

Evolution to CATS Tonometry
A Long-Awaited Game Changer
in IOP Measurement

Elliot M. Kirstein, OD, FAAO

Harper's Point Eye Associates

Glaucoma and Diabetes Eye Institute

Financial Interests

- Alcon - speaker
- Haag- Streit - speaker
- Optovue - speaker
- Ocuflow – consultant
- Reichert - consultant
- Diopsys - research

Better assessment of IOP

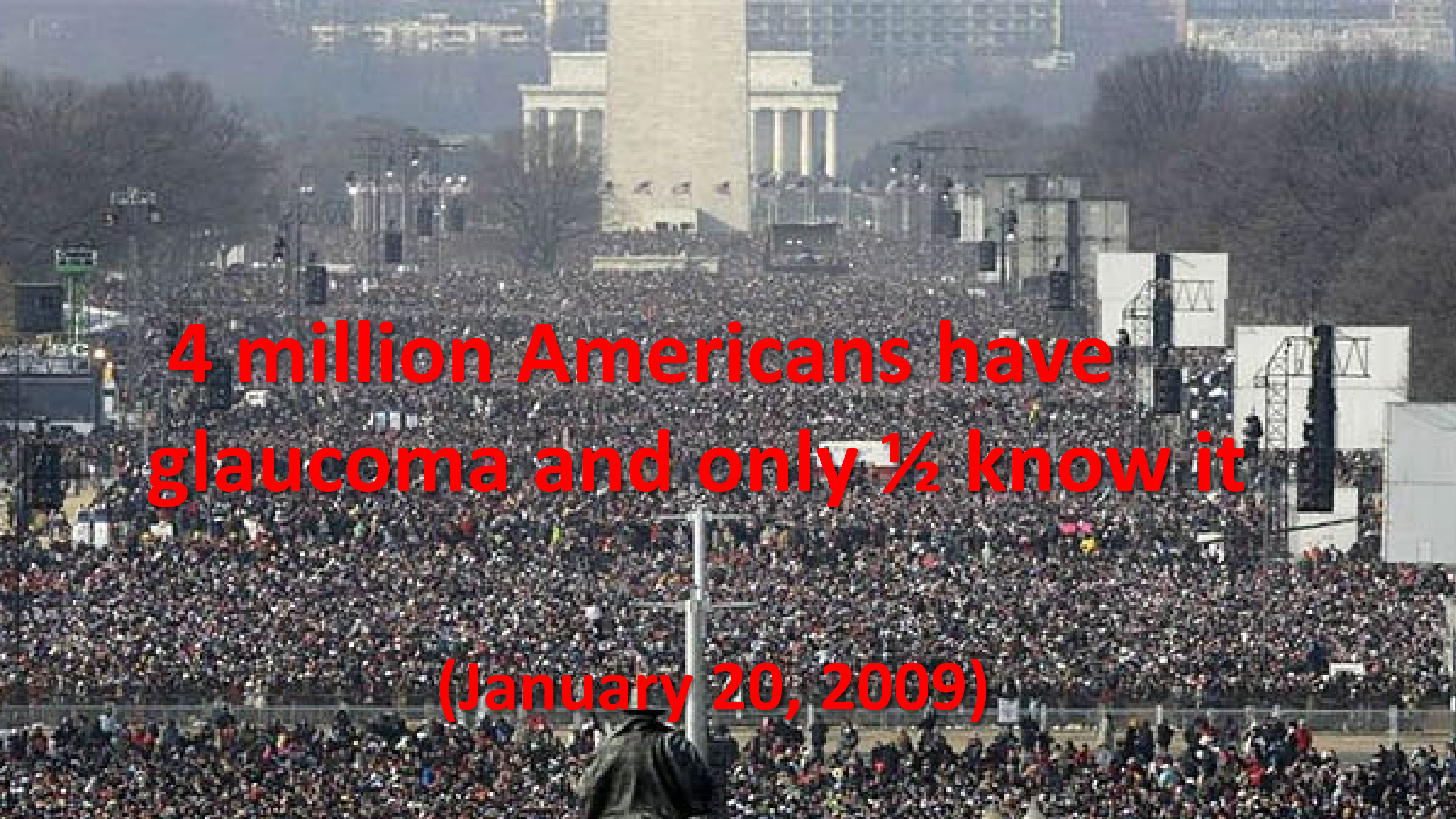
- IOP as an independent risk factor
- IOP measurement fact and fiction





Correct IOP How Important is it?

Elevated IOP is a significant risk factor for Glaucoma; accuracy matters. Since IOP reduction is the only available treatment for Glaucoma, it makes sense to measure our treatment as accurately as possible.

A large crowd of people is gathered in front of the Lincoln Memorial in Washington, D.C. The crowd is dense and extends far into the background. The Lincoln Memorial is visible in the center background, with its iconic columns and steps. The sky is overcast and grey. The text is overlaid on the image in a bold, red font.

**4 million Americans have
glaucoma and only ½ know it**

(January 20, 2009)

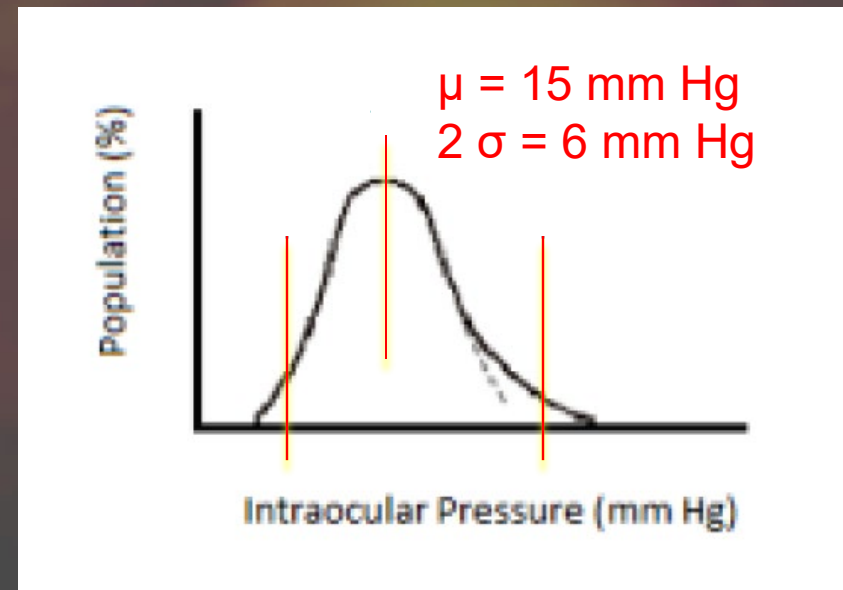
glaucoma referrals

- At least 90% of referrals to glaucoma clinics are patients with IOP over 21 mmHg

Laydecker . The Phasic variations
In the ocular tension in Primary Glaucoma.
Am J Ophthalmol 1952 Jan;35(1):1-21.

Elliot M. Kirstein, Ahmed Elsheikh
and Pinakin Gunvant.

Tonometry – Past, Present and Future
DOI: 10.5772/37393 November 9, 2011



IOP distribution

IOP and progression time to treat?

- Australian Blue Mountain Study – IOP 21 mm and over has 4.7 X the risk compared with normal pressure range

Niese P, Flammer J: Correlations between intraocular pressure, visual field and visual acuity, based on 11 years of observations of treated chronic glaucomas. *Int Ophthalmol* 3: 31–5, 1980

- Baltimore Eye Study – IOP of 30 mm and over has 38 X greater chance of progression

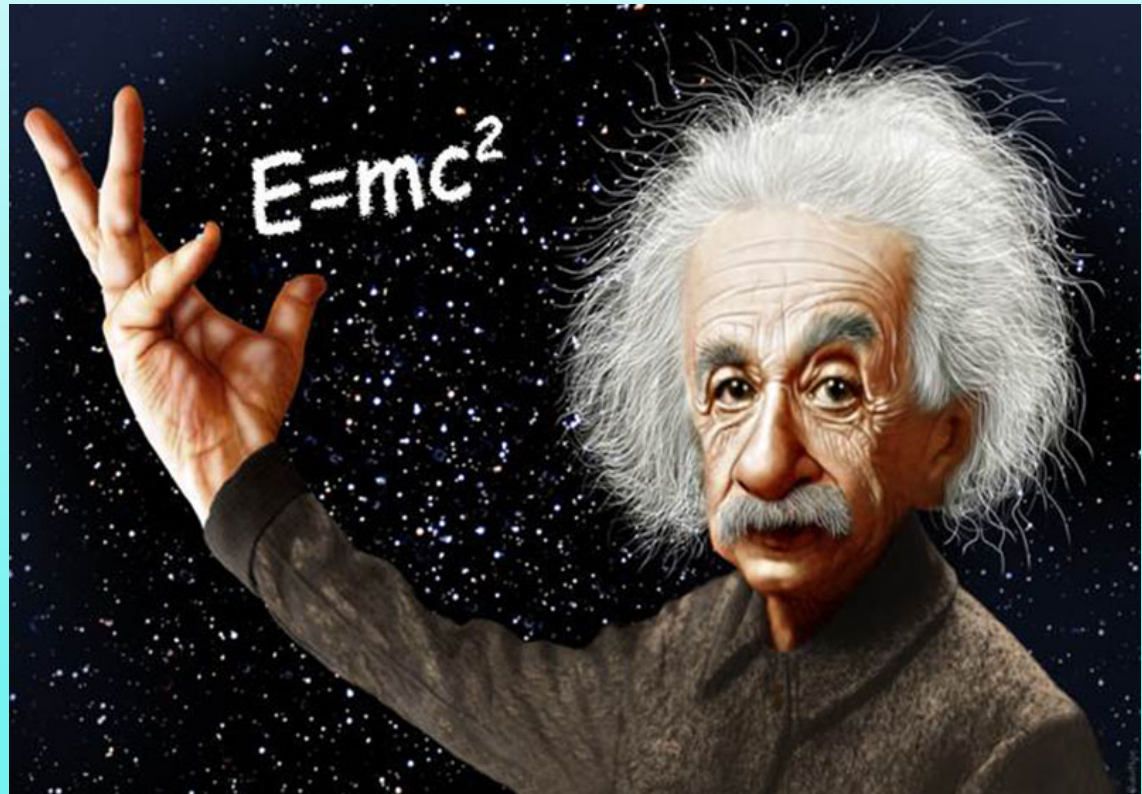
Sommer A, Tiesch JM, Katz J, et al: Relationship between intraocular pressure and primary open angle glaucoma among white and black Americans. The Baltimore Eye Survey. *Arch Ophthalmol* 109:1090–5, 1991

Using outdated tonometry you will miss...

- Glaucoma in patients with borderline IOP
- Glaucoma in LASIK patients

IOP correction formula for LASIK

Don't count
on it!



