The Ocular Response Analyzer

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INTRODUCTION

The Ocular Response Analyzer (ORA; Reichert Inc, Depew, NY) is a novel instrument for measuring the intraocular pressure (IOP) of the eye (Fig. 1). It is also the only instrument capable of measuring the biomechanical properties of the cornea. Corneal biomechanical properties influence intraocular pressure measurement, undergo alterations in corneal pathology and following corneal refractive surgery. Corneal Hysteresis (CH), which is the result of viscous damping in the corneal tissue, is a new indicator of corneal biomechanical properties.

PRINCIPLE

The ORA utilizes a dynamic, bidirectional applanation process for measuring IOP. A rapid air impulse is used to apply force to the cornea. The deformation of the cornea is monitored using an advanced electro-optical system. The precisely metered, collimated air pulse causes the cornea to move inwards causing applanation, similar to conventional noncontact tonometers. However, in the ORA, the air impulse continues to deform the cornea past applanation into slight concavity. Then, the air pump shuts off and, as the pressure decreases, the cornea begins to return to its normal configuration. During this process, it once again passes through an applanated state. The entire process takes only 20 milliseconds, a time sufficiently short to ensure that ocular pulse effects or eye position does not change during the measurement process. These deformation changes are monitored by the electro-optical detection system. Two independent pressure values are derived from the inward and outward applanation events. These two pressure values are not the same. Due to the dynamic nature of the air pulse, viscous damping (energy absorption) in the cornea causes delays in the inward and outward applanation events, resulting in two different pressure values (Fig. 2). The difference between these two pressure values is Corneal Hysteresis (CH). The average of these two applanation events provides a repeatable, Goldmann-correlated IOP measurement (IOPg).

METHOD OF OPERATION

The patient is seated in front of the machine and asked to fixate on a green light. The instrument has an innovative, automatic alignment system that eliminates operator subjectivity and provides precise, repeatable measurements. The system positions an air tube to a precise position relative to the apex of the cornea. The air pulse then applies pressure to the cornea.
Corneal deformation is recorded and measurement signals are obtained. The measurement signals consist of a green symmetric curve, which corresponds to the air pulse pressure, and a red asymmetric curve, which indicates the raw signal corresponding to the applanation of the cornea. The blue curve is a filtered version of the red curve, designed to identify the optimum point of applanation in less than ideal signals. The red curve has 2 principal peaks. The applanation pressure is determined by drawing a line down from the peak of each applanation spike to the intersection of the green pressure curve. These points, P1 and P2 are graphically indicated as blue squares on the green curve. P1 is the pressure at the first applanation event as the cornea moves inward under the increasing force of air pulse (inward applanation). P2 is the pressure corresponding to the second applanation event as the cornea returns to its normal curvature under the decreasing force of the air pulse (outward applanation). P2 is always lower than P1 due to Corneal Hysteresis.

The applanation signal curves may vary significantly in appearance from measurement to measurement. Ideally, the height of the applanation signals (spikes) will be above the green curve. Both spikes should have a clearly defined and relatively well-centered high point (peak). Such signals would generate highly reliable measurement results. Repeated measurements on the same eye should produce similar looking signals.

### Measurement Parameters

The ORA provides 4 different measurement parameters:

- **IOPg**: A Goldmann-correlated IOP value.
- **CH**: (P1-P2) A measure of viscous damping in the cornea.
- **IOPcc (Corneal-Compensated Intraocular Pressure)**: An intraocular pressure measurement that is less affected by corneal properties.
- **CRF (Corneal Resistance Factor)**: An indicator of the overall “resistance” of the cornea.

The ORA also has a built in 20 MHz ultrasound pachymeter that measures **CCT** - Central corneal thickness.

Corneal hysteresis is a function of the corneal viscous resistance (damping/energy absorption) properties. Corneal hysteresis is the difference between pressures P1 and P2, a numerical value denoting viscoelastic corneal tissue response to a dynamic deformation. A greater difference generates a higher CH, suggestive of a stiffer cornea. CH is influenced by the rate of force application and is likely linked to the stromal collagen nature and state of hydration. Normal values of CH and CRF measured in a recent study were 10.8 mm Hg ± 1.5 (SD) and 11.0 mm Hg ± 1.6 mm Hg respectively. Corneal resistance factor and IOPcc are calculated using a linear combination of P1 and P2. IOPcc measurement is designed to reduce the effect of corneal thickness and properties on the IOP measurement process, wherein the IOP has been adjusted utilizing the information provided by the corneal hysteresis measurement. CRF is derived from the formula P1 – kP2, where k is a constant, derived from the relationship between changes in P1 and P2, with change in IOP. CRF is more heavily weighted by corneal elasticity (static resistance).

