

## Corneal Hysteresis and IOPcc: Glaucoma Vitals for the Modern Era

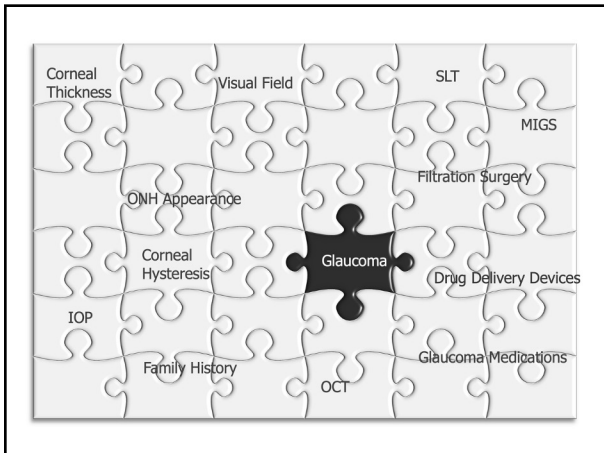
Nate Lighthizer, OD, FFAO  
Professor  
Associate Dean  
Director of Continuing Education  
Chief of Specialty Care Clinics  
Oklahoma College of Optometry  
[lighthiz@nsuok.edu](mailto:lighthiz@nsuok.edu)

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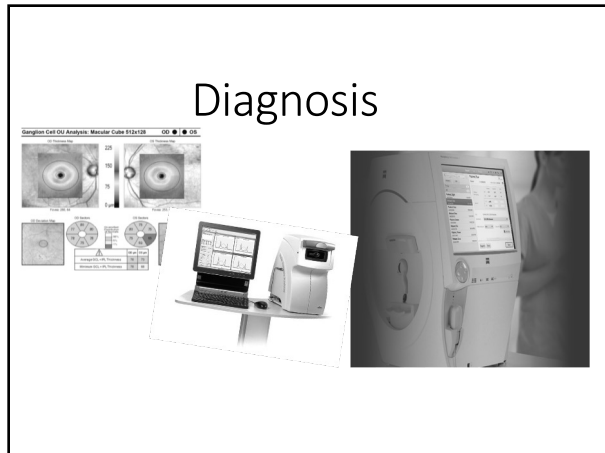
## Disclosures

- Aerie Pharmaceuticals
- Diopsys
- Ellex
- EyePromise
- iCare
- Ivantis
- Lumenis
- Maculogix
- Nidek
- Nova Oculus
- Novartis
- Optovue
- Quantel
- Reichert
- RevolutionEHR
- Sight Sciences
- Sun Pharma
- Triad Ophthalmics

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### Lowering IOP Reduces the Risk of Disease Progression

Study	IOP	Progression (Tx/No Tx)
OHTS <sup>1</sup>	20% reduction	4.4%/9.5% (5 years)
EMGT <sup>2</sup>	25% reduction	45%/62% (6 years)
CNTGS <sup>3</sup>	30% reduction	12%/35% (7 years)
CIGTS <sup>4</sup> (medicine)	≈35% reduction	No progression (5 years)
CIGTS <sup>4</sup> (surgery)	≈48% reduction	No progression (5 years)
AGIS <sup>5</sup>	< 18 mm Hg	No progression (6 years)
AGIS <sup>5</sup>	> 18 mm Hg	1.93 units (7 years)

1. Kass et al. Arch Ophthalmol. 2002; 2. Heijl et al. Arch Ophthalmol. 2002; 3. CNTS Study Group. Am J Ophthalmol. 1996; 4. Lichter et al. Ophthalmology. 2001; 5. AGS Investigators. Am J Ophthalmol. 2000.


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### Target pressure rules of thumb:

- Early POAG and ocular hypertension: Reduction of 25-30% from high IOP reading
  - OHTS, EMGT, CIGTS
- Moderate POAG: 35% or more reduction; no higher than 18 mmHg
  - AGIS, CIGTS
- Severe POAG: no higher than 15 mmHg and optimally 10-12 mmHg
  - AGIS
- Always exceptions! And the target is not set in stone

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### Recognizing Mild or Early Stage Glaucoma



Optic nerve abnormalities associated with glaucoma

But NO visual field abnormalities on any visual field test


OR abnormalities present only on short-wave-length automated perimetry or frequency doubling perimetry

• Current ICD-10 Glaucoma Reference Guide

Source: American Academy of Ophthalmology  
American Glaucoma Society

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### Moderate Stage Glaucoma



Optic nerve abnormalities consistent with glaucoma

AND glaucomatous visual field abnormalities in ONE hemifield and

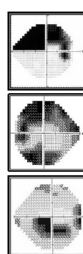
NOT within 5 degrees of fixation

• Current ICD-10 Glaucoma Reference Guide

Source: American Academy of Ophthalmology  
American Glaucoma Society

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### Advanced, Late, Severe Stage Glaucoma



Optic nerve abnormalities consistent with glaucoma

AND glaucomatous visual field abnormalities in BOTH hemifields

AND/OR loss within 5 degrees of fixation in at least one hemifield

• Current ICD-10 Glaucoma Reference Guide

Source: American Academy of Ophthalmology  
American Glaucoma Society

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### Target pressure rules of thumb:

- Early POAG and ocular hypertension: Reduction of 25-30% from high IOP reading
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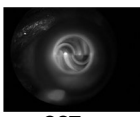
## Corneal Hysteresis

A Piece to the Glaucoma Puzzle?