LASIK

- More than 20 million people worldwide have had LASIK surgery (2013)
- Applanation tonometry does not work with LASIK
- With applanation IOP, late diagnosis is almost inevitable
- DCT, ORA and CATS are reliable in LASIK patients

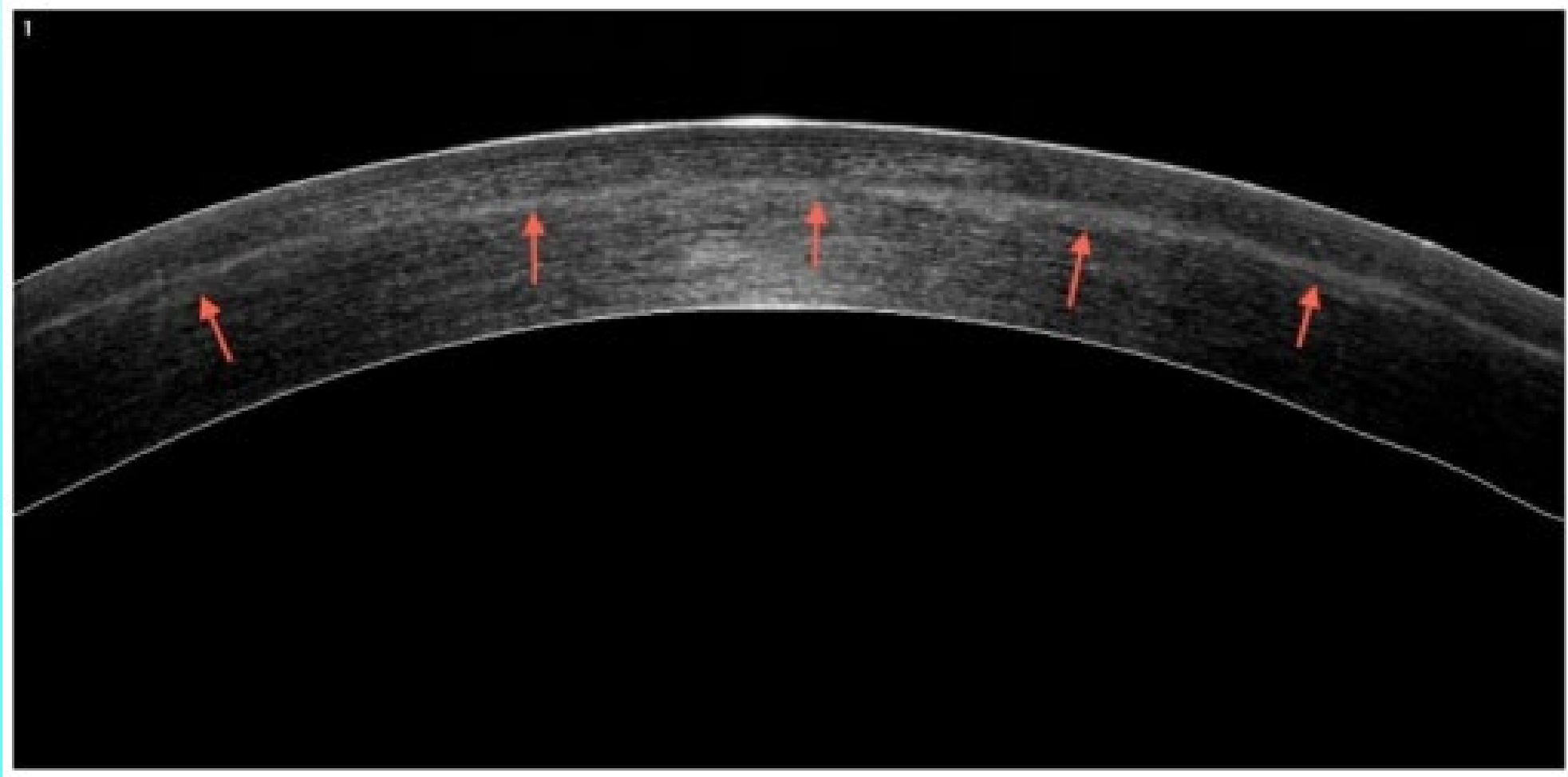


Glaucoma and buckeyes grow in Ohio

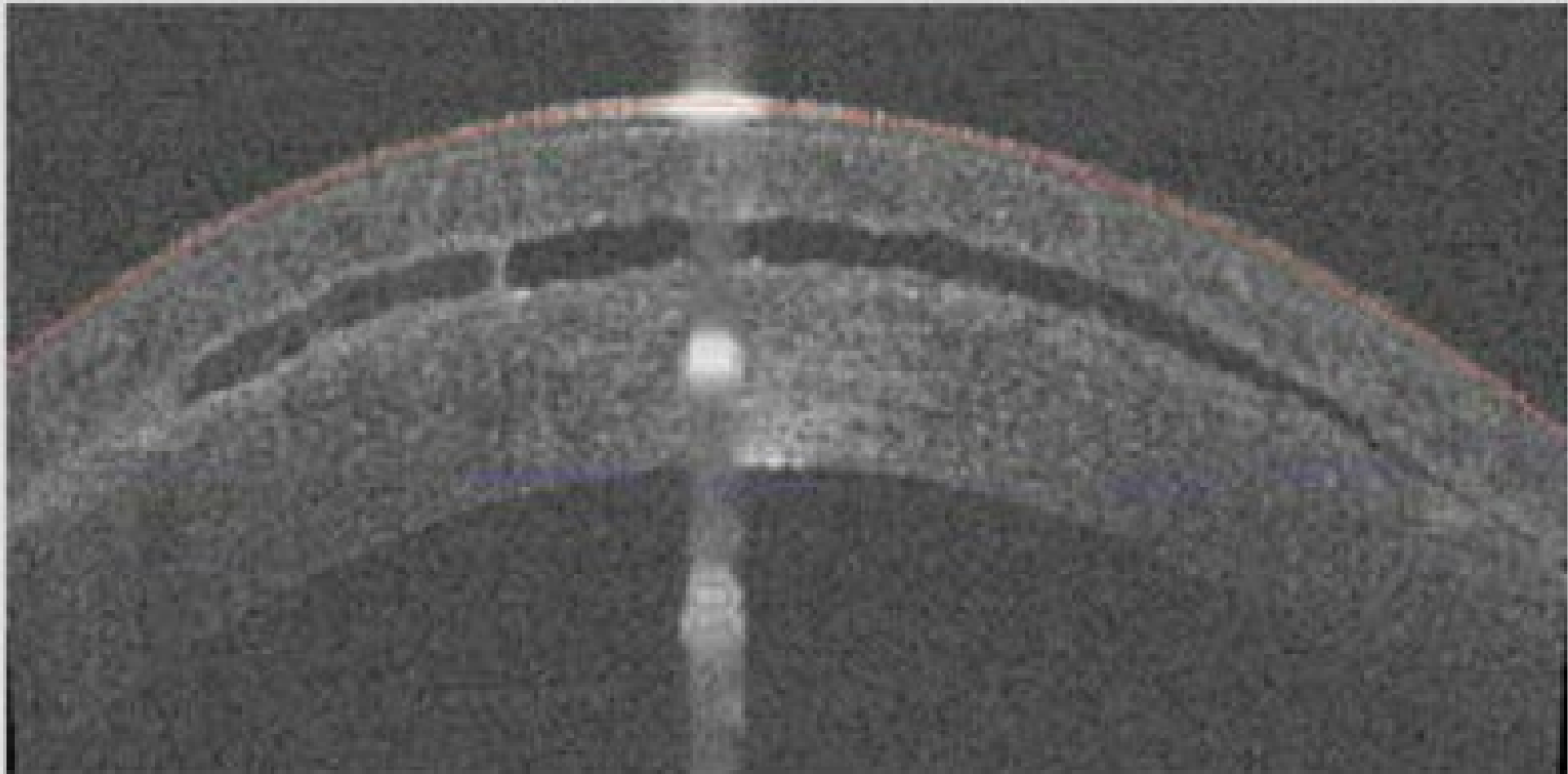
- 3% U.S Population = 10 million
- 3% 15 million in U.S. post LASIK = 450,000 in Ohio
- 2.5% of 450,000 with glaucoma = 11,250 have or will have glaucoma



Post LASIK flap



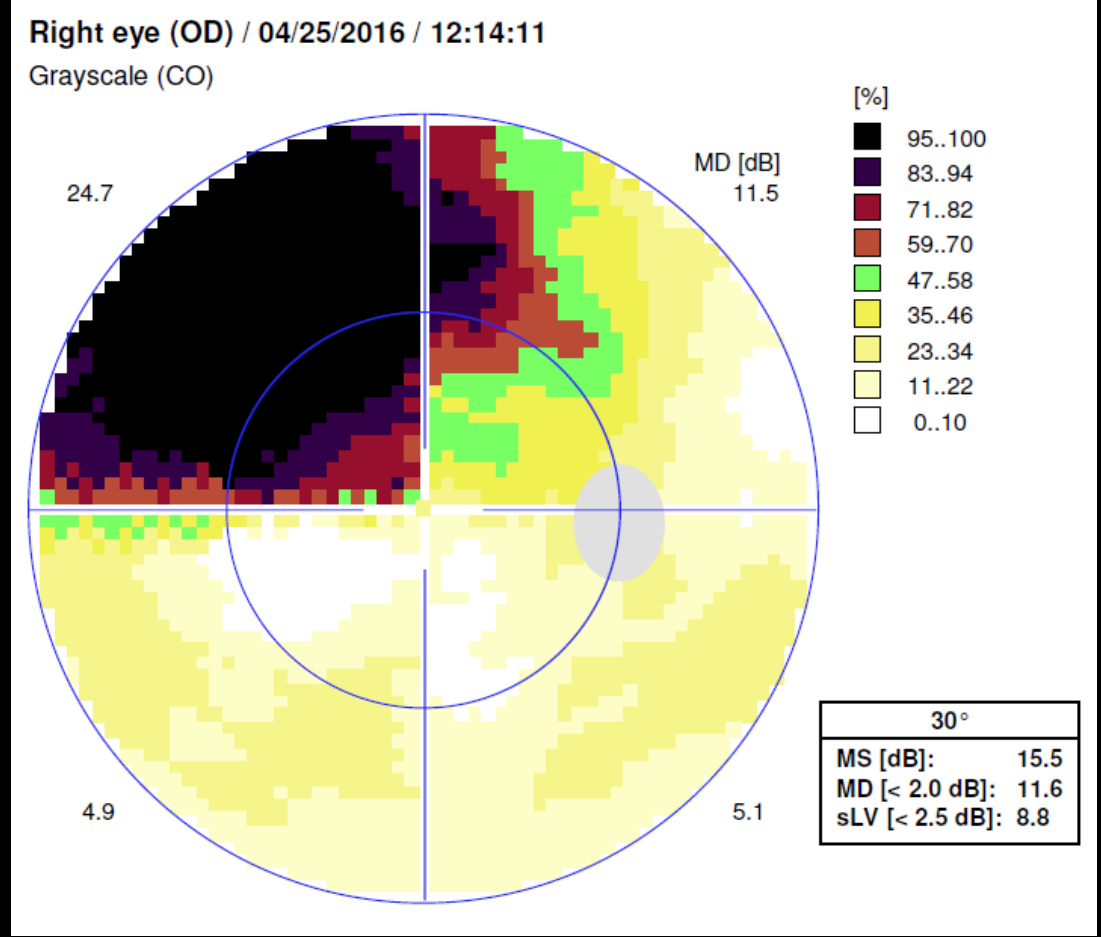
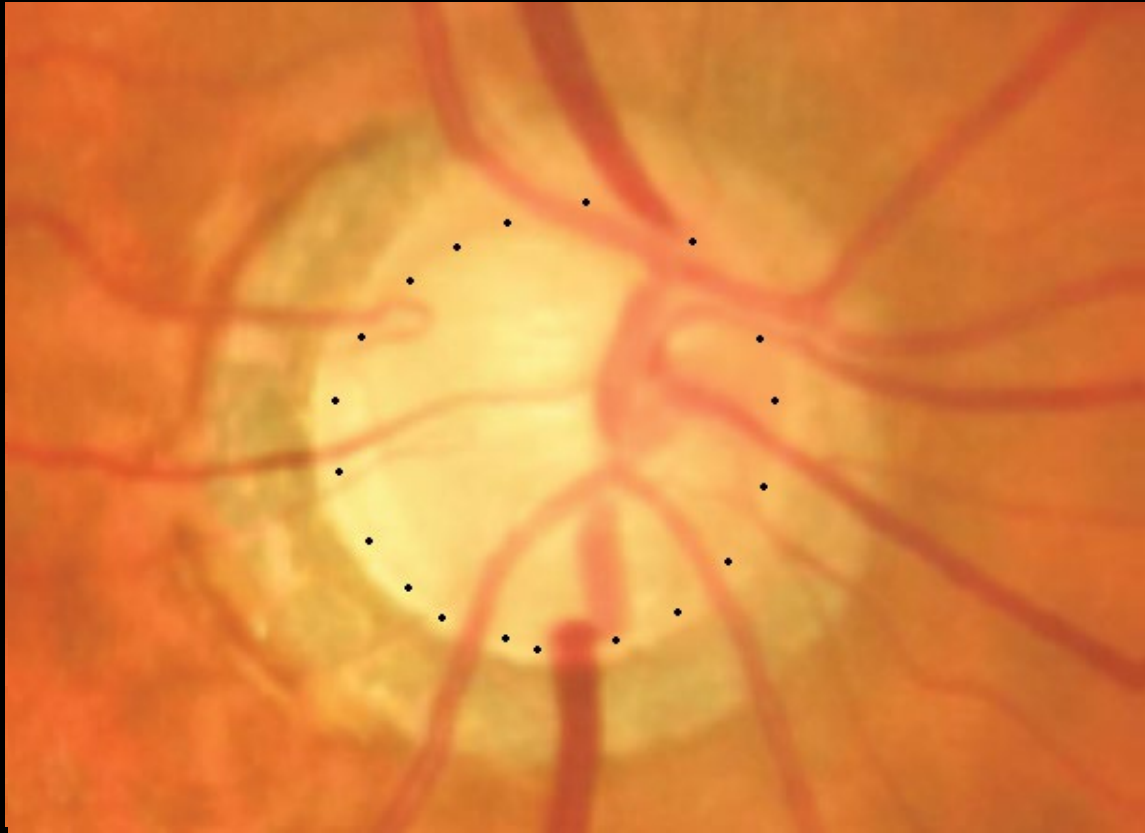
fluid in interface



