Toolbox in managing glaucoma: Tonometry, pachymetry etc.

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Disclosure

- Equipment support from Ziemer Ophthalmology Pascal tonometer
- Equipment support Reichert Ocular Response Analyzer

Intraocular pressure

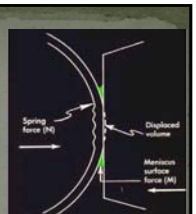
- Diagnosis- not helpful
- Treatment- only proven method
- Progression- very closely associated with IOP
- Risk factor- without a doubt most important risk factor

- In fact only alterable risk factor!

Types of tonometry

- Indentation-Schiötz tonometry – only theoretical interest
- Applanation –
    - Goldmann, Perkins
    - Mackay-Marg-Tonopen
    - Pneumotonometer
    - Non-contact
- Others
    - Dynamic Contour Tonometer
    - Ocular Response Analyzer
    - 7CR
    - Diaton
    - Rebound tonometer

Applanation tonometry



Imbert-Fick law

W = P x A

Where

1. W= external force
2. A=Area
3. P=pressure inside sphere

Conditions for Imbert-Fick Law

- Perfect sphere
- Dry
- Infinitely thin

- $W = P_1 \times A$

Applanation tonometry-2

Modified Imbert-Fick law

$W + S = P \times A + B$

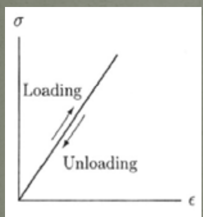
Where
1. S = Surface tension
2. B = Force required to bend the cornea

Factors affecting IOP measurements

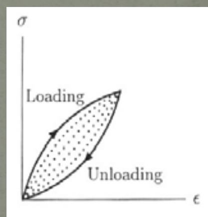
- Central corneal thickness
- Corneal curvature
- Age related changes to cornea
- IOP effects on cornea
- Biomechanical properties
  - Rigidity
  - Hydration
  - Elasticity

Whitacre, M. M. and Stein, R. (1993) Sources of error with use of Goldmann-type tonometers, Surv Ophthalmol, 38, 1-30

Principles



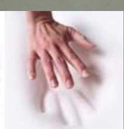
Elastic



Viscoelastic

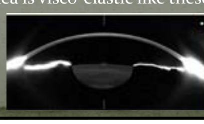
Hysteresis

Many common visco-elastic materials and systems exhibit hysteresis.

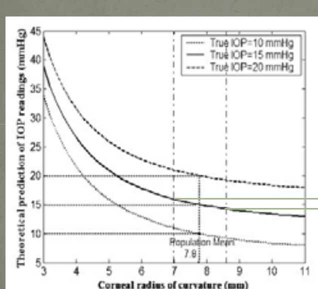




- Automotive struts
- Foam mattresses
- Viscous fluids like honey and oil
- Door dampers (closers)

The Cornea is visco-elastic like these examples



Corneal curvature

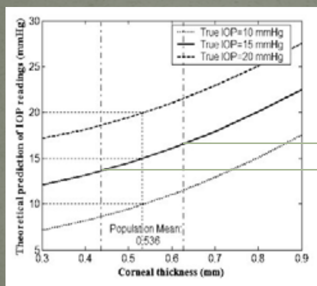


Normal range = mean ± 3 SD

Difference = 1.76mmHg

Liu J & Roberts CJ (2005)
Influence of corneal biomechanical properties on intraocular pressure measurement - Quantitative analysis.
J Cataract Refract Surg 31:146-155

Corneal thickness

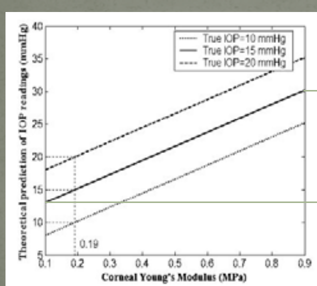


Normal range = mean ± 3 SD

Difference = 2.87mmHg

Liu J & Roberts CJ (2005)
Influence of corneal biomechanical properties on intraocular pressure measurement - Quantitative analysis.
J Cataract Refract Surg 31:146-155