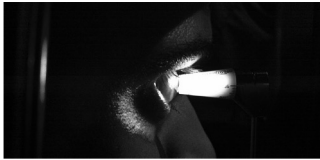


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### Influences on IOP Measurement

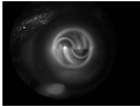


CCT




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### Influences on IOP Measurement



CCT

Post-Refractive  
Time of Day  
Medications



Physical Activity and Posture

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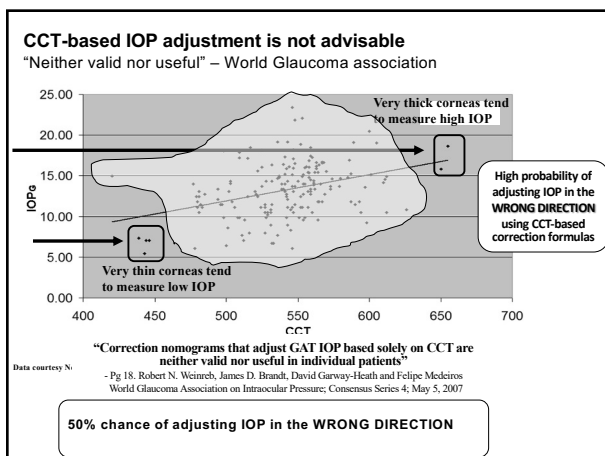
### Reducing the Corneal effect on Measured IOP

ORA's Patented IOPcc

- Goldmann and other tonometers provide *one number*, but this number is comprised of *two things*:  
IOP and cornea

**You can't measure two things with one number!**

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### CCT-based IOP adjustment is not advisable

From the OHTS

Published in final edited form as:  
Ophthalmology. 2012 March; 119(3): 437-442. doi:10.1016/j.ophtha.2011.03.018.

#### Adjusting Intraocular Pressure for Central Corneal Thickness Does Not Improve Prediction Models for Primary Open-Angle Glaucoma

James D. Brandt, M.D.<sup>1</sup>, Mae O. Gordon, PhD<sup>2,3</sup>, Feng Gao, PhD<sup>3</sup>, Julia A. Beiser, M.S.<sup>2</sup>, J. Phillip Miller, A.B.<sup>3</sup>, and Michael A. Kass, M.D.<sup>2</sup> for the Ocular Hypertension Treatment Study Group

<sup>1</sup> University of California, Davis, Department of Ophthalmology & Vision Science  
<sup>2</sup> Washington University School of Medicine, Department of Ophthalmology and Visual Sciences  
<sup>3</sup> Washington University School of Medicine, Division of Biostatistics

**Abstract**

**Purpose**—To determine if the accuracy of the baseline prediction model for the development of primary open-angle glaucoma (POAG) in ocular hypertension patients can be improved by correcting intraocular pressure (IOP) for central corneal thickness (CCT).  
**Design**—Re-analysis of the baseline prediction model for the development of POAG from the Ocular Hypertension Treatment Study (OHTS) substituting IOP adjusted for CCT using 5

Data courtesy New England College of Optometry

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### Reducing the Corneal effect on Measured IOP

ORA's Patented IOPcc


- Goldmann and other tonometers provide *one number*, but this number is comprised of *two things*:  
IOP and cornea

**You can't measure two things with one number!**

- How can we overcome the corneal influences?**
  - CATS
  - ORA/IOPcc

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### The Correcting Applanation Tonometer Surface (CATS)



British Journal of  
**Ophthalmology**

Modified Goldmann prism intraocular pressure measurement accuracy and correlation to corneal biomechanical metrics: multicentre randomised clinical trial @

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### CATS: Correcting Applanation Tonometry Surface "The New Shape" of Goldmann IOP

Invented by Sean McCafferty (Ophthalmologist / mechanical and optical engineer). FDA Cleared in 2018.

CATS is simply a replacement prism for the Goldmann applanation tonometer. The CATS prism utilizes a dual-curved contact surface to minimize corneal bending resistance and tear-film adhesion error factors.

**TRADITIONAL GOLDMANN PRISM**

- Flattens the Cornea
- Amplifying Intraocular Stress and IOP errors

**CATS™ TONOMETER PRISM**

- Reduces Tear Film Adhesion (Convex)
- Reduces Bending Resistance (Concave)

Sean McCafferty, MD

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### Goldmann vs CATS IOP Error Relative to True Intercameral IOP

- IOP measured with a CATS and GAT prism on 58 eyes undergoing cataract surgery
- Pressure set to 10, 20, and 40 mmHg, monitored with intercameral transducer
- CATS and GAT difference from true IOP correlated to error parameters (CCT and CH)

Average GAT and CATS IOP Measurement Error from True Intercameral pressure in Thin Corneas (CCT<530 microns) in Vivo (95%CI)