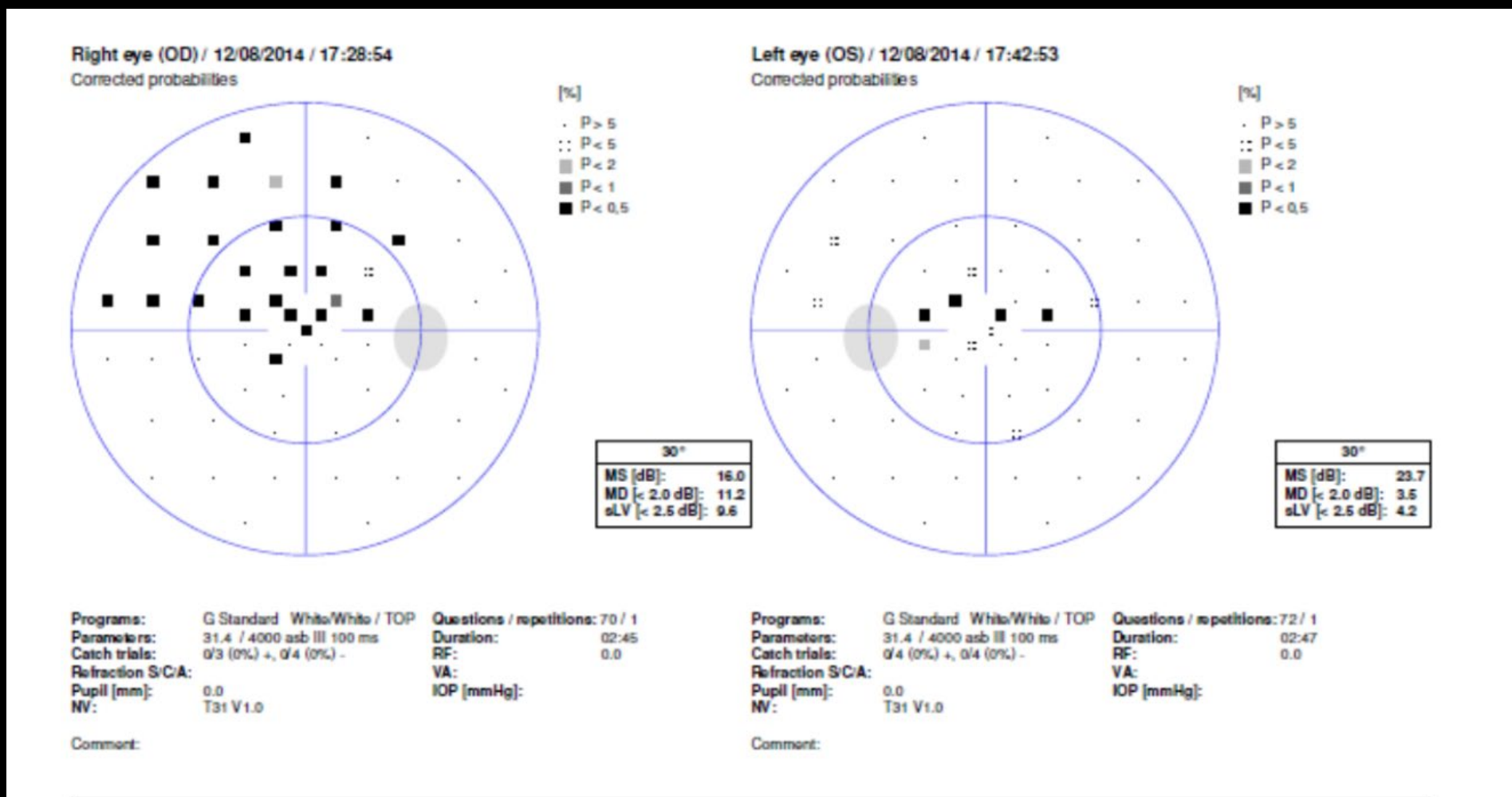
3. Interface fluid and epithelial ingrowth are observed with anterior segment OCT in a LASIK patient.

58 y/o male
25 years post LASIK

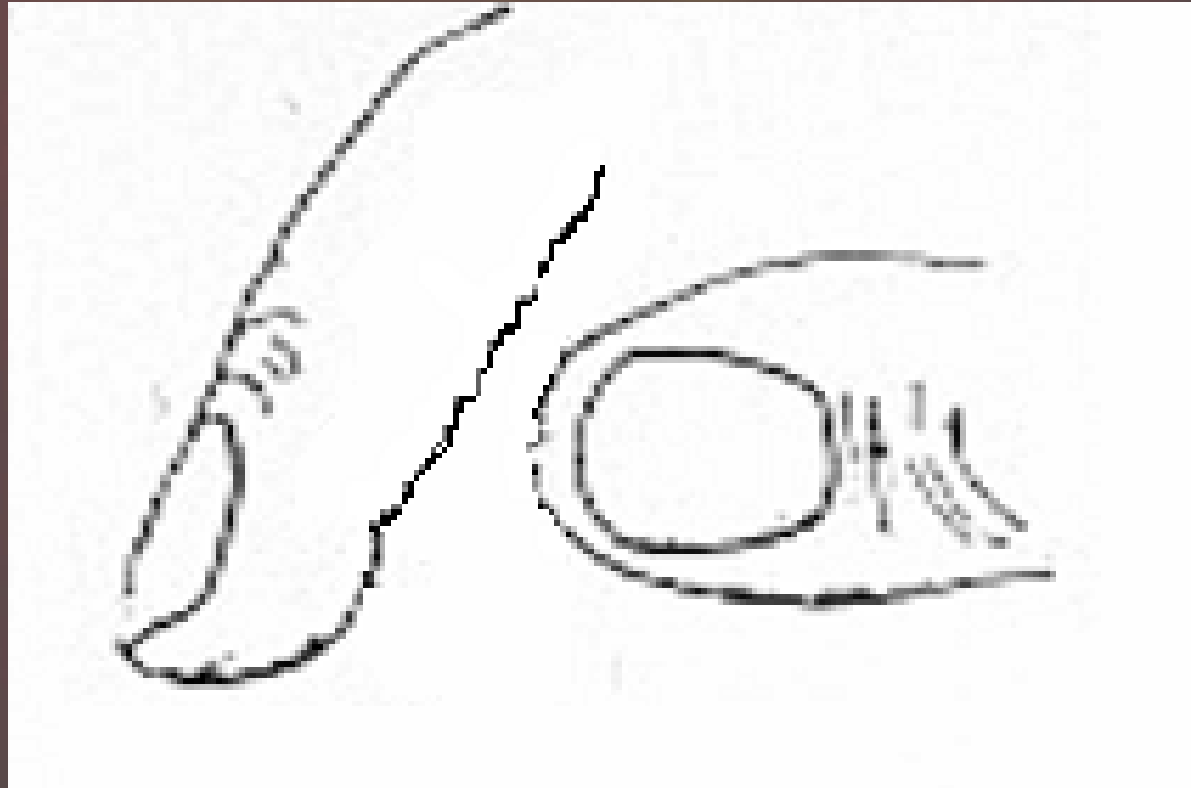
- OD = 20/70 OS = 20/25
- Goldmann IOP 21
- Low blood pressure



Late diagnosis - LASIK

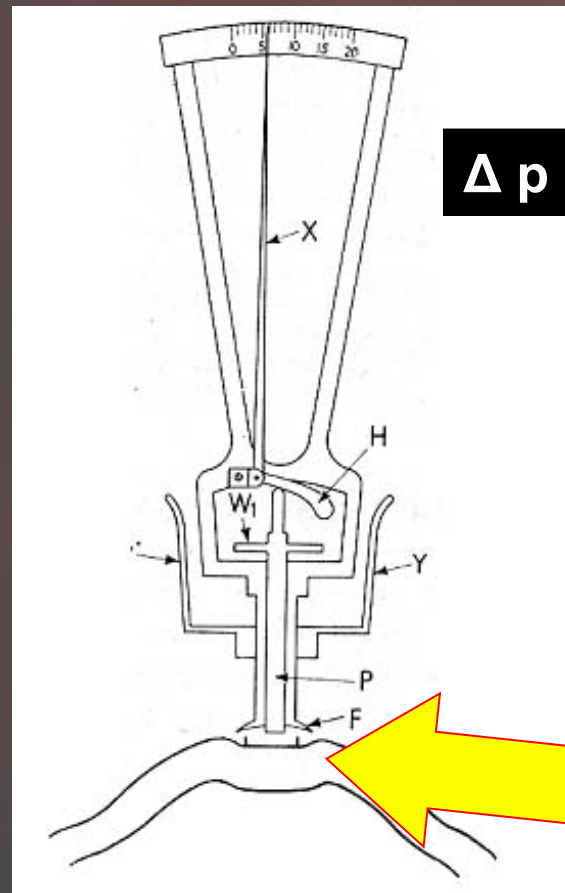


The First Tonometer



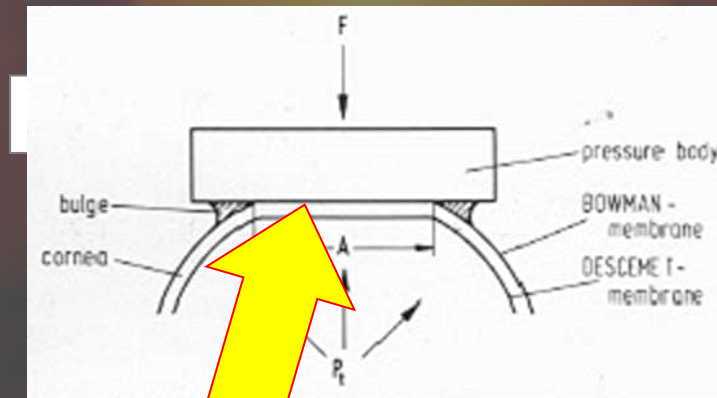
Force Tonometers

Indentation Tonometry



$$\Delta p = \Delta f / A$$

Applanation Tonometry



Cornea is distorted!

Tonometers not discussed



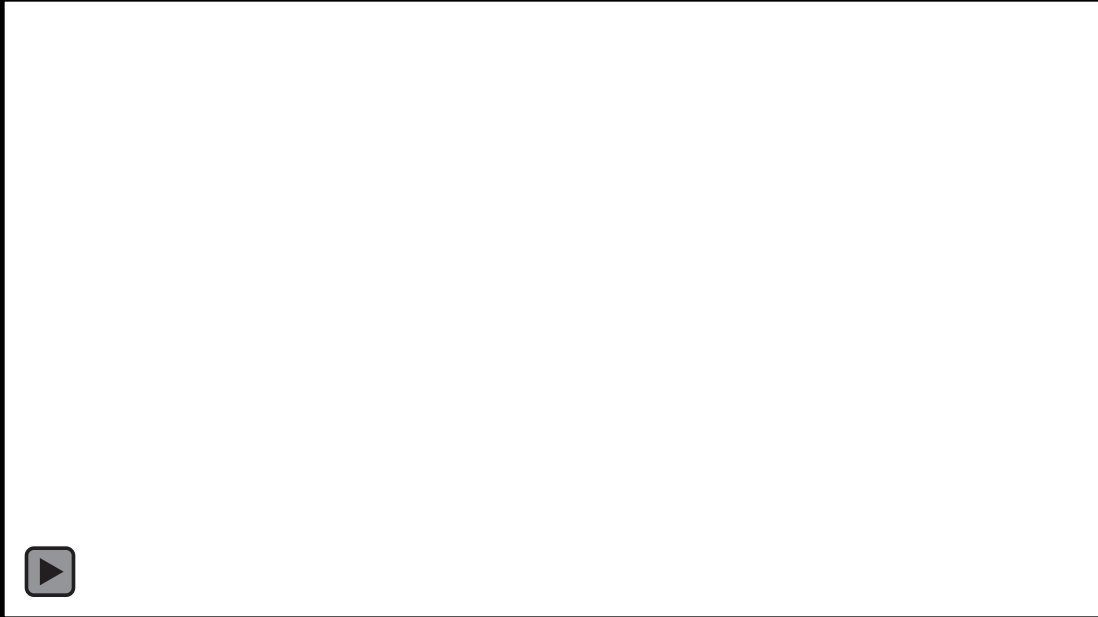
Diaton

I Care

Tonopen

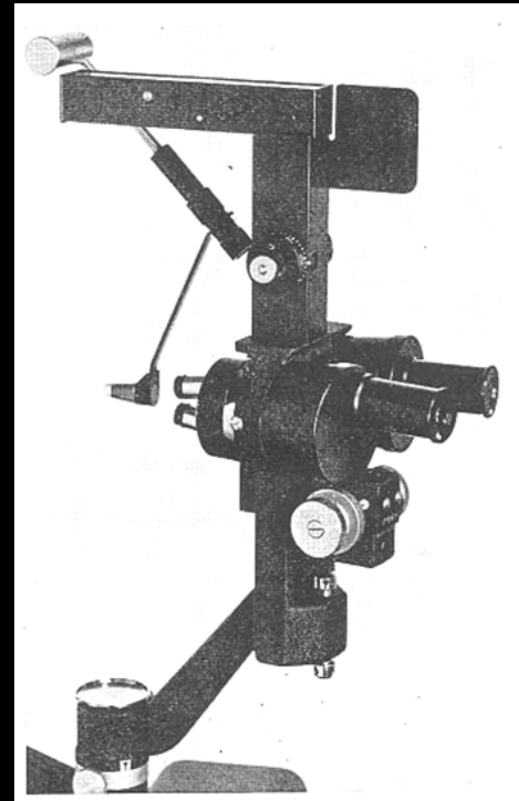
Tonometer often forgotten





**Goldmann is a
dinosaur**

circa 1951



The term “**gold standard**” is
not scientific



Is There a “Thin Cornea Glaucoma Syndrome”? “Soft Cornea Syndrome”