Corneal biomechanics

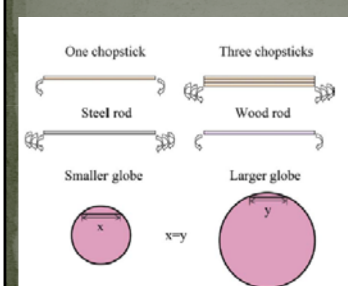


Normal range = uncertain
(range used = published values)

Difference = 17.26mmHg

Liu J & Roberts CJ (2005)
Influence of corneal biomechanical properties on intraocular pressure measurement - Quantitative analysis.
J Cataract Refract Surg 31:146-155

Understanding biomechanics of cornea



Liu J & Roberts CJ (2005)
Influence of corneal biomechanical properties on intraocular pressure measurement - Quantitative analysis.
J Cataract Refract Surg 31:146-155

Inherent differences

- Contact area and region
- Anesthetic required
- Non-contact
- portable or hand held
- disinfection required
- observer dependence

Error due to corneal parameters

- Hans Goldmann knew that his tonometer will be affected by central corneal thickness should it vary largely from average.
- Ehlers 1975 series of papers showed the IOP measured using the Goldmann applanation tonometer systematically varied with central corneal thickness.

IOP and Glaucoma

- Elevated IOP is associated with glaucoma for more than a century. But.......NTG? OHT?
- NTG have thinner than average CCT
  - IOP underestimated
- OHT have thicker than average CCT
  - IOP overestimated

IOP and refractive surgery

- Drop in IOP:
  - 0.46 mmHg per 10 µm (NCT)
    - Chatterjee et al. Ophthalmology 1997;104:355-9
  - 0.62 to 1.00 mmHg per 10 µm (NCT)
  - 0.71 mmHg per 10 µm (GAT)
    - Cennamo et al Ophthalmologica 1997;211:341-3

Tonometric correction factors

IOP correction factors

- Corrected IOP was calculated using:
  - Ehlers model (1975)
    - Manometry and simultaneous tonometry
    - Table for correction factors
  - Orssengo and Pye model (1999)
    - Finite element analysis
    - Calculates stress and strain on cornea
    - Does not assume linearity

Ehlers correction factor

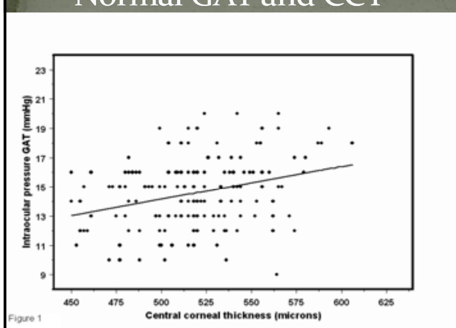
- 5 mmHg for 70 micron change in CCT.