- Significant underestimation in GAT IOP measurement (5.2 +/-1.6 mmHg)
- Significant GAT correlation to CCT *In vivo*,  $r^2=0.78$
- No CATS correlation to CCT demonstrated

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### The Correcting Applanation Tonometer Surface (CATS)

**Surgical Intraocular (I1.3mmHg) Average IOP Measurement**

**Surgical Intraocular (22.0mmHg) Average IOP Measurement**

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### Reducing the Corneal effect on Measured IOP ORA's Patented IOPcc

- Goldmann and other tonometers provide *one number*, but this number is comprised of *two things*:  
IOP and cornea

**You can't measure two things with one number!**

- How can we overcome the corneal influences?**
  - CATS**
  - ORA/IOPcc**
    - IOPcc is still a Goldmann correlated IOP measurement. That is, it is designed to agree with Goldmann on average, but is not influenced by the cornea in the same way as Goldmann and other tonometers are.
    - IOPcc has no correlation with CCT, changes minimally after refractive surgery, and is more associated with glaucoma status than actual GAT values.

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### Ocular Response Analyzer Generation 3 device

- 3<sup>rd</sup> Generation "ORA G3" introduced September 2015

Measures:

- Corneal Hysteresis (CH)
- Goldmann-correlated IOP (IOP<sub>G</sub>)
- Corneal compensated IOP (IOP<sub>CC</sub>)
- Waveform Score (WS)

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### Ocular Response Analyzer Technology Interpretation of measurement values

**Corneal Compensated IOP:** An IOP measurement that is less influenced by corneal properties than Goldmann or other tonometers. This value is closer to the "true pressure" and has been shown to be a better indicator of glaucoma than Goldmann. Matches GAT on average, so numerical "Scale" is the same.

**Corneal Hysteresis:** An indication of corneal biomechanical properties that has been shown to be independently predictive of future glaucoma progression. Reimbursable under CPT 92145. Typical average value is 10.5. Typical Range is 8-14. Low is a risk.

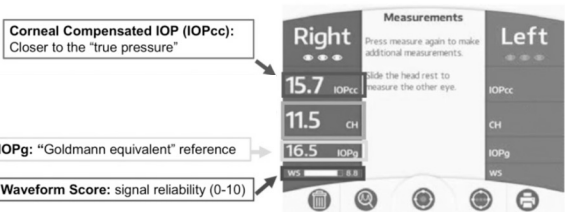
**IOP<sub>G</sub>:** A Goldmann-correlated IOP measurement for reference purposes so that clinicians can appreciate what a Goldmann would read simultaneously with the IOPcc value above.

**Waveform Score:** A signal analysis algorithm that rates the "quality" of the measurement signal on a scale of 0-10. The higher the value, the more reliable the IOP and CH values are. 6-10 is excellent, 4-5 is not so good, 3 or below is poor.

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### Ocular Response Analyzer G3

Measurement Values, range, and interpretation



**Corneal Compensated IOP (IOPcc):**  
Closer to the "true pressure"

**IOPg:** "Goldmann equivalent" reference

**Waveform Score:** signal reliability (0-10)

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### Corneal Compensated IOP (IOPcc):

Making a more accurate pressure measurement based on Corneal Hysteresis

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### Reducing the Corneal effect on Measured IOP

ORA's Patented IOPcc

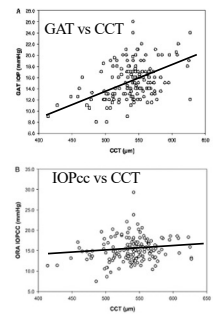
- Goldmann and other tonometers provide *one number*, but this number is comprised of two things:  
IOP and cornea  
**You can't measure two things with one number!**
- The ORA Bi-Directional Applanation process results in *two* applanation measurements in rapid succession. The derived Corneal biomechanical information, which gives us Corneal Hysteresis, can also be used to quantify (and reduce) the biomechanical impact of the cornea on the IOP measurement.
- IOPcc** is a pressure measurement that is less affected by corneal properties than other methods of tonometry, such as Goldmann (GAT).
  - IOPcc is still a *Goldmann correlated* IOP measurement. That is; it is designed to agree with Goldmann on average, but is not influenced by the cornea in the same way as Goldmann and other tonometers are.
  - IOPcc has no correlation with CCT, changes minimally after refractive surgery, and is more associated with glaucoma status than actual GAT values.

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### IOPcc – a superior indicator of IOP

Not correlated with CCT

Parameter	Mean ± Standard Deviation	Range
CCT (µm)	538 ± 35	414-627
Corneal curvature (mm)	7.74 ± 0.33	7.00-9.04
Axial length (mm)	23.62 ± 1.08	20.02-26.70
GAT IOP (mm Hg)	15.3 ± 3.3	8.0-26.0
ORA IOPcc (mm Hg)	15.2 ± 3.0	7.4-29.3
CRF (mm Hg)	9.41 ± 1.75	4.03-14.15



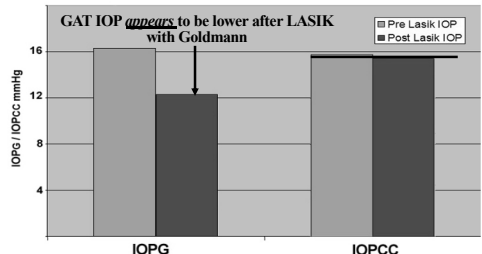
**IOPg agrees with Goldmann. IOPcc provides an estimate of IOP that is less influenced by corneal properties than those provided by GAT**

Evaluation of the Influence of Corneal Biomechanical Properties on Intraocular Pressure Measurements Using the Ocular Response Analyzer. Hoopes, A. Jackson, MD and Robert N. Weinreb, MD. J Glaucoma 2006;15:364-370.