- Some say it's real
- Some maintain that it's all about late diagnosis
- Research has failed to adequately pair CCT alone with progression or glaucomatous nerve characteristics

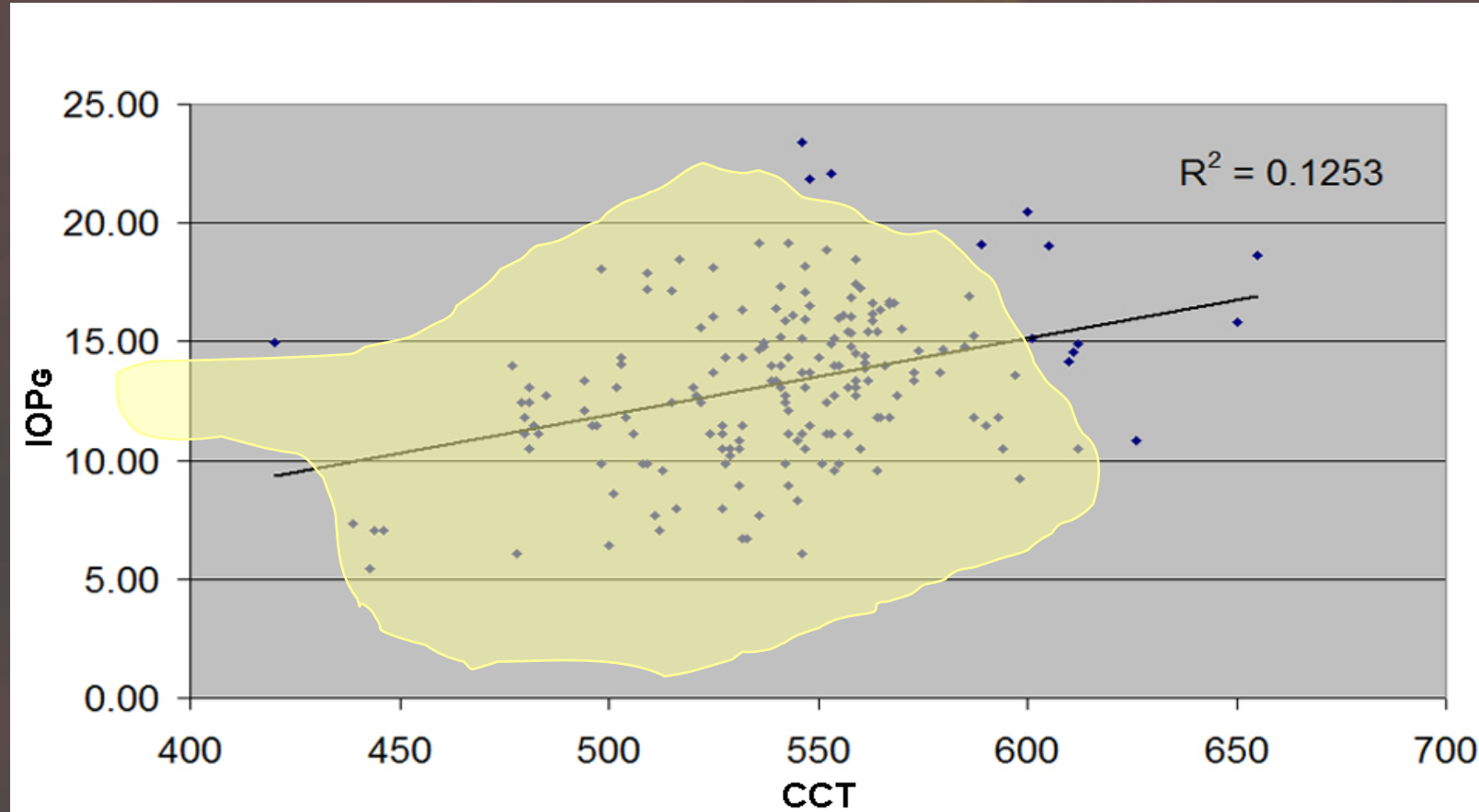


Corneal Thickness & IOP

- Calculation based on data of Ehlers et al (1975)
- Modified from Stodtmeister (1998)
- Arithmetic mean of corneal thickness in healthy subjects: $545 \mu\text{m}$ (Doughty and Zaman 2000)

CCT (μm)	Correction Value (mm Hg)
465	+6
485	+5
505	+3
525	+1
545	0
565	-1
585	-3
605	-4
625	-6

CCT-based IOP correction is invalid



SCATTER in the data makes accurate mathematical “adjustment” of IOP impossible for individuals!

Can IOP measurement be corrected by a simple conversion based on thickness?

- **Not Accurately !!!**
- What about thick, soft corneas and thin, stiff corneas?
- Which parameters dominate the measurement artifact?
- Theory predicts that corneal biomechanical properties dominate!!

Liu and Roberts, JCRS, January 2005



What about OHTS?

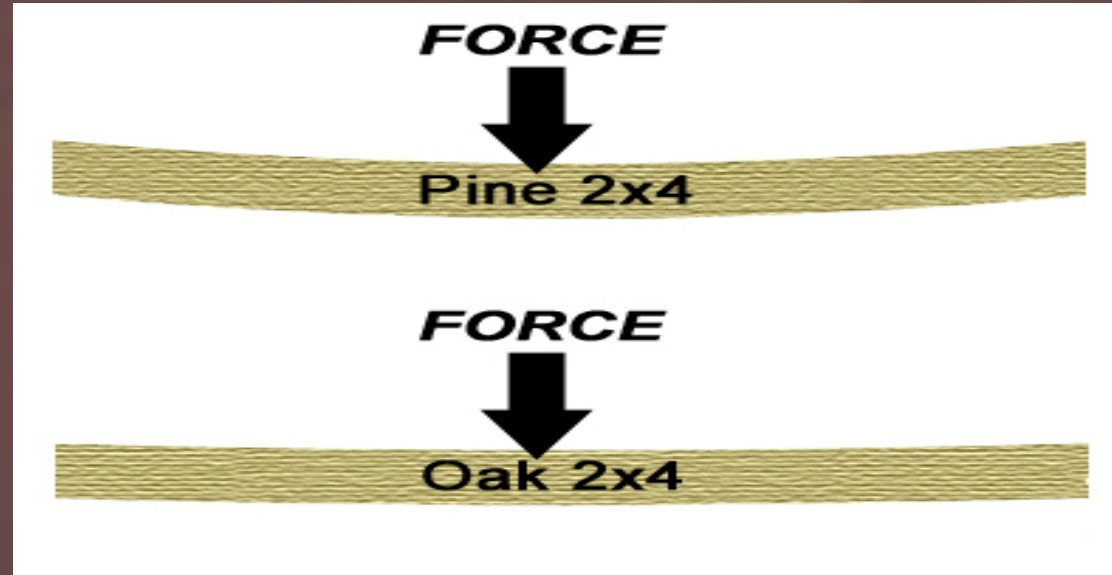


James Brandt, MD
Director Glaucoma Services
UC Davis

“Assuming that CCT can be used as a correction factor for GAT is a misinterpretation of the results of OHTS... that couldn't be further from the truth. Adjusting IOP based on CCT is attempting to instill a degree of precision into a *flawed measurement*. **You may actually correct in the wrong direction.** The issues related to the most accurate tonometry need to include the material properties of the cornea”



Why CCT-based IOP correction is flawed



A force (applanation) tonometer is simply a gauge that measures the force required to flatten the cornea

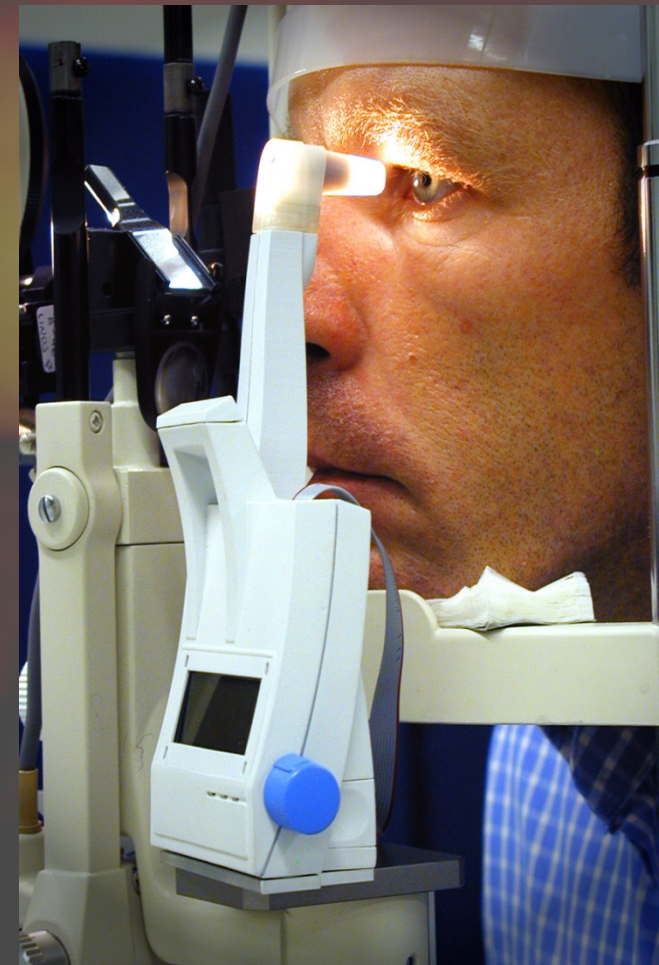
Corneal Resistance to bending is not dependent thickness, but on material properties