### ORA IN GLAUCOMA

The influence of central corneal thickness (CCT) on intraocular pressure (IOP) measurements using Goldmann applanation tonometry (GAT) has been well-recognized. Intraocular pressure is overestimated in thick corneas or underestimated in thin corneas. However, it is likely that factors other than CCT, including corneal hydration, connective tissue composition, and bioelasticity, contribute to the response of the corneal-scleral shell, to the force applied during the measurement of IOP. The ORA provides IOP measurements taking into consideration these biomechanical properties of the cornea (Figs 3 to 5). IOPcc and IOPg have shown good correlation with GAT IOP measurements. GAT IOP measurements are significantly associated with CCT, whereas IOPcc measurements are not associated with any of the variables - CCT, corneal curvature, axial length, and age. The difference between GAT and IOPcc measurements is significantly influenced by corneal thickness. Patients with thicker corneas tend to have higher GAT IOP measurements compared with IOPcc, whereas in patients with thinner corneas, GAT IOP measurements tend to be lower than IOPcc. Variations of the elasticity of the cornea within a range predicted to occur in a normal population, was found to result in an error of IOP measurement as high as 17 mm Hg. Also, the influence of CCT on applanation tonometry readings was found to depend on the modulus of elasticity of the cornea. In a study by Congdon et al, lower corneal hysteresis value, but not CCT, was associated with visual field progression. In the study by Touboul et al, CH values were found to be lower in glaucomatous eyes than in normal eyes. CRF was higher than CH values in normal and glaucomatous eyes. True IOP was underestimated by Goldmann applanation tonometry in underdamped corneas and should be an interesting factor in glaucoma management.

### ORA IN CORNEAL PATHOLOGY

Clinical data has shown that the Corneal Hysteresis measurement is useful in identifying corneal pathologies and may be valuable in identifying potential LASIK (laser assisted in situ keratomileusis) candidates who are at risk of developing ectasia (Figs 6 to 8). In patients with Fuchs’ dystrophy, the cornea is thicker, but they are less rigid (lower CH) and...
generally show lower Goldmann readings. Eyes with keratoconus also have low CH values.\textsuperscript{1,11} CH was higher than CRF in eyes with keratoconus.\textsuperscript{1} Low CH and CRF were well-correlated with the weakest corneas and should be helpful in keratoconus screening as a new risk factor.\textsuperscript{1} In a study by Ortiz et al, it was found that higher the keratoconus grade, the lower the corneal hysteresis and corneal resistance factor values.\textsuperscript{12}

**ORA IN REFRACTIVE SURGERY**

Refractive surgery currently uses corneal thickness as a basic qualification and planning parameter.\textsuperscript{10,11} However, corneal hysteresis may be more useful as a qualification factor for LASIK and related corneal refractive surgery procedures because different subjects with the same corneal thickness may display significantly different corneal mechanical properties\textsuperscript{11} (Figs 6 and 7). A significant decrease in the IOP and biomechanical properties is found in eyes following LASIK surgery. In the study by Ortiz et al, corneal hysteresis and corneal resistance factor decreased significantly, one month post LASIK.\textsuperscript{12} The creation of the corneal flap, and corneal thinning caused by ablation weaken the cornea. A good correlation was observed between the corrected refractive defect and the change in biomechanical properties. Both IOPcc and IOPg showed a decrease after LASIK surgery. However, the decrease in IOPcc was much lower than the decrease in IOPg,\textsuperscript{12} suggesting that the IOPcc is a more accurate indicator of the true IOP.

**INTERPRETING ORA SIGNALS**

The morphological signal that is produced by the Ocular Response Analyzer is a unique “signature” for the eye being measured. Following are few typical examples.
The assessment of corneal biomechanical properties with the ORA is useful in evaluating the influence of corneal properties on IOP measurements. These new, objective methods of IOP measurement appear to be less dependent on corneal rigidity than Goldmann applanation tonometry. The clinical applications of this novel device range from corneal pathology diagnosis, pre-ectasia screening and post LASIK IOP measurement to glaucoma screening, diagnosis and treatment efficacy monitoring. The information obtained using this instrument is invaluable in appropriate, long-term management in these conditions.

REFERENCES


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“I learned this, at least, by my experiment: that if one advances confidently in the direction of his dreams and endeavors to live the life he has imagined, he will meet with success unexpected in common hours.”

—Thoreau