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### IOPcc – a superior indicator of IOP

Little influence from refractive surgery



**GAT IOP appears to be lower after LASIK with Goldmann**

Legend: Pre Lasik IOP (light grey), Post Lasik IOP (dark grey)

Y-axis: IOPg / IOPcc mmHg

X-axis: IOPg, IOPcc

28 eyes pre and post LASIK. Data courtesy Dr. David Castellano, MD / Dr. Jay Pepose, MD

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### IOPcc – a superior indicator of IOP

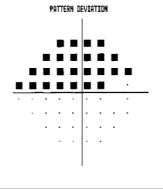
Case 2: IOPcc agrees better with status of VF loss

53 yo black male with Glaucoma

- CCT 598/582
- GAT: 15mm Hg
- On IOP medication OU

**IOPcc Measurements**

- IOPg: 15.5 OD / 15.0 OS
- IOPcc: 19.2 OD / 18.9 OS

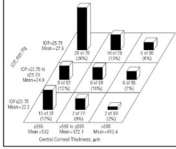


**Note: IOPcc is the opposite direction from a CCT adjustment and is properly associated with the status of glaucoma**

Data Courtesy of Nathan Radcliffe, MD Assistant Professor of Ophthalmology, Weill Cornell Medical College, New York-Presbyterian Hospital

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### The cornea and glaucoma Lessons from the OHTS




**OHTS put the cornea on the map in glaucoma**

- Corneal Thickness was found to be an independent risk factor for development of glaucoma
  - NOT an IOP correction factor
- But CCT is a simple geometrical attribute of the cornea / eye
  - Investigations into the "connection" between CCT and whole eye (scleral, ONH, lamina cribrosa) properties have come up empty
- Is there a corneal property that better explains back of the eye behavior?
  - Corneal Hysteresis
    - **What is it?**
    - **How is it measured?**
    - **What is normal? What is abnormal?**
    - **The literature**

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### Ocular Response Analyzer Technology Interpretation of measurement values



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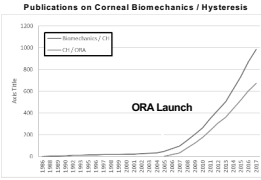
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### What is Corneal Hysteresis (CH)?

- **CH is a tissue property that reflects the ability of the cornea to absorb and dissipate energy<sup>1</sup>**
  - Measurement output specific to the Patented Reichert Ocular Response Analyzer
  - The only in-vivo measurement of ocular biomechanics
  - Indicative of visco-elastic damping<sup>2</sup>
  - "How good of a shock absorber is the eye?"
- **Commercial availability since 2005**
  - ORA G3 model 2015

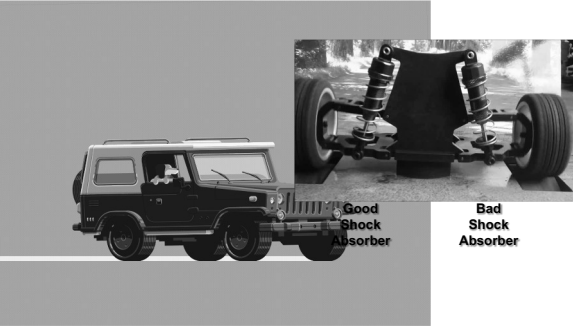


**Publications on Corneal Biomechanics / Hysteresis**

1. Luce DA. J Cataract Refract Surg. 2005;31:1556-162.  
Dugas W Jr. J Cataract Refract Surg. 2007;33:1499-1501.  
2. Published research on ocular biomechanics: "Normal hysteresis". ORA peer reviewed bibliography provided by Reichert, with review of the sample size (N) in each publication

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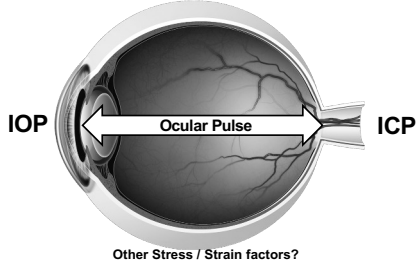
### How is the eye like automotive suspension? Energy and Damping



**Good Shock Absorber**      **Bad Shock Absorber**

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### How good of a shock absorber is your eye?



- What's happening to this energy?
- Can the eye absorb & dissipate all this shock?
- **Can we measure the shock-absorption capacity of the eye?**

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### Hysteresis

**What it is – What it is NOT**

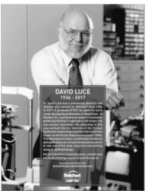
**Hysteresis** characterizes the response to application and removal of force in materials that **dissipate a portion of applied energy**.<sup>1</sup>

- Not a new concept (term defined in 1890)
- 13,000+ medical publications on hysteresis in a variety of fields?