Thick and thin is WRONG. Think weak and strong

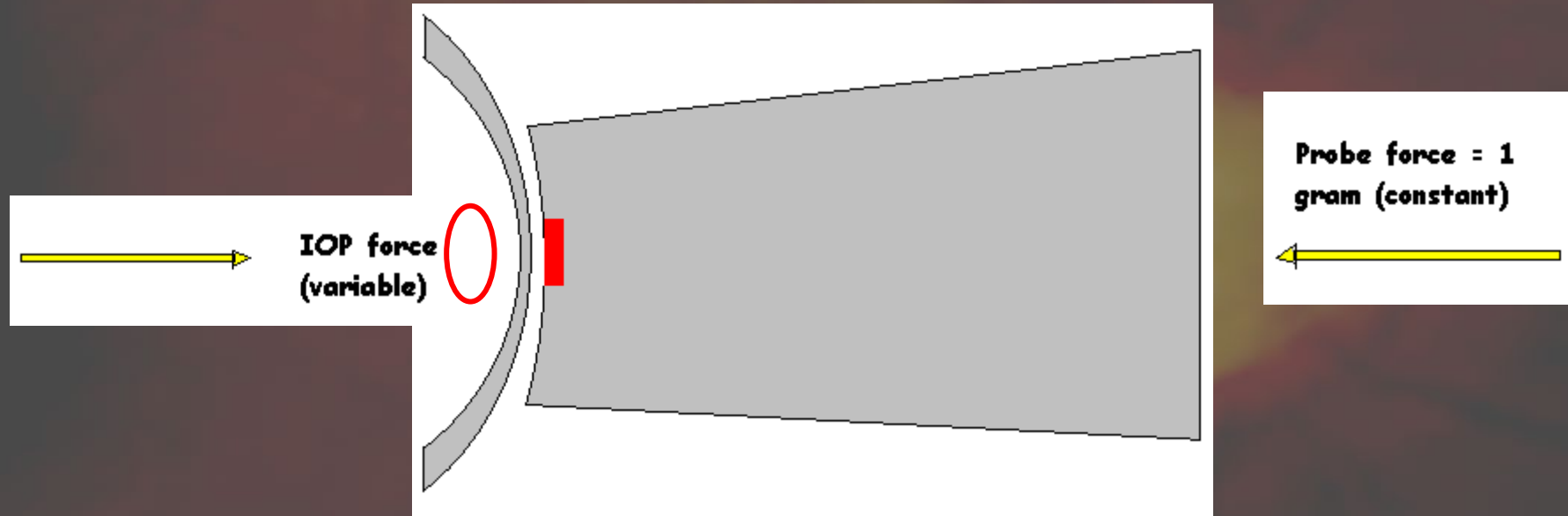


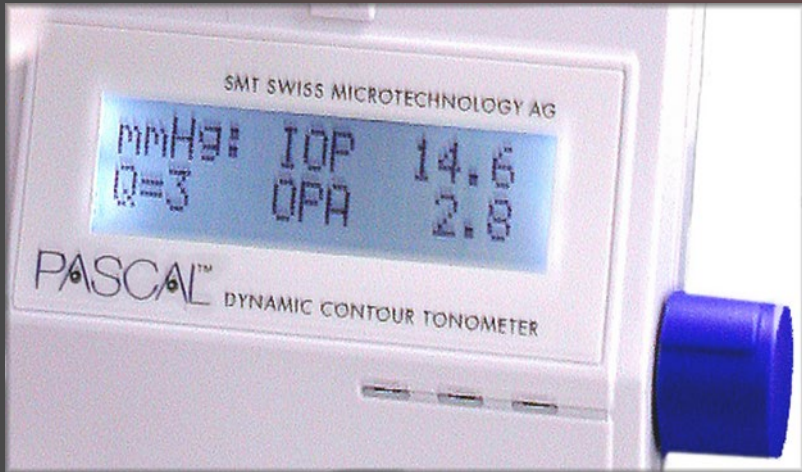
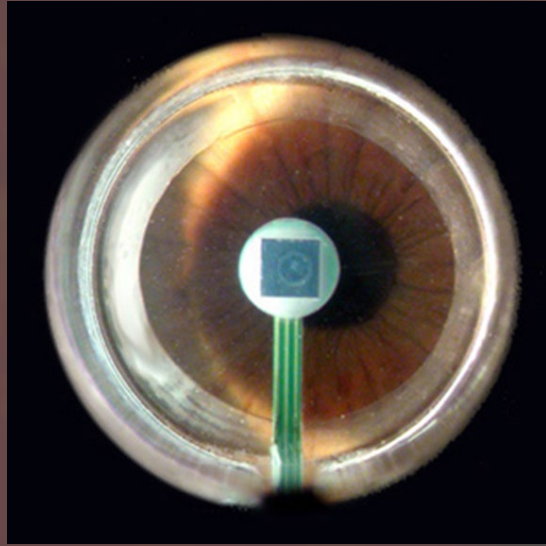
PASCAL Dynamic Contour Tonometry

- independent of biomechanical properties of the cornea (CCT, radius, astigmatism, hydration)
- dynamic IOP furnishes additional diagnostic information: Ocular Pulse Amplitude (OPA)

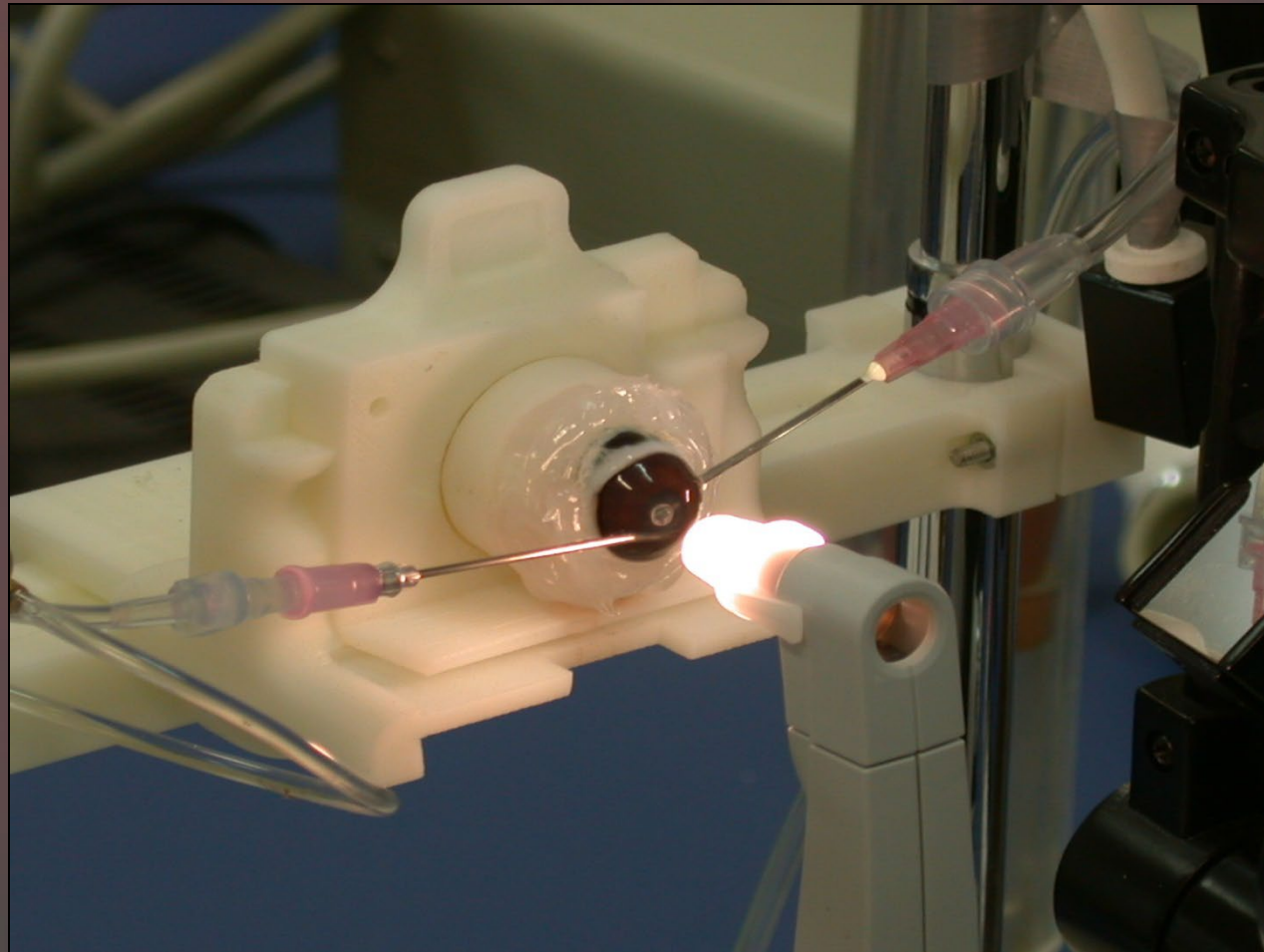


Contour Matching





In Vitro Cannulation



In Vivo Cannulation

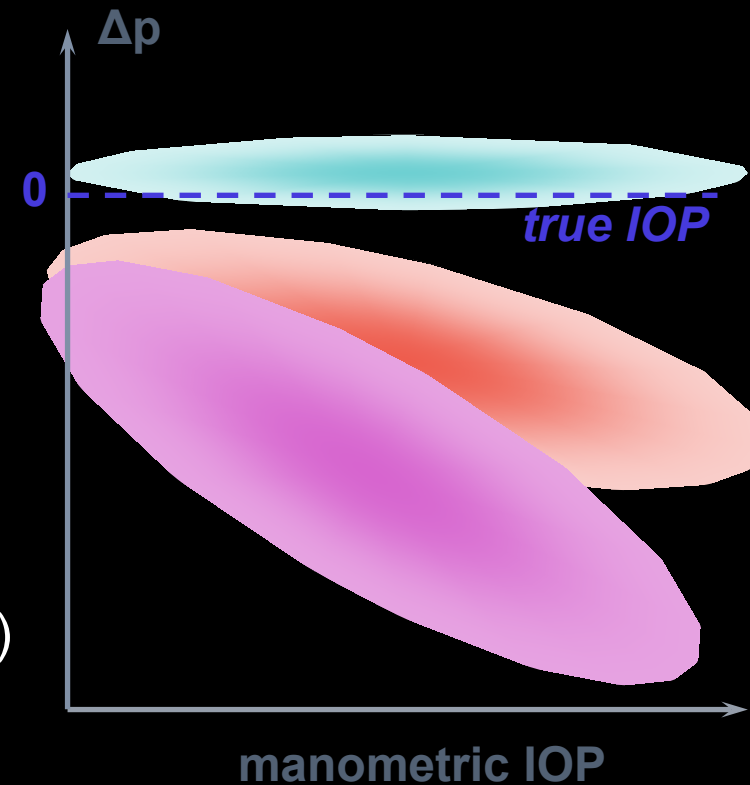


Weber A, Boehm AG, Spoerl E, L, Pillunat LE

In Vitro Cannulation

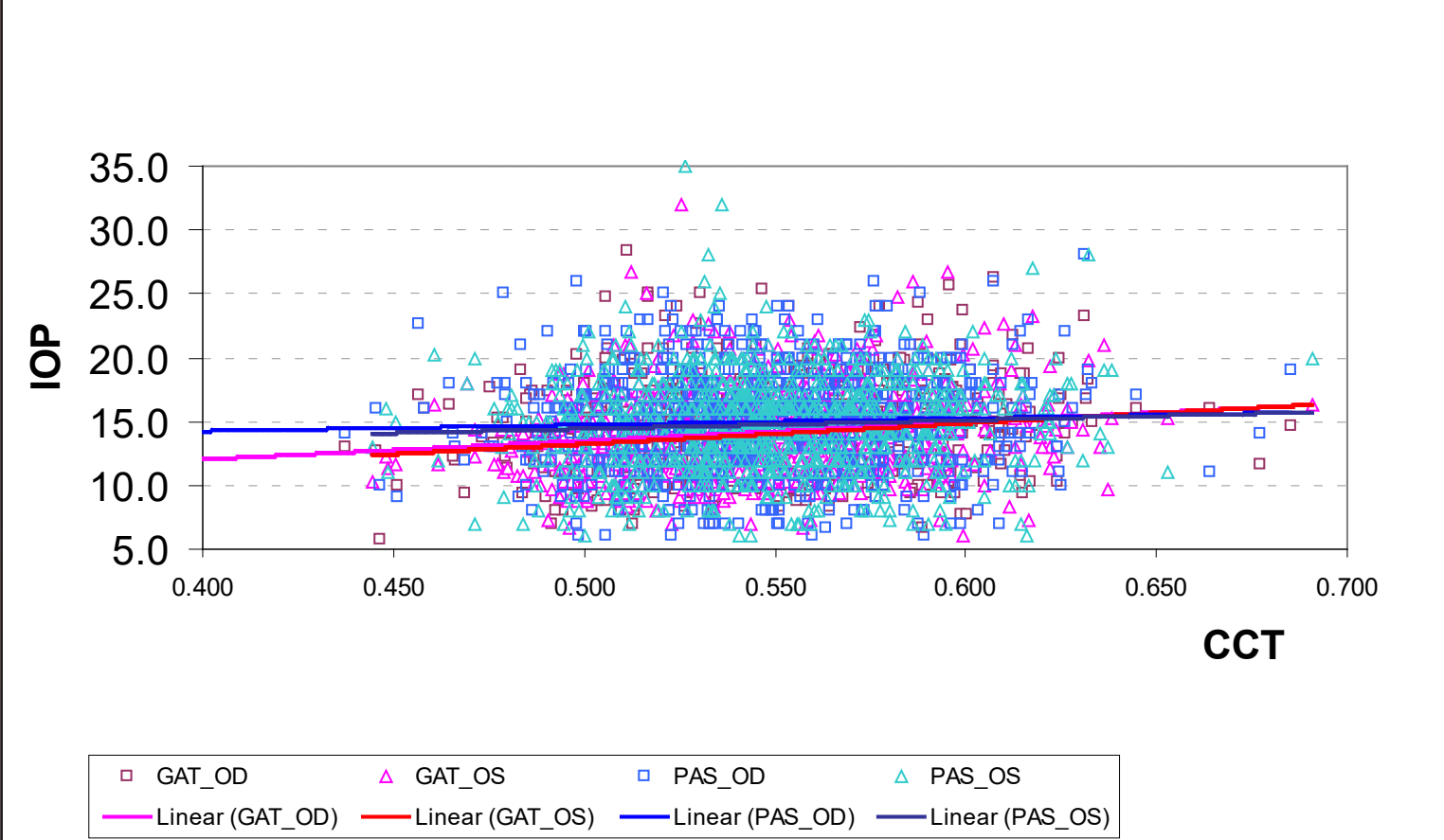
- Comparison of methods (cannulated bulbi):

