New Tonometers: Ready for Prime Time?

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• None Relevant
Measuring IOP

“It is easy enough to estimate the tension of the eye, though there is a right and a wrong way of doing even so simple a thing... With medical men, the touch is already an educated sense, and a very little practice should suffice to apply it successfully to the eye.”

Sir William Bowman before the British Medical Association, 1852
Early mechanical tonometers

von Graefe’s tonometer (1862?)
described by Monnik (1868)

Albrecht von Graefe
(1828 - 1870)
Tonometry met with skepticism

“I do not object to having a patient of mine subjected to examination with a mechanical tonometer, but expect very little from this test since digital tonometry by an expert is a much more accurate test....”

Isador Schnabel (1842-1908)
before the Vienna Ophthalmological Society, 1908
Measuring IOP

• Palpation
  – Richard Bannister (1626)
  – Johann Zacharias Platner (1738)

• Manometry

• Tonometry- the cornea is the only structure of the eye that is accessible to external tonometry
  – Indentation
  – Applanation
  – Contour matching
  – Rebound
Schiøtz Tonometer

• Advantages
  – Portable
  – Inexpensive (≈$200)

• Disadvantages
  – High variability
  – Greatly affected by scleral or corneal rigidity
  – Useful for range of IOP only

Schiøtz, Hjalmar (1850-1927), Norwegian physician. With the French ophthalmologist Louis-Emile Javal (1839-1907), Schiøtz invented a tonometer for measuring intraocular pressure. They introduced their tonometer in an article published in 1881.
Goldmann Tonometry

- Goldmann tonometry (GAT) is the most widely used method of measuring intraocular pressure (IOP)
- Well known that corneal parameters affect the accuracy of this instrument
Corneal Deformation
Goldmann Tonometry

• Advantages
  – Highly accurate (the “Gold Standard”)