**Corneal Hysteresis (CH)**

Reflects cornea's ability to **absorb and dissipate energy**.<sup>2</sup>

- An indication of "damping" capacity of the ocular tissue
  - NOT an indication of "stiffness" or "rigidity"



*David Luce PhD 1935-2017  
Pioneered Corneal Hysteresis*

**"The eye is under a constant assault"**

Hysteresis tells us "How good of a shock absorber" the eye is.

1. Vincent J. Basic electricity and electrostatics. In: Vincent J. ed. Structural Biomechanics. 3rd ed. Princeton, NJ: Princeton University Press; 2012:1-26.  
2. PubMed Search for "hysteresis" on March 11, 2021 returned 13,760 results.  
3. Luce DA. J Cataract Refract Surg. 2005;31:1556-162.

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### Ocular Response Analyzer Technology

Method of Operation

Measured by rapidly deforming the cornea under a gentle air pulse

- This is not your father's NCT!

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### Ocular Response Analyzer G3

Method of Operation

**Dynamic bi-directional applanation**

Pressure (mmHg)

Time - msec

Cornea: Normal Flat Indented Flat Normal

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### Ocular Response Analyzer Technology

Bi-directional Applanation Signal

Pressure / Signal

Time - msec

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### Corneal Hysteresis: Basic Evidence

CH Average Values in Normal Subjects

CH Values in Normals around the world	N	CH*
Brazil <sup>1</sup>	105	10.1 ± 1.8
UK <sup>2</sup>	272 pairs	10.2 ± 1.2
China <sup>3</sup>	125	10.9 ± 1.5
Japan <sup>4</sup>	204	10.2 ± 1.3
Spain <sup>5</sup>	88	10.8 ± 1.5
USA <sup>6</sup>	44	10.5 ± 1.2

\*CH units are mmHg

1. Forbes BM J Refract Surg. 2008 Nov;24(9):941-5.  
2. Caterson: The Nucleolus of Corneal Hysteresis and Ocular Pulse Amplitude A Twin Study doi:10.1016/j.opht.2008.02.011  
3. Lam A. Et Al. Optom Vis Sci. 2007 Sep;84(9):909-14.  
4. Kuriyama Et Al. J Refract Surg. 2008 Oct;25(10):689-93  
5. Oishi Et Al. J Cataract Refract Surg. 2007 Aug;33(8):1371-6  
6. John Et Al. 2007 Spring;38(1):9-14

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### Ocular Response Analyzer G3

Measurement Values, range, and interpretation

- Average Normal CH is 10.5 mmHg
- Standard dev 1.5 mmHg
- Fairly stable diurnally and with age

**Corneal Compensated IOP (IOPcc):** Closer to the "true pressure"

**Corneal Hysteresis: Normal average 10.5**  
Typical Range is 8-14 (low = risk)

**IOPg:** "Goldmann equivalent" reference

**Waveform Score:** signal reliability (0-10)

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### The Evidence

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### What is Corneal Hysteresis (CH)?

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  - The only in-vivo measurement of ocular biomechanics
  - Indicative of visco-elastic damping<sup>2</sup>
  - "How good of a shock absorber is the eye?"<sup>3</sup>
- 700 publications citing clinical evidence
  - with data from 80,000+ patients<sup>3</sup>
- Commercial availability since 2005
  - ORA G3 model 2015

Publications on Corneal Biomechanics / Hysteresis

ORA Launch

1. Linn DA. J Cataract Refract Surg. 2005;31:158-162.  
 2. Chappo RA, et al. J Cataract Refract Surg. 2007;33:1886-1891.  
 3. PubMed search on terms "normal biomechanics" & "normal hysteresis". ORA peer reviewed bibliography provided by Reichert, with review of the complete size (N) of each publication.

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### Corneal Hysteresis: Basic Evidence

#### CH Diurnal Stability and changes over time

- CH does not display a 24-hour rhythm<sup>1</sup>
- CH has been shown to decrease slightly with age<sup>2</sup>

CH vs Age

Diurnal CH, CCT, IOP

1. Kida T et al. Invest Ophthalmol Vis Sci. 2006;47:4222-4228.  
 2. Fortes BM. J Refract Surg. 2008;Nov;24(9):941-5.

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### Corneal Hysteresis in Glaucoma

#### Association with Progression in a Retrospective Study

	OR	LCL	UCL	P-value
Age per year <65	1.12	1.01	1.24	.03
Age per year >65	1.08	1.01	1.15	.02
GAT IOP per mmHg	1.22	0.95	1.58	.12
Treatment	1847.6	3.16	10 <sup>6</sup>	.02
IOP by treatment interaction	0.79	0.61	1.03	.08
CCT per 100 microns	1.65	0.66	0.98	.30
Years with glaucoma	1.00	0.96	1.04	.98
Baseline IOP	0.99	0.93	1.06	.79
CH per mmHg	0.81	0.66	0.98	.03

- 230 POAG or suspected POAG patients were included in the study
- 3 years or more FU
- Minimum 5 VF exams