- "True" manometric IOP
- DCT readings (PASCAL)
- GAT readings (Goldmann)
- PTG readings (Pneumatography)

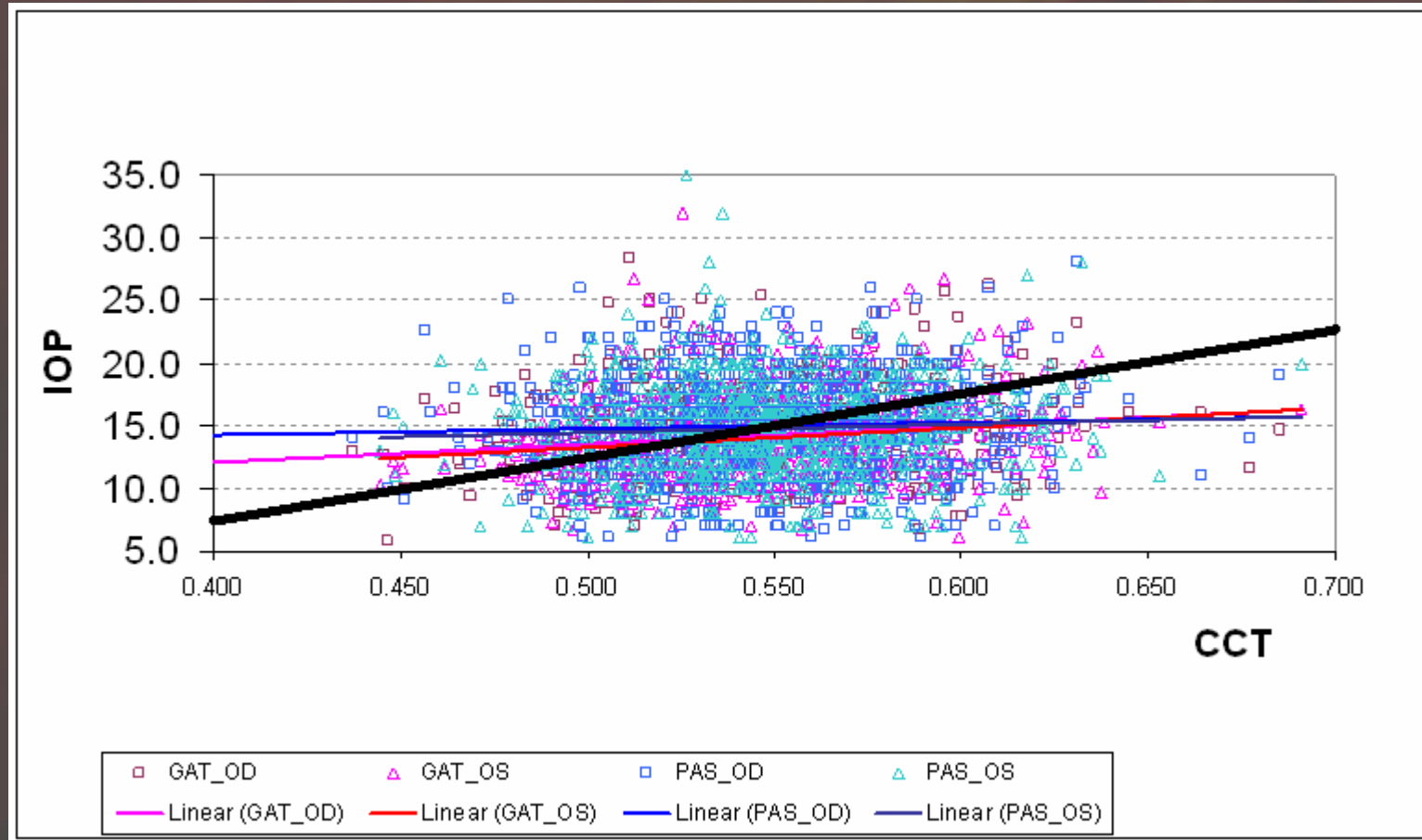


Stamper, Kniestedt et al., Arch Ophthalmol 2004; 122: 1287-1293

Latino Eye Study Correlation of IOP with CCT, GAT and DCT



If the formula was correct....



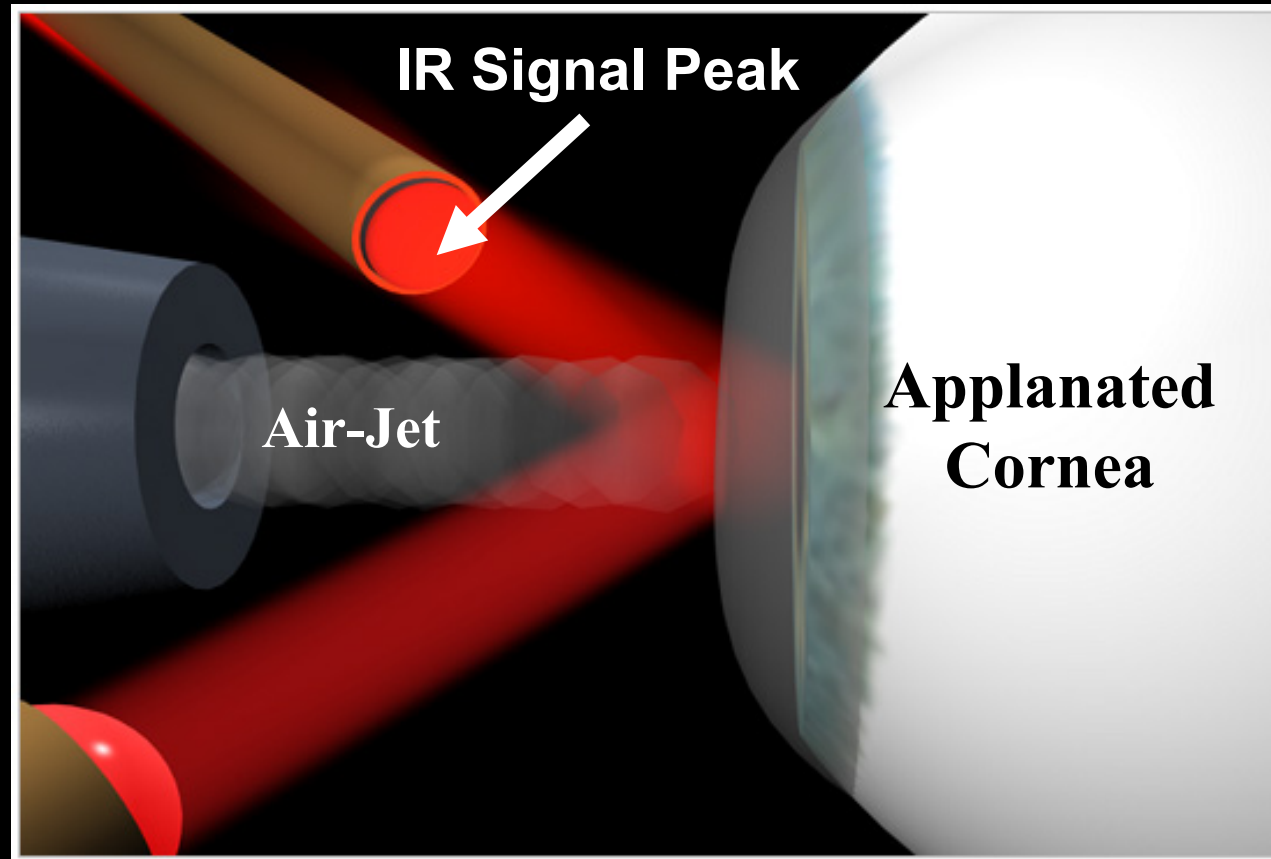


Corneal Hysteresis

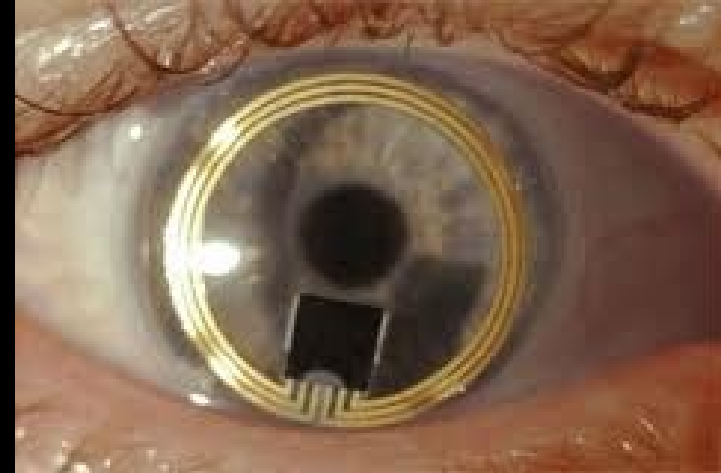
CPT code 92145: Corneal hysteresis determination, by air impulse stimulation, unilateral or bilateral with interpretation and report

Dynamic Bi-Directional Applanation

Air pulse is delivered, inward applanation is recorded



Is 24-hour IOP the new frontier?



Sensimed Triggerfish



The enemy!

late diagnosis....

Bob & Tom 2006

CATS IOP 25 mm + Family Hx

Work up as suspect

Plan...Treat (prostaglandin qd OU)

GAT 20 mm + Family Hx

Plan.....RTO 2 years

Bob



Tom



Bob & Tom 2012

- CATS 19 mm
(prostaglandin qd)

Bob



- GAT 21 mm
- 6 years late!