Orssengo and Pye equation

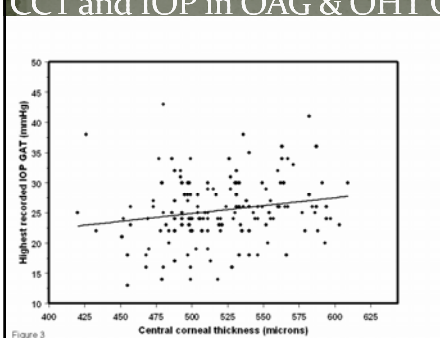
Study participants

- Total n = 324 subjects
  - Normal = 175
  - OAG or OHT = 149

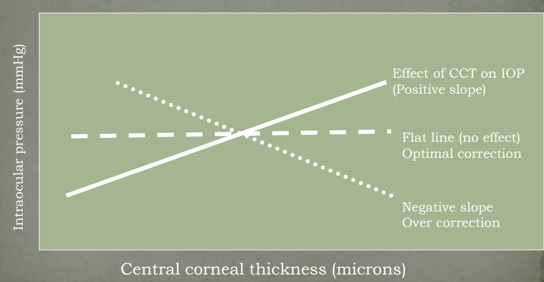
Normal GAT and CCT



CCT and IOP in OAG & OHT Group



Effect, correction and over-correction



Corrected IOP Normal

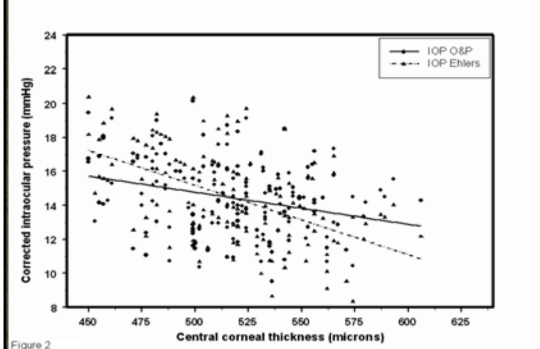


Figure 2

**

Corrected IOP OAG & OHT Group

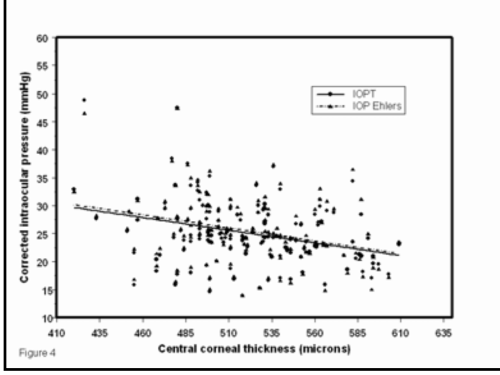


Figure 4

**

Summary of scatter plots

- There is a statistically significant residual effect of CCT after correcting IOP.
- There is a negative residual slope after correction indicating over correction.

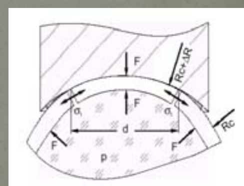
Gunvant et al. Evaluation of tonometric correction factors.
J Glaucoma. 2005 Oct;14(5):337-43

Take home message from tonometric correction factors

- Do not depend on it!

Pascal -Dynamic Contour Tonometer

Dynamic contour tonometer

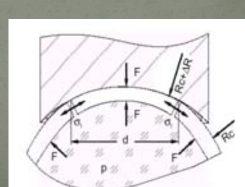


Dynamic contour tonometer (cont 2)

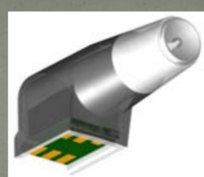
- Minimal corneal deformation, allowing transducer to measure IOP directly
- Digital output
- Continuous recording of IOP waveform

Dynamic contour tonometer (cont 3)

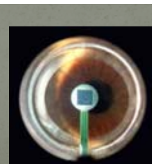
- The corneal biomechanical contribution to IOP measurement is largely removed when the cornea takes up the shape of the tip.
- Tip radius of curvature is 10.5mm.
- Pressure sensor is 1.5 mm.



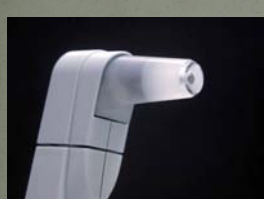
The PASCAL SensorTip:



- Contour-matched concave tip surface
- Built-in pressure sensor
- Transparent tip permits view of cornea interface for centering and control.



PASCAL SensorCaps

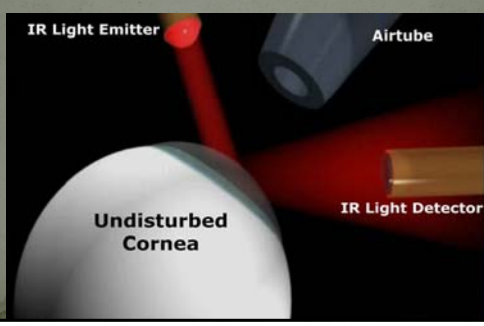


- SensorCap protects the patient
- SensorCap protects the tip

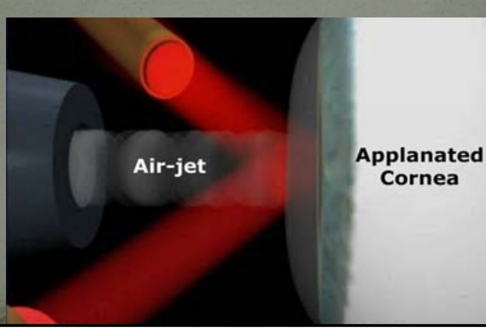
Ocular Response Analyzer

- **IOPG** - Goldmann Correlated IOP
- **IOPCC** - Corneal Compensated IOP
- **CH** - Corneal Hysteresis
- **CRF** - Corneal Resistance Factor
- **CCT** - Central Corneal Thickness