Conclusions: Corneal Hysteresis was the parameter most associated with progressive field worsening

1. Congdon NG et al. Am J Ophthalmol. 2006;141:888-895.

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### Corneal Hysteresis in Glaucoma

#### Association with Progression in Normal Tension Glaucoma (NTG)

- A retrospective study to investigate the clinical significance of CH in patients with progressing NTG.
- 82 eyes of 82 NTG patients receiving topical anti-glaucoma medications were included.
  - Subjects were included if they had an established diagnosis of NTG made by a glaucoma specialist based on glaucomatous optic disc damage and abnormal VF test results. Signs of glaucomatous optic disc damage were considered diffuse or localized neuroretinal rim loss, excavation, and RNFL defects.
  - An abnormal VF was defined as a pattern standard deviation outside of the 95% normal confidence limits or a Glaucoma Hemifield Test result outside normal limits.
  - At least two consecutive abnormal VF examinations were required, with the most recent test performed within 12 months of enrollment.
- NTG was defined by repeatable IOP  $\leq 21$  mm Hg, glaucomatous optic disc changes, and VF loss.
- Patients were allocated to two groups based on the mean value of corneal hysteresis
  - Mean CH was 10.08 mmHg.
  - Assessment of progression was based on the trend analysis using VF MD slope.
- Uni and multivariable analyses were constructed to identify factors associated with increased odds of progression, including CH, IOP, central corneal thickness (CCT), and RNFL thickness.

1. Park E, et al. Br J Ophthalmol. 2015; Jan 2; pii: bjo.2014.305962. doi: 10.1136/bjo.2014.305962.

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### Corneal Hysteresis in Glaucoma

#### Association with Progression in Normal Tension Glaucoma (NTG)

Logistic regression with VF progression as a binary outcome (stepwise MV)	$\beta$ (95% CI)	P-Value
Baseline VF MD (dB)	1.18 (0.96 to -1.44)	0.12
CCT ( $\mu$ m)	0.99 (0.97 to 1.01)	0.35
Subfoveal choroidal thickness	0.99 (0.98 to 1.00)	0.08
RNFL thickness (average)	0.96 (0.92 to 0.99)	0.04
RNFL thickness (temporal)	0.97 (0.94 to 1.01)	0.09
RNFL thickness (inferior)	0.98 (0.96 to 1.01)	0.13
Corneal Hysteresis (mmHg)	0.32 (0.17 to 0.62)	<0.01

- Of the 39 eyes with low CH, 26 (66.7%) showed progression of VF damage while 13 (53.3%) showed no progression.
- Of the 43 eyes with high CH, 15 (34.9%) showed progression of VF damage, whereas 28 (65.1%) showed no progression.

These findings suggest that CH can be used as one of the prognostic factors for progression, independent of corneal thickness or IOP

1. Park E, et al. Br J Ophthalmol. 2015; Jan 2; pii: bjo.2014.305962. doi: 10.1136/bjo.2014.305962.

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### Corneal Hysteresis in Glaucoma

#### Predictive of Progression in Prospective, Longitudinal Study (DIGS)

- Adults  $\geq 18$  years of age<sup>1</sup>
- Only subjects with open angles on gonioscopy were included<sup>1,2</sup>
- Excluded subjects<sup>1,2</sup>
  - BCVA  $< 20/40$
  - Spherical refraction outside of  $\pm 5.0$  diopters or cylinder correction outside 3.0 diopters
  - Any ocular or systemic disease that could affect the optic nerve or visual field