Tom



Subjects with GAT from 18 - 21 mm Hg GAT the diagnosis “hot spot”

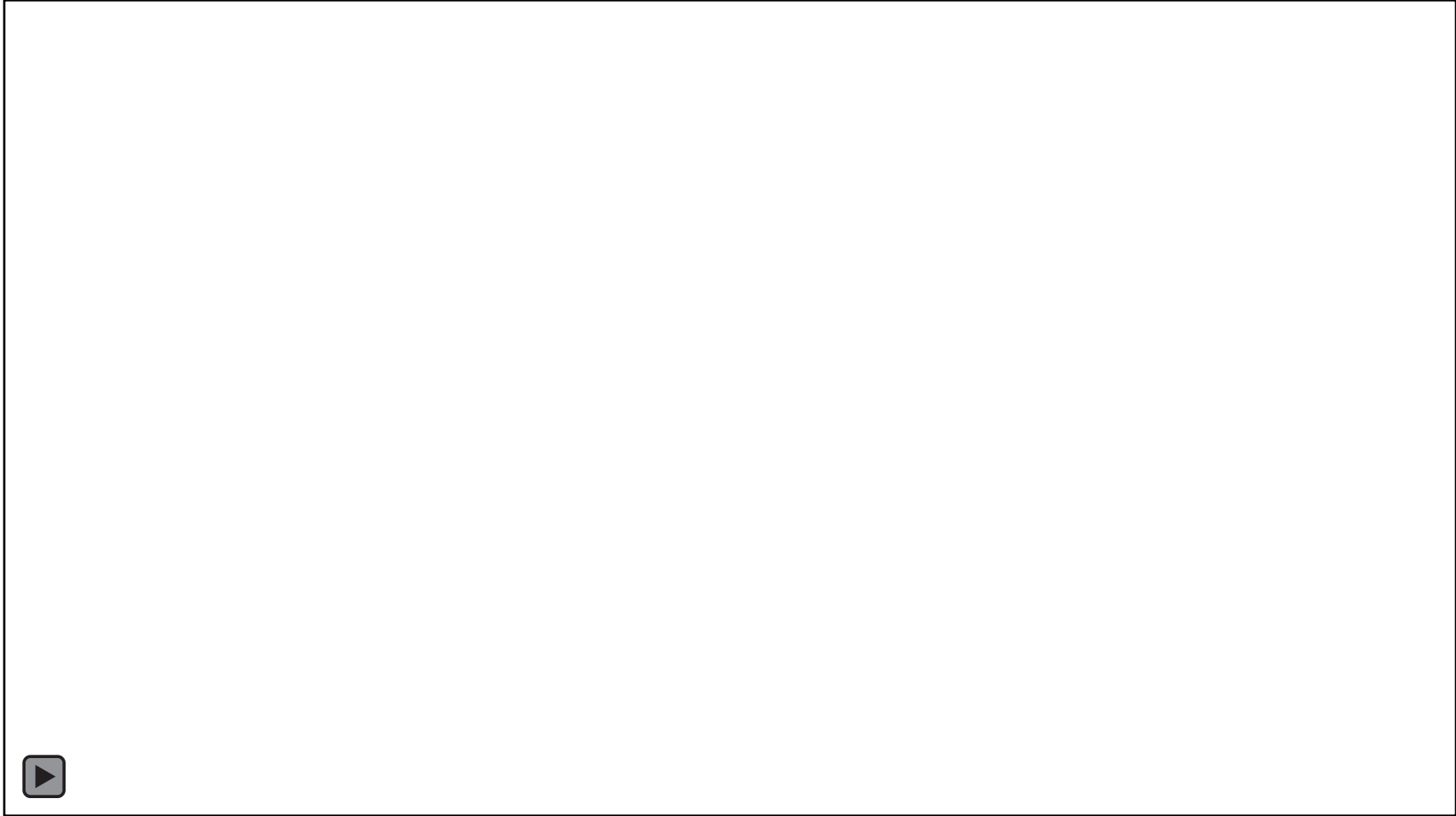
- DCT > GAT > 3mm = 38% > 4.5mm 10.6%
- DCT > GAT > 4mm = 13.7% > 5.5mm 4.4%
- DCT > GAT > 5mm = 5% > 6.5mm 2.5%

*(1.5 mm adjustment in normative
values between instruments)*

CATS

Correcting Applanation Tonometer Surface





From: Goldmann Tonometer Prism with an Optimized Error Correcting Applanation Surface
Trans. Vis. Sci. Tech.. 2016;5(5):4. doi:10.1167/tvst.5.5.4

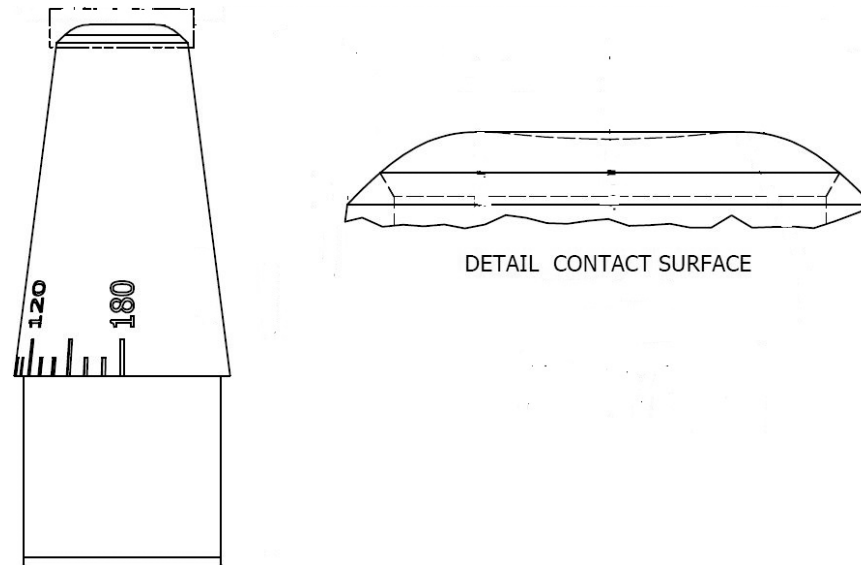
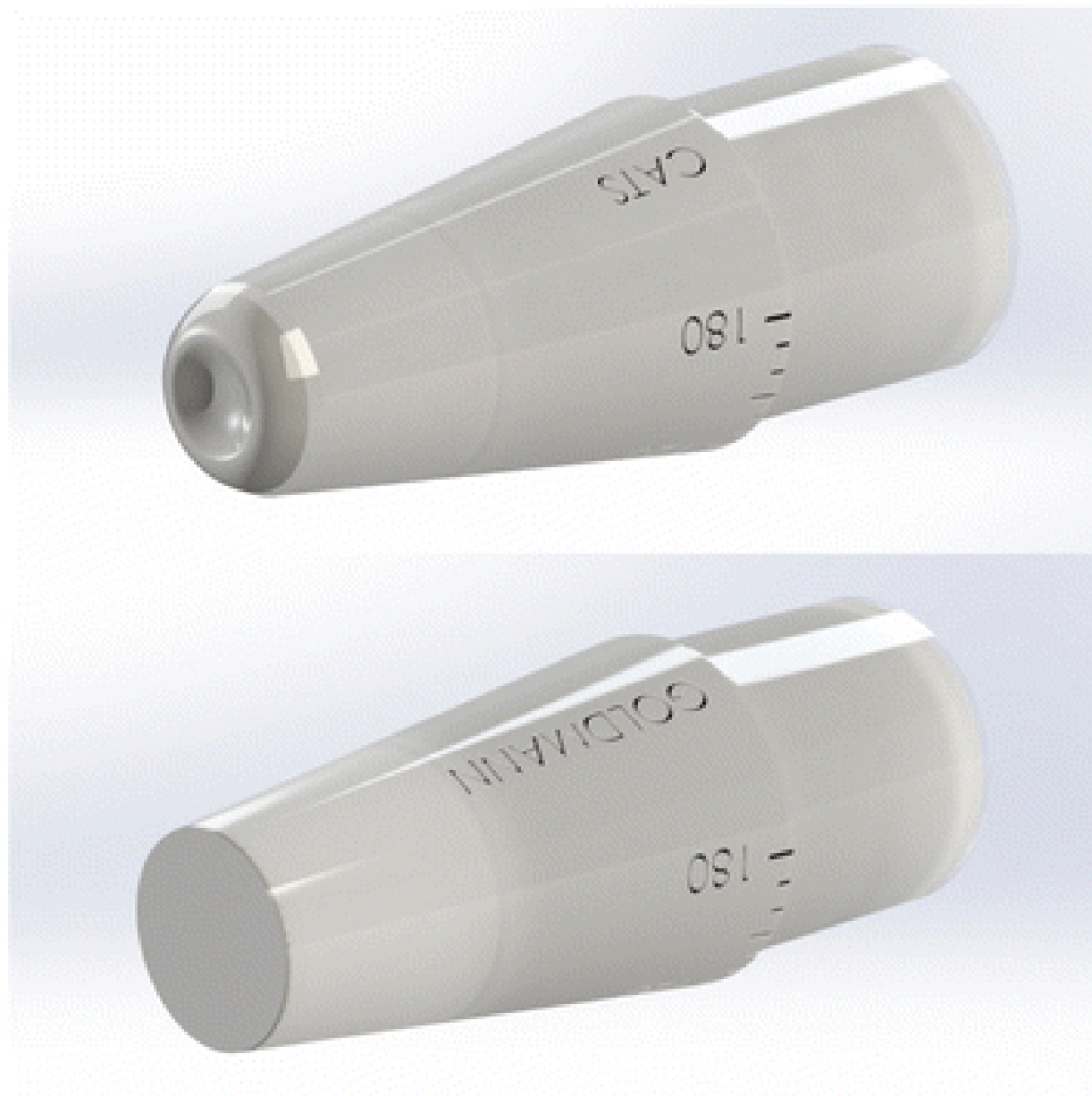
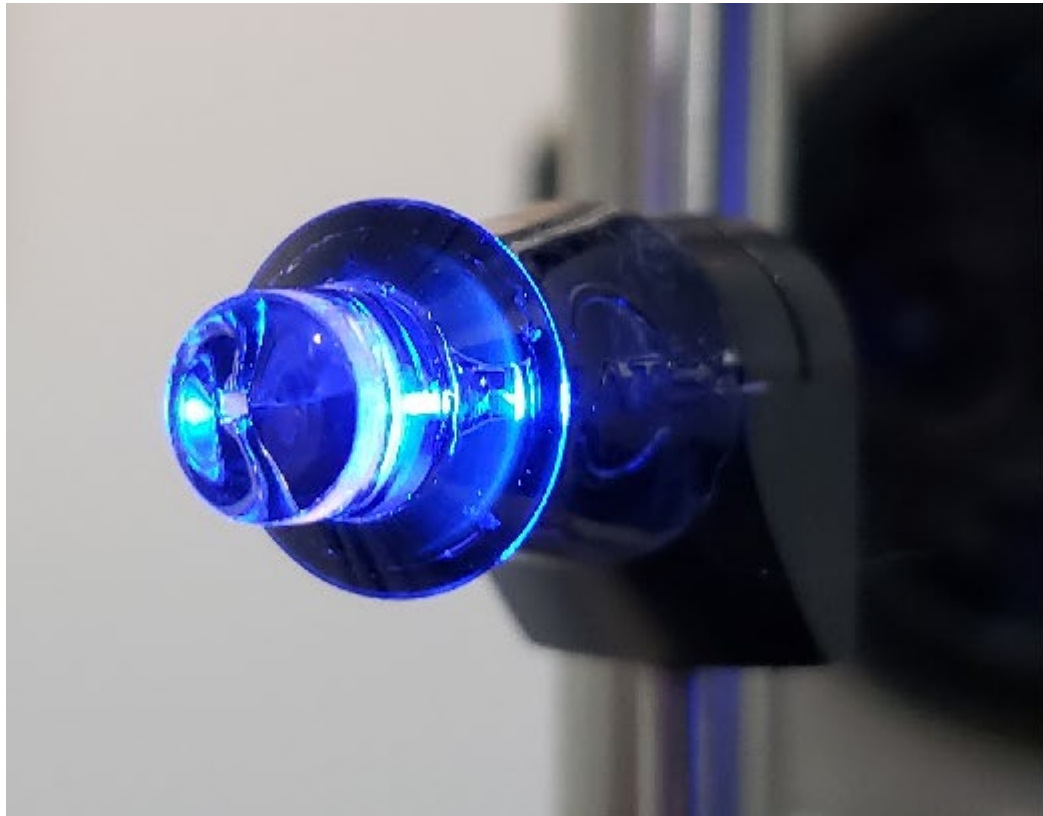


Figure Legend:

Sagittal cross-section of the CATS tonometer prism applanating surface.

CATS and Goldmann tips





From: Goldmann Tonometer Prism with an Optimized Error Correcting Applanation Surface
Trans. Vis. Sci. Tech.. 2016;5(5):4. doi:10.1167/tvst.5.5.4

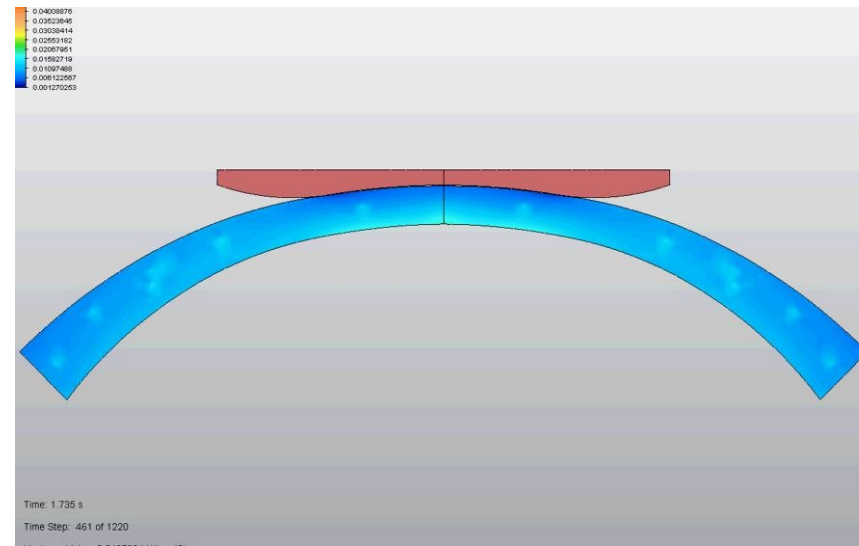


Figure Legend:

Concave-convex prism surface cross-section of the CATS prism surface in contact with the cornea.