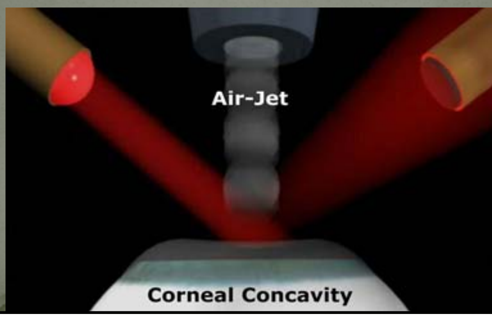
Applanation Detection



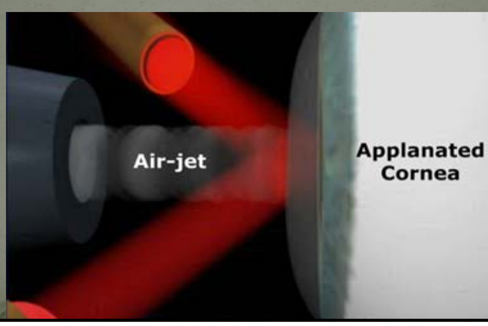
Applanation Detection II



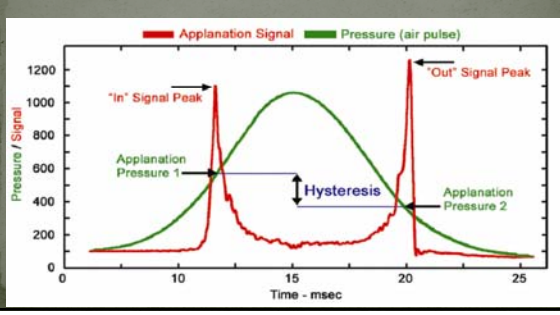
Applanation Detection III



Applanation Detection IV



Applanation Signal Plot

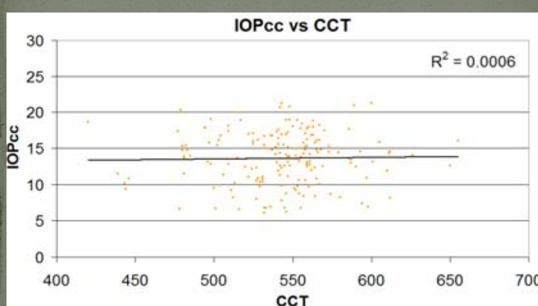


Reichert 7CR

AUTO TONOMETER + CORNEAL RESPONSE TECHNOLOGY

The Glaucoma Tonometer

7CR IOPcc vs CCT Normals



IOPcc is not influenced by the thickness of the cornea

Data courtesy New England College of Optometry

Tonopen

Mackey-Marg devices

Advantages
- Small area of contact
- Sterile caps
- In scarred and irregular cornea
- In post LASIK and post-operative cornea – peripheral measurements can be obtained
- Portable

Disadvantages
- Expensive over time
- Need anesthetic
- Calibration issues
- Battery
- Fragile

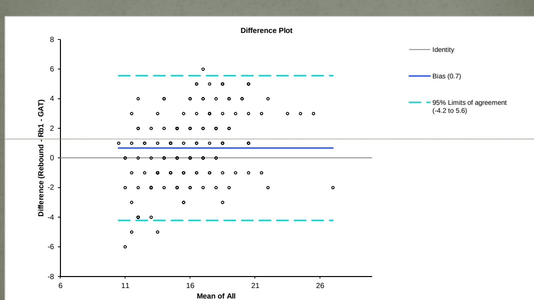
Rebound tonometer

Procedure

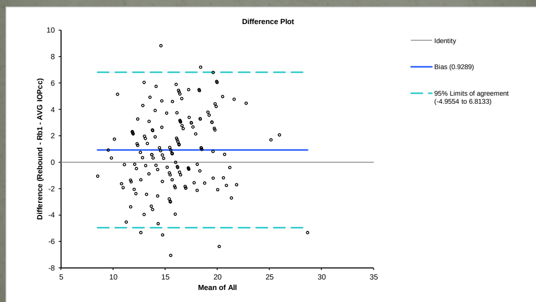
Advantages

- No anesthetic requirements
- More natural position rather than slitlamp
- Disposable probe
- May have use in screenings

Goldmann applanation tonometer versus Rebound tonometer



ORA and Rebound tonometer



Intraocular pressure telemetry

Need of IOP telemetry

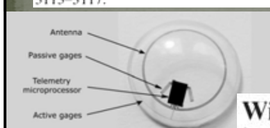
- 24-hour IOP measurement not easy
- Uncertain cases of NTG, progression, high risk for progression
- Need to evaluate clinical efficacy of drugs
- New drugs and modalities testing
- May be more accurate than clinical measurements
- Continuous monitoring will help identify spikes in IOP both short and long term

Types of IOP telemetry

- Non invasive- temporary
  - CL's
  - continuous applanation or indentation devices
- Invasive- permanent
  - Subconjunctival
  - anterior chamber implants
    - in AC
    - as IOL haptics
    - Scleral buckle
    - scleral fixated sensor
  - Posterior chamber implants –choroidal

Temporary devices contact lenses

Leonardi M, Leuenberger P, Bertrand D, et al. First steps toward noninvasive intraocular pressure monitoring with a sensing contact lens. *Invest Ophthalmol Vis Sci.* 2004;45: 3113–3117.

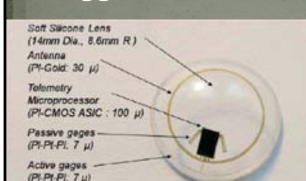


Wireless contact lens sensor for intraocular pressure monitoring: assessment on enucleated pig eyes

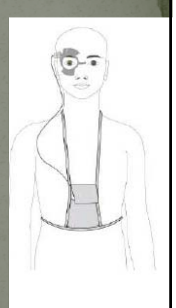
Matteo Leonardi,[1] Elie M. Pitchon,[1,2] Arnaud Bertsch,[1] Philippe Renaud[1] and André Mermoud[2]

SENSIMED
innovation in medical micro-technology

Triggerfish



Central Corneal Radius (Flat Meridian)	7.0–7.65 mm 48–44 D		7.65–8.4 mm 44–40 D	
Corneo-scleral Profile	Fluent	Marked	Fluent	Marked
Base Curve	8.4 (STEEP)	8.7 (MEDIUM)	8.7 (MEDIUM)	9.0 (FLAT)



Cost 500 Euro. Not available for sale in USA

Summary

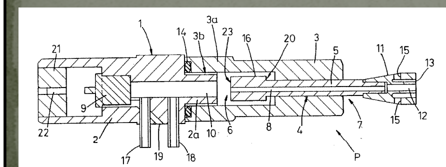
- Goldmann applanation tonometer (GAT) still the gold standard
- Pascal and Ocular response analyzer both provide IOP measurement that is better than GAT
- Tonopen and Icare should not be used clinically if the GAT can be performed successfully
- IOP telemetry may provide very useful clinical information

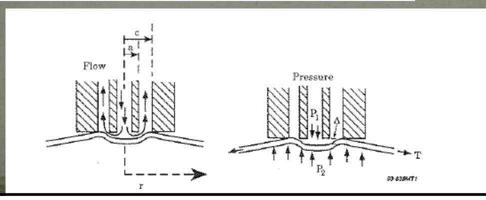
Blood Flow analyzers

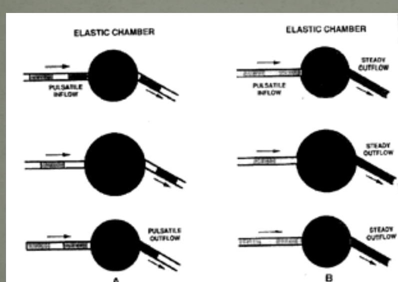
Pneumotonometer

- IOP: 200 /sec
- Up to 20 seconds
- Measures 7 pulses and selects 5 best to calculate IOP and POBF
- Also gives pulse amplitude and calculates pulse volume

Pulsatile ocular blood flow







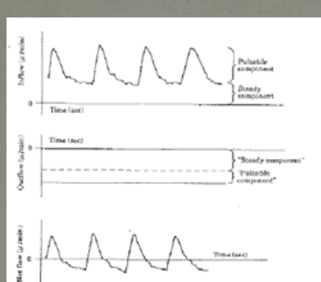


Table 3 Comparison of the mean pulsatile ocular blood flow reported in different studies

Study	*Total subjects*	*POBF (μl/min)*	*Instrument*	*Male:female*
Massey *et al*[17]	664	808 (Mean POBF)	OBF system (Software version unknown)	Not known
Yang *et al*[10]	167	756 (Mean POBF)	OBF system (Software version unknown)	73:94
Fontana *et al*[11]	777 (1554 eyes)	824 (Median POBF)	OBF system (Software version 3.01)	347:430
Gekkieva *et al*[21]	155	685 (Mean POBF)	Langham Blood Flow system	86:69
Mori *et al*[20]	80	593.3 (Median POBF)	Langham Blood Flow system	27:53
Lam *et al*[8]	74	661.2 (Mean POBF)	OBF system (Software version unknown)	33:41
Morgan *et al*[9]	16	1198 (Mean POBF)	OBF system (Software version unknown)	Not known
Indians (Present study in India)	252	1176.3 (Mean POBF)	OBF system (Software version 16.2)	122:130

Gunvant et al. Comparison of pulsatile ocular blood flow in Indians and Europeans *Eye*, 2005, 19, 1163-1168.

Pulsatile ocular blood flow

- A calculated value
- Suggested that could be indicative of a disease.
- Large range of normality and is derived making numerous assumptions.

Ocular pulse amplitude

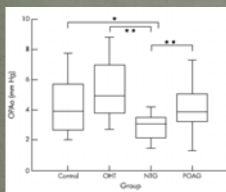


Table 2 Group comparisons by two sample Wilcoxon tests

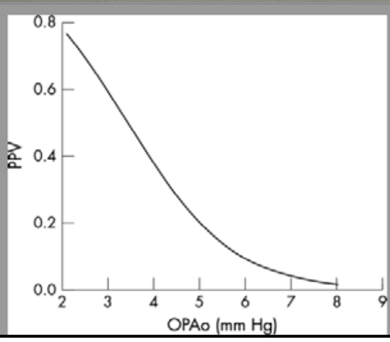
	OPA	Pachymetry (CCT)
POAG/NTG	p<0.01*	p=0.43
POAG/OHT	p=0.09	p=0.03*
POAG/control	p=0.99	p=0.57
NTG/OHT	p<0.01*	p=0.01*
NTG/control	p=0.01*	p=0.68
OHT/control	p=0.09	p<0.01*

*Indicates local statistical significance.

O Schwenn, R Troost, A Vogel, F Grus, S Beck, N Pfeiffer

Br J Ophthalmol 2002;86:981–984

OPA and NTG

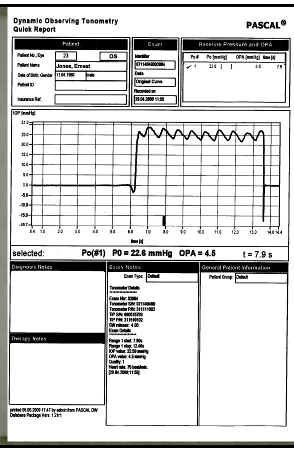


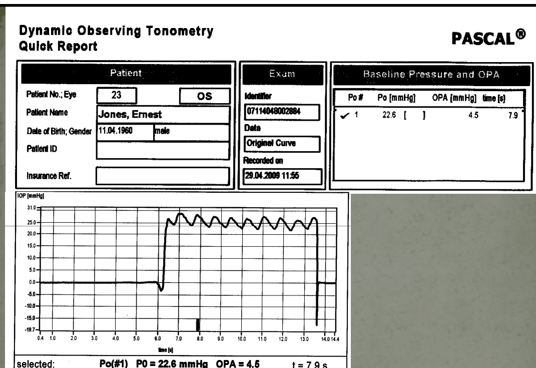
Ocular Pulse Amplitude in Normal Tension and Primary Open Angle Glaucoma