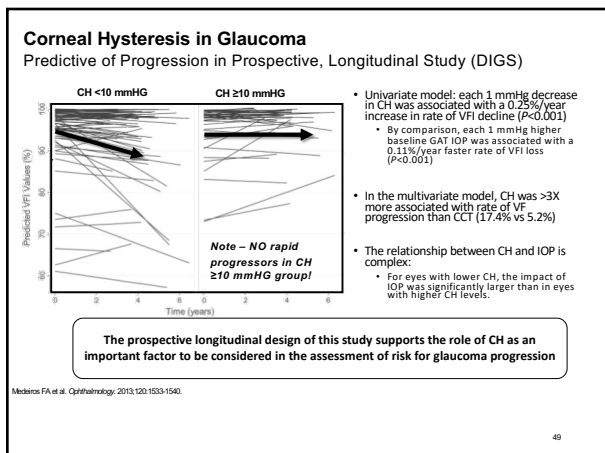
Evaluation<sup>2</sup>

- Follow-up at 6 month intervals with comprehensive ophthalmologic exam

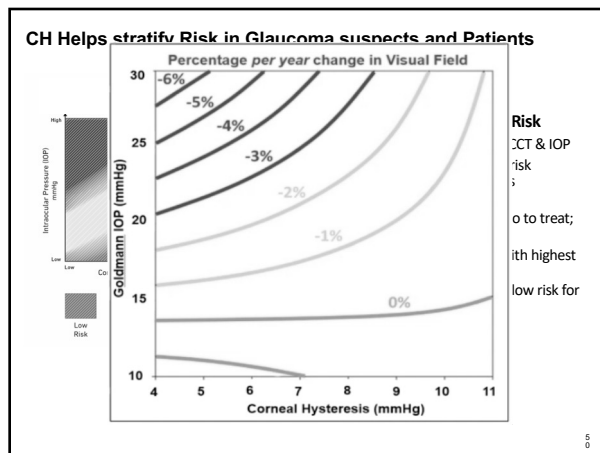
<ul style="list-style-type: none"> <li>Review of medical history</li> <li>BCVA</li> <li>Slit lamp biomicroscopy</li> <li>IOP measurement (GAT)</li> <li>Gonioscopy</li> </ul>	<ul style="list-style-type: none"> <li>Dilated fundoscopic exam</li> <li>Stereoscopic optic disc photography</li> <li>Automated perimetry</li> <li>CCT (ultrasound pachymetry)</li> <li>Axial length (IOL Master)</li> </ul>
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1. Medeiros FA et al. Ophthalmology. 2013;120:1533-1540.

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## Clinical Evidence

### Why is CH relevant in Glaucoma?

(Low) CH has been consistently shown to be independently and strongly associated with or predictive of glaucoma progression

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Ophthalmology. 2013 Aug;120(8):1533-40. doi: 10.1016/j.ophtha.2013.01.032. Epub 2013 May 1.

### Corneal hysteresis as a risk factor for glaucoma progression: a prospective longitudinal study.

Medeiros FA<sup>1</sup>, Meira-Freitas D, Lisboa R, Kuang TM, Zanwill LM, Weinreb RN.

**Abstract**

**PURPOSE:** To evaluate the role of corneal hysteresis (CH) as a risk factor for the rate of visual field progression in a cohort of patients with glaucoma followed prospectively over time.

**DESIGN:** Prospective observational cohort study.

**PARTICIPANTS:** The study group included 114 eyes of 68 patients with glaucoma followed for an average of 4.0 ± 1.1 years. Visual fields were obtained with standard automated perimetry. Included eyes had a median number of 7 (range, 5-12) tests during follow-up.

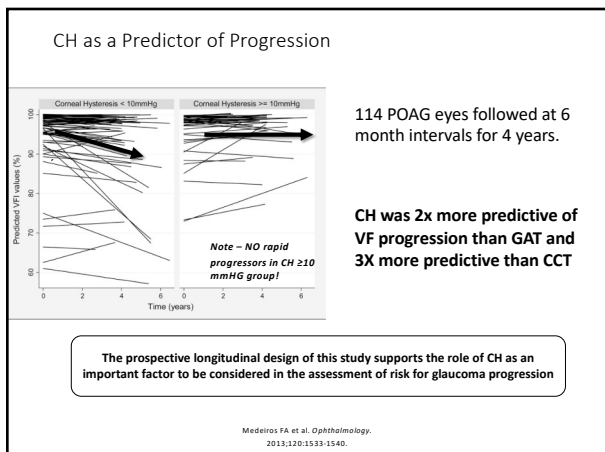
**METHODS:** The CH measurements were acquired at baseline using the Ocular Response Analyzer (Reichert Instruments, Depew, NY). Evaluation of rates of visual field change during follow-up was performed using the visual field index (VFI). Linear mixed models were used to investigate the relationship between rates of visual field loss and baseline CH, baseline intraocular pressure (IOP), and central corneal thickness (CCT), while adjusting for potentially confounding factors. An interaction term between IOP and CH was included in the model to investigate whether the effect of IOP on rates of progression depended on the level of CH.

**MAIN OUTCOME MEASURES:** Effects of CH, IOP, and CCT on rates of VFI loss over time.

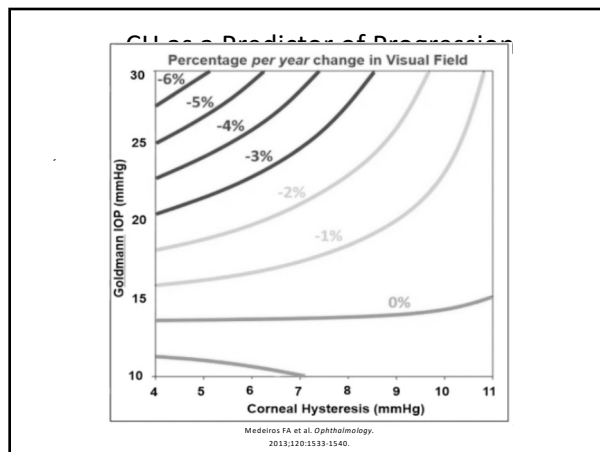
**RESULTS:** The CH had a significant effect on rates of visual field progression over time. In the univariate model including only CH as a predictive factor along with time and their interaction, each 1 mmHg lower CH was associated with a 0.25%/year faster rate of VFI decline over time ( $P<0.001$ ). The multivariable model showed that the effect of IOP on rates of progression depended on CH. Eyes with high IOP and low CH were at increased risk for having fast rates of disease progression. The CH explained a larger proportion of the variation in slopes of VFI change than CCT (17.4% vs. 5.2%, respectively).