Goldmann tonometry tear film error and partial correction with a shaped applanation surface

McCafferty SJ, Enikov ET, Schwiegerling J, Ashley SM

Clinical ophthalmology

Conclusion: The results validate the CATS prism's improved accuracy and expected reduced sensitivity to Goldmann errors without IOP bias as predicted by mathematical modeling.

The CATS replacement for the Goldmann prism does not change Goldmann measurement technique or interpretation.

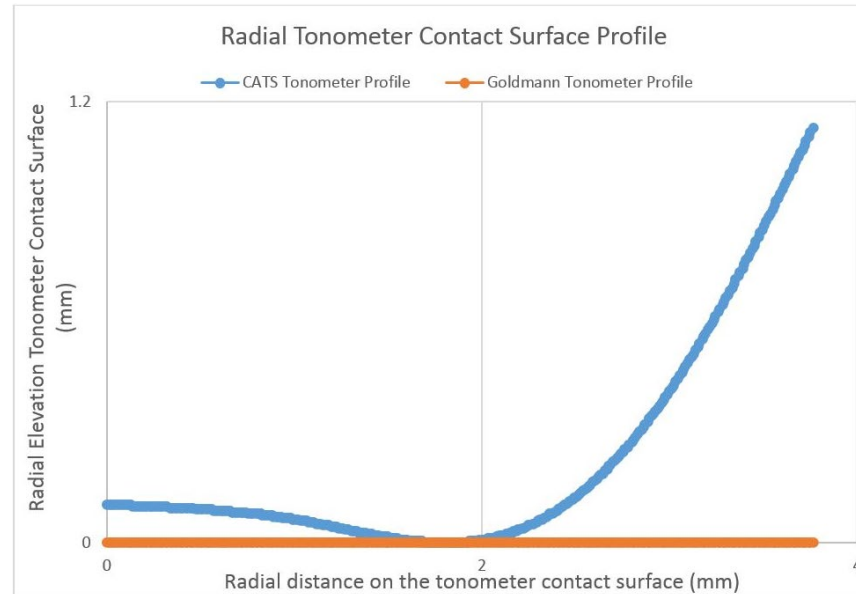


Figure Legend:

Optimized radial profile of the CATS tonometer prism surface designed to minimize the corneal mechanical and tear film hydrostatic contributions to measured IOP in applanation tonometry.

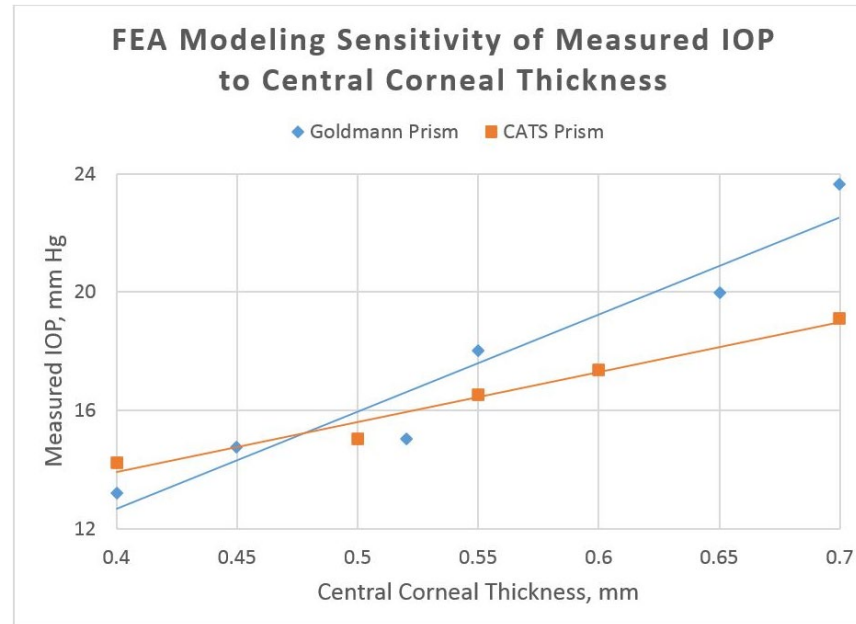


Figure Legend:

Finite element analysis modeling CCT error sensitivity with constant Young's modulus, constant corneal curvature, and constant IOP (note reduced slope indicating decreased error sensitivity with the CATS prism).

Goldmann and error correcting tonometry prisms compared to intracameral pressure

Sean McCafferty, Jason Levine, Jim Schwiegerling & Eniko T. Enikov

BMC Ophthalmology

Conclusion: A CATS prism in Goldmann tonometer armatures significantly improve the accuracy of IOP measurement compared to true intracameral pressure across a physiologic range of IOP values.

The CATS prism is significantly more accurate compared to the GAT prism in thin and less rigid corneas. The in vivo intracameral study validates mathematical models and clinical findings in IOP measurement between the GAT and CATS prisms.



Figure 4. Ocular globe stabilizing apparatus for measuring IOP.

In vitro comparison to GAT



From: **Goldmann Tonometer Prism with an Optimized Error Correcting Applanation Surface**
Trans. Vis. Sci. Tech.. 2016;5(5):4. doi:10.1167/tvst.5.5.4

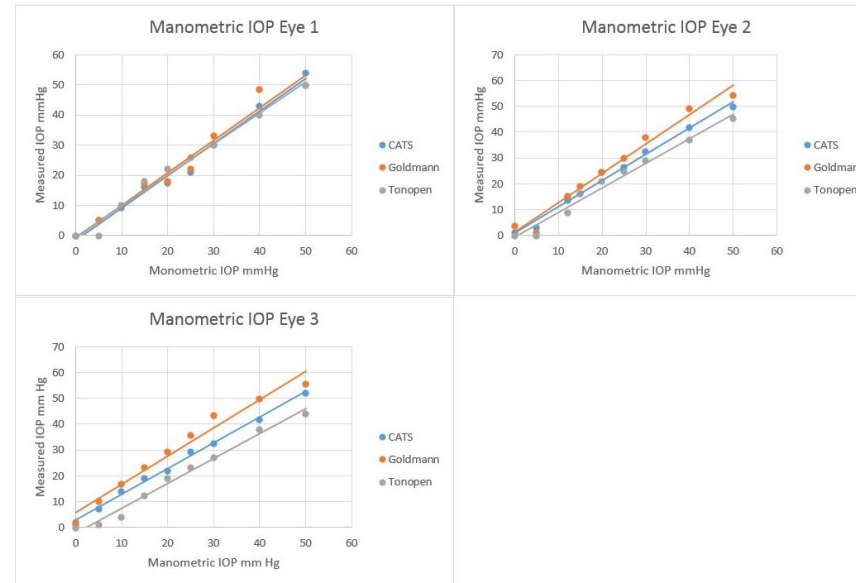


Figure Legend:

Measurement of IOP in (3) cadaveric human globes (A), (B), and (C), using the GAT prism, CATS prism, and Tonopen versus manometric intracameral IOP.

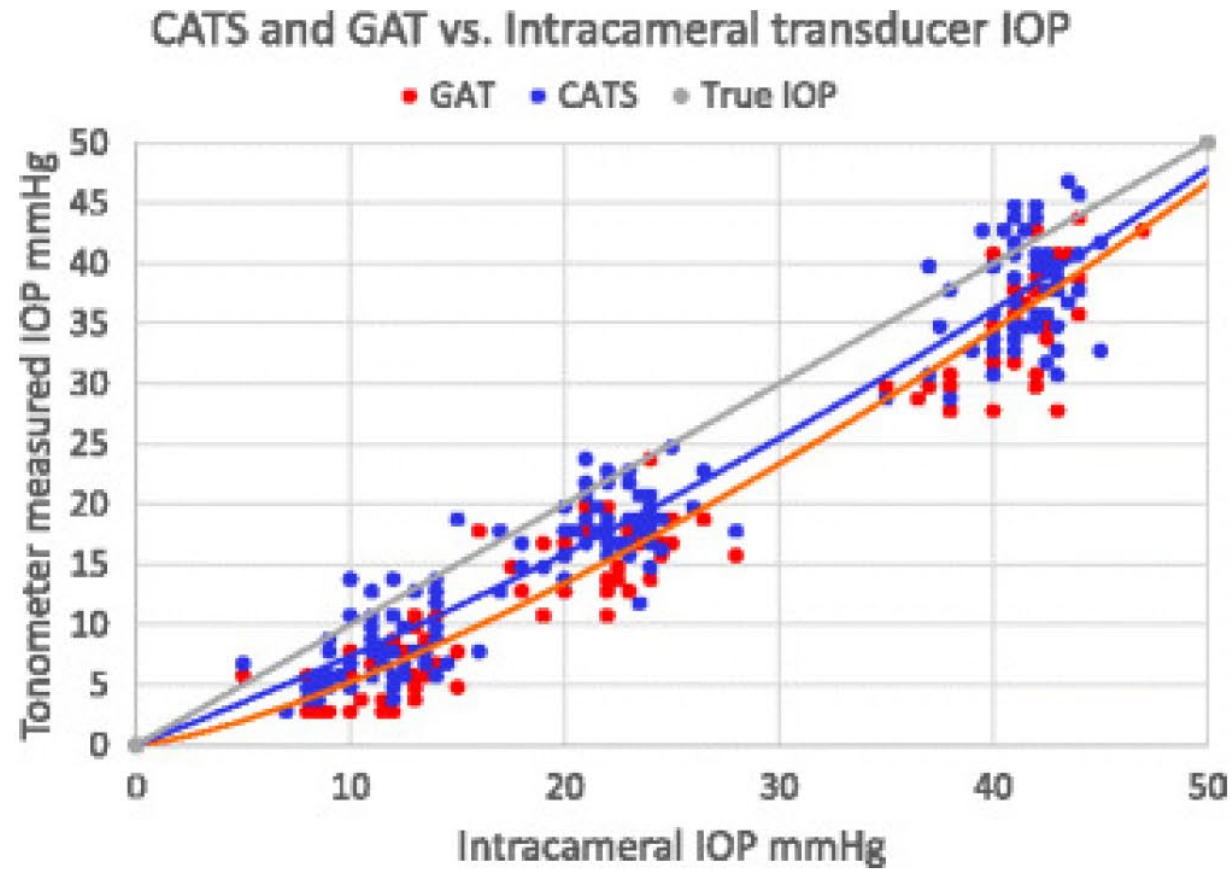
Goldmann applanation tonometry error relative to true intracameral intraocular pressure in vitro and in vivo

Sean McCafferty, Jason Levine, Jim Schwiegerling & Eniko T. Enikov

BMC Ophthalmology

Conclusion:

Goldmann IOP measures significantly lower than true intracameral IOP by approximately 3 mmHg in vitro and 5 mmHg in vivo. The Goldmann IOP error is increased an additional 2.8 mmHg lower in the supine position. CCT appears to significantly affect the error by up to 4 mmHg over the sample size.



In Vivo Perkins IOP measurement scatterplot using the CATS and GAT prisms over all Intracamer al IOPs In live human eyes undergoing cataract surgery

Summary of evidence

Five scientific studies demonstrated the clinical performance of the CATS™ prism in comparison to the GAT prism. The peer-reviewed publications included a direct comparison to the existing GAT prism; human cadaver eye intracameral pressure transducer comparison of the CATS and GAT; an actual intracamerally placed pressure transducer comparison of the CATS and GAT in live human eyes, and tear-film hydrostatic study.

All five studies confirmed the original mathematical modeling design predictions developed in a National Institute of Health, SBIR Phase I grant. Additionally, subgroups of pediatric patients and post-refractive (LASIK, PRK, SMILE, and RK) surgery patients have significantly improved IOP measurements.

Summary of evidence

Studies demonstrated the CATS Prism improves IOP accuracy by 94% over the GAT for this patient population.



Why CATS?

- Simple conversion
- Low cost
- Compelling need for more accurate IOP

Thank you!

Elliot M. Kirstein, OD, FAAO

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Cincinnati, Ohio