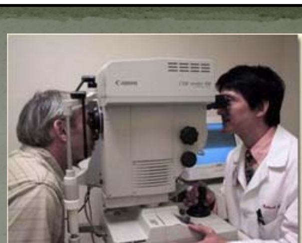
Ingeborg Stalmans, MD, PhD, Alon Harris, PhD,† Veerle Vanbellinghen, BSc,* Thierry Zeyen, MD, PhD,* and Brent Siesky, PhD†*

Conclusions: OPA is reduced in normal tension and POAG patients compared with healthy controls. OPA is influenced by IOP, but not by corneal thickness.

(*J Glaucoma* 2008;17:403–407)







Cannon laser blood flowmeter

Technology

- Uses two lasers
  - One measures blood velocity
  - Second laser measures vessel diameter
- Unit is a fundus camera
- Large artery or vein is selected
- Unit measures at a specific site
  - Blood flow is calculated

Principles

- Based on Doppler principles
- Blood vessel gives back same frequency because it is stationary – not Doppler shifted
- Moving blood is Doppler shifted
- Light from these two reflective sources- interference pattern is produced
- This interference pattern moves
- Thus blood flow is calculated.

Heidelberg retinal flowmeter

- Combines confocal scanning laser technology and Doppler principles

Summary

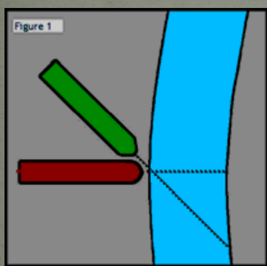
- No gold clinical gold standard where ocular blood flow measurement is concerned
- Expensive
- Noise in measurement is high thus making it difficult to obtain data consistently.

Pachymetry

Ultrasound pachymetry is standard

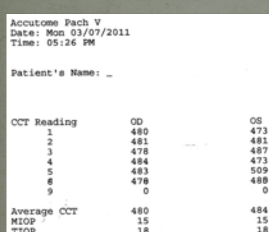
- As central data as possible
- Greater number of measurements increase your reproducibility of data
- Always use lowest data

Why lowest data?



- Perpendicular measurements are lowest or smallest in value

Why not average the data?



Accutome Pach V
Date: Mon 03/07/2011
Time: 05:26 PM

Patient's Name: _

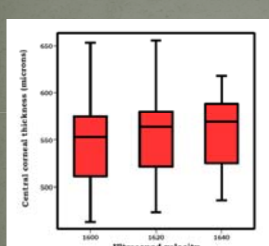
CCT Reading	OD	OS
1	480	473
2	481	481
3	478	487
4	484	473
5	483	509
6	478	488
9	0	0
Average CCT	480	484
MIOP	15	15
TIOP	18	18

- Average 484 microns
- Lowest 473 microns
- Averaging helps decrease error but does not eliminate it.

A Haun, P Gunvant, M Baskaran, L Vijaya: Central corneal thickness measurement using a pachometer: Mean or lowest values? Invest Ophthalmol Vis Sci, 2004, 45: E-Abstract 137

Do all pachymeters give us the same measurements?

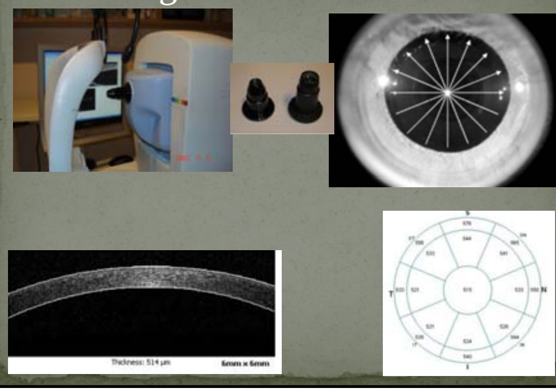
- **NO**
- values vary on the basis of
  - Velocity of ultrasound used in algorithm
  - MHz of probe
    - 20 MHz $\pm$ 3 microns accuracy
    - 50 MHz $\pm$ 1 micron accuracy



