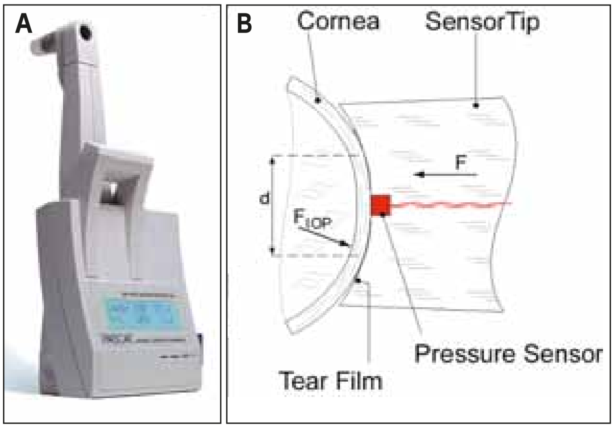

Figure 3. The Pascal Dynamic Contour Tonometer (A) utilizes the principle that, when the contours of the cornea and tonometer match, then the pressure measured at the surface of the eye equals the pressure inside the eye (B).

feedback provides the operator with instant clues about the quality of the measurements, and a digital display shows the final averaged IOP as well as a Q-value that may be used objectively to judge the quality of the final measurement.

Ease of Clinical Use

Both systems are objective, unlike Goldmann tonometry, and simple enough to use that technicians can quickly learn to operate them reliably. The advantages of the Ocular Response Analyzer include the rapidity and ease with which measurements are obtained (similar to standard noncontact tonometry). With a noncontact approach, corneal epithelial trauma or infectious disease transfer is not an issue. In addition to IOP, other information concerning corneal biomechanical properties is obtained (ie, corneal-resistance factor [reflecting corneal elasticity] and corneal hysteresis. These data may be used in the diagnosis and study of iatrogenic and pathologic corneal conditions, and they may be an adjunct to topography in a patient's risk assessment for the development of forme fruste keratoconus following LASIK.

A limitation of the Ocular Response Analyzer is that it requires a trained person to interpret the graphs. Another relative drawback is that the device takes measurements during a short period of time (a fraction of a second), so variations in ocular pulse amplitude are not considered. Confirmation of the extent of corneal compensation in the IOP-CC measurement is undergoing a prospective clinical evaluation.

One of the strengths of the Pascal Dynamic Contour Tonometer (which gathers multiple measurements during fluctuations in ocular pulse amplitude) is that it obtains a true average IOP measurement that is not subject to short-term fluctuations in IOP resulting from pulse pressure or other short-term variables. In a randomized comparative study (manuscript in preparation) of tonometers, the Pascal Dynamic Contour Tonometer showed the lowest percentage of absolute change in IOP pre- and post-LASIK. Other advantages of the Pascal Dynamic Contour Tonometer are its digital display, auditory clues during tonometry, and Q-value readings, which may increase the reliability and reproducibility of measurements. Single-use, disposable sensor caps limit the possibility of microbial transfer.

Disadvantages of the Pascal Dynamic Contour Tonometer include a defined learning curve for operating the device and the requirement for extended tonometer-to-cornea contact. The latter could lead to epithelial damage or microabrasions in less cooperative patients if the device is not used by a skilled staff member.

THE BOTTOM LINE

In the next decade, refractive surgeons will need to consider new ways to monitor IOP, especially as baby boomers approach an age of higher glaucoma risk and as more patients undergo LASIK surgery. The Ocular Hypertension Treatment Study demonstrated unequivocally that Goldmann applanation tonometry has limitations, and subsequent observations have shown that there is not a strong linear relationship between it and corneal thickness.[4]

In LASIK surgery, there are postoperative changes in corneal viscoelastic properties induced by laser ablation and flap creation. These new, objective methods to determine IOP appear to be more independent of corneal rigidity than Goldmann applanation tonometry. They may prove valuable for the long-term management of patients with glaucoma who have undergone corneal refractive surgery (as well as other corneal surgeries) and patients with corneal diseases as well as for the general screening of populations in which individual variations affect corneal rigidity. ■

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