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-Schötz 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

\[ W = P \times A \]

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

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 also visco-elastic like these examples.
Corneal thickness

\[
\text{Normal range} = \text{mean} \pm 3 \text{ SD}
\]

\[
\text{Difference} = 2.87 \text{ mmHg}
\]


Corneal biomechanics

\[
\text{Normal range} = \text{uncertain (range used = published values)}
\]

\[
\text{Difference} = 17.26 \text{ mmHg}
\]


Understanding biomechanics of cornea

One chipstick

Steel rod

Smaller globe

Three chipsticks

Wood rod

Larger globe

\[
? = \text{x}
\]
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

Show me the data!

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 of CCT on IOP

- Positive slope: Effect of CCT on IOP
- Flat line (no effect): Optimal correction
- Negative slope: Over correction

Central corneal thickness (microns)

**Corrected IOP Normal**

**Corrected IOP OAG & OHT Group**
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.


Take home message from tonometric correction factors
- Do not depend on it!

Pascal - Dynamic Contour Tonometer
Minimal corneal deformation, allowing transducer to measure IOP directly

- Digital output
- Continuous recording of IOP waveform

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
The Glaucoma Tonometer

Data courtesy New England College of Optometry

IOPcc is not influenced by the thickness of the cornea

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

Difference Plot
- 95% Limits of agreement (-4.2 to 5.6)
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 buckles
    - scleral fixated sensor
  - Posterior chamber implants – choroidal

Temporary devices contact lenses


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

Matteo Leonardi,1 Elie M. Plichon,2 Aurélie Berard,1 Philippe Kemeny,1 and André Mermoud1

SENSIMED
innovation in medical mini-technology

Triggerfish

Cost 300 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
Gunvant et al. Comparison of pulsatile ocular blood flow in Indians and Europeans

Eye, 2005, 19, 1163-1168.

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

Table 1. Comparison of the mean pulsatile ocular blood flow reported in different studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Total subjects</th>
<th>NBF (subjects)</th>
<th>Instrument</th>
<th>Multi-study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matsun et al.</td>
<td>36</td>
<td>48</td>
<td>(Mean Max + 50%)</td>
<td>CBF system (Software version unknown)</td>
</tr>
<tr>
<td>Tsupa et al.</td>
<td>25</td>
<td>32</td>
<td>(Mean Max + 50%)</td>
<td>CBF system (Software version unknown)</td>
</tr>
<tr>
<td>Collette et al.</td>
<td>115</td>
<td>132</td>
<td>(Mean Max + 50%)</td>
<td>CBF system (Software version unknown)</td>
</tr>
<tr>
<td>Miett et al.</td>
<td>60</td>
<td>92</td>
<td>(Mean Max + 50%)</td>
<td>Transonic Nuss Flow System</td>
</tr>
<tr>
<td>North et al.</td>
<td>18</td>
<td>20</td>
<td>(Mean Max + 50%)</td>
<td>CBF system (Software version unknown)</td>
</tr>
<tr>
<td>Ming et al.</td>
<td>12</td>
<td>18</td>
<td>(Mean Max + 50%)</td>
<td>CBF system (Software version unknown)</td>
</tr>
</tbody>
</table>

Obtained study in India.
Ocular Pulse Amplitude in Normal Tension and Primary Open Angle Glaucoma

Ingrid Bachmann, MD, PhD.† Alan Harris, PhD.† Veronique Vandebempt, RSc.† Thiray Zekes, 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.
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
Perpendicular measurements are lowest or smallest in value.

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

Values vary on the basis of:
- Velocity of ultrasound used in algorithm
- MHz of probe
- 20 MHz + 3 microns accuracy
- 50 MHz + 1 micron accuracy

The whiskers represent 95% CI of population.

Do all pachymeters give us the same measurements? NO
**Difference between optical and ultrasound pachymetry measurements**

<table>
<thead>
<tr>
<th>Author</th>
<th>Difference in OCT and ultrasound values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim et al AJO 2008</td>
<td>26 microns</td>
</tr>
<tr>
<td>Wang et al J Refract Surg 2008</td>
<td>38 microns</td>
</tr>
<tr>
<td>Gunvant &amp; Darner Medical Imaging 2011</td>
<td>13 microns</td>
</tr>
</tbody>
</table>

**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.
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!