The whiskers represent 95% CI of population

MB Taub, FW Chang, **P Gunvant**: Factors affecting measurement of central corneal thickness. ***Optometry and Vision Science***, 2007; 84: E-abstract 075286

Anterior segment OCT

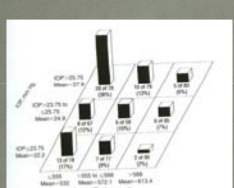


Difference between optical and ultrasound pachymetry measurments

Author	Difference in OCT and ultrasound values
Kim et al *AJO 2008*	26 microns
Wang et al *J Refract Surg 2008*	38 microns
Gunvant & Darner *Medical Imaging 2011*	13 microns

Kim, H.Y., Budenz, D.L., Lee P.S, et al., " Comparison of central corneal thickness using anterior segment optical coherence tonography vs ultrasonic pachymetry, Am J Ophthalmol,; 145:228-232 (2008).
Wang, J.C., Bunce, C., and Lee, H.M., " Intraoperative corneal thickness measurement using optical coherence pachymetry and corneo-gage plus ultrasound pachymetry J Refract Surg. 24(6):610-4 (2008
P Gunvant, R Darner: Evaluation of corneal thickness measurements obtained using optical coherence tomography and ultrasound technique and determination of specificity in keratoconus screening **Medical Imaging:** 79661 B1-B8

How to use CCT data in glaucoma management?



- Error in IOP measurements
- Ocular hypertensive patients
  - Thinner cornea at greater risk of developing glaucoma

The Scoring Tool for Assessing Risk (S.T.A.R. II) calculator

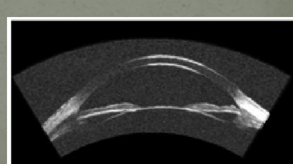
- OHTs and EGPS data
- Intended for use only in untreated OHT patients
- Age (30-80)
- IOP 20-32 mmHg
- CCT 475 to 650 microns
- PSD 0.50 to 3.00 dB
- C/D ratio vertical 0.00 to 0.8

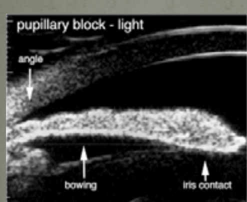
Probability of conversion in 5- years
<5% observe and monitor
5 to 15% consider treatment
>15% treat

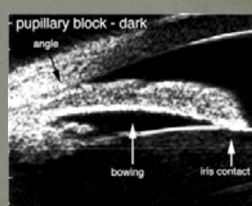
Ultrasound biomicroscope

Technology

- Uses 35 MHz probe
- Can work well through opaque media – OCT does not work well.

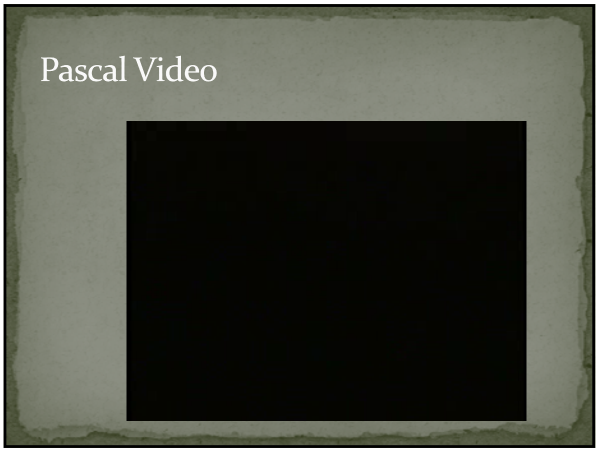






Summary

- Tools, tools and more tools in glaucoma
- All these have a role to play in managing glaucoma patients.
- Can we do a good job without some of these tools
  - I think yes- blood flow etc is nice to know … and yet its utility?
  - Corneal thickness is must as per laws
  - A good reliable and accurate tonometers can do wonders in identifying glaucoma suspects accurately and managing glaucoma patients!


Pascal Video