**CONCLUSIONS:** The CH measurements were significantly associated with risk of glaucoma progression. Eyes with lower CH had faster rates of visual field loss than those with higher CH. The prospective longitudinal design of this study supports the role of CH as an important factor to be considered in the assessment of the risk of progression in patients with glaucoma.

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### CH is Predictive of Response to Glaucoma Therapy

Table 2. IOP response to therapy by baseline CH and CCT

	Baseline CH (mm Hg)	Baseline IOPg (mm Hg)	IOPg change (mm Hg)	p-value	IOPg percent change	p-value
First quartile CH	7.0	19.4	-5.8	ANOVA: p=0.002	-29.0%	ANOVA: p=0.008
Second quartile CH	8.8	17.4	-3.7	0.1 <sup>1</sup>	-20.7%	0.2 <sup>1</sup>
Third quartile CH	10.0	16.5	-3.7	0.2 <sup>1</sup>	-19.9%	0.3 <sup>1</sup>
Fourth quartile CH	11.9	15.9	-1.1	0.001 <sup>1</sup>	-7.6%	0.006 <sup>1</sup>

	Baseline CCT (μm)	Baseline IOPg (mm Hg)	IOPg change (mm Hg)	p-value	IOPg percent change	p-value
First quartile CCT	497.3	16.4	-3.9	ANOVA: p=0.7	-21.9%	ANOVA: p=0.4
Second quartile CCT	525.2	17.1	-4.0	0.8 <sup>1</sup>	-23.1%	0.8 <sup>1</sup>
Third quartile CCT	549.1	16.9	-3.1	1.0 <sup>1</sup>	-15.9%	0.8 <sup>1</sup>
Fourth quartile CCT	586.2	18.3	-2.6	0.5 <sup>1</sup>	-13.4%	0.5 <sup>1</sup>

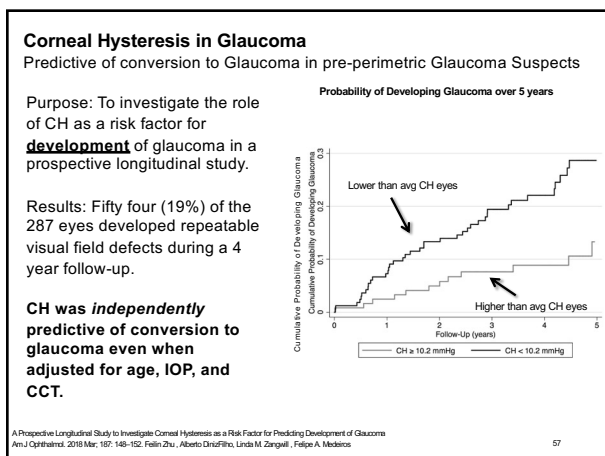
Baseline CH is independently associate with the magnitude of IOP reduction from PGA therapy.

The relationship between corneal hysteresis and the magnitude of intraocular pressure reduction with topical prostaglandin therapy. Br J Ophthalmol. 2012 Feb;96(2):254-7. Daniel R. Agarwal, Joshua R. Ehrlich, Mitsugu Shimizu, Nathan M. Raboff

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• How about diagnostically?

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**Corneal Biomechanics and Visual Field Progression in Eyes with Seemingly Well-Controlled Intraocular Pressure**

Blanca N. Swann, MD,<sup>1,2,3</sup> Nara G. Ogata, MD,<sup>1</sup> Alejandro A. Jammal, MD,<sup>1</sup> Carolina N. Swann, MD,<sup>1,2,3</sup> Samuel J. Berdack, PhD,<sup>1,4</sup> Felipe A. Medeiros, MD, PhD<sup>1</sup>

460 eyes of 334 glaucoma patients  
Follow-up – 4.3 years  
Well controlled if IOP < 18 mm HG

CH (8.6 vs 9.4)  
CCT (515 vs 531)

68% higher risk of progression

179 eyes well controlled  
42 (23.5%) of those eyes had VF progression

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### Relationship of Corneal Hysteresis and Anterior Lamina Cribrosa Displacement in Glaucoma

BRANDON J. WONG, SASAN MOGHIMI, LINDA M. ZANGWILL, MARK CHRISTOPHER, AKRAM BELGHITH, EREN EKICI, CHRISTOPHER BOWD, MASSIMO A. FAZIO, CHRISTOPHER A. GIRKIN, AND ROBERT N. WEINER

147 eyes of 96 glaucoma patients  
Follow-up – 3.5 years

Choroidal thickness = posterior ALCS displacement  
Low Corneal hysteresis =

Each 1 mmHg lower CH = 0.66 microns of posterior ALCS displacement

Wong BJ, Moghimi S, Zangwill LM, et al. Relationship Of Corneal Hysteresis and Anterior Lamina Cribrosa Displacement in Glaucoma. Am J Ophthalmol. 2019 Nov 23.

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### Ocular Response Analyzer Corneal Hysteresis

# 92145

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Corneal Hysteresis and IOPcc:  
Glaucoma Vitals for the Modern Era

Nate Lighthizer, OD, FAAO  
Professor  
Associate Dean  
Director of Continuing Education  
Chief of Specialty Care Clinics  
Oklahoma College of Optometry  
[lighthiz@nsuok.edu](mailto:lighthiz@nsuok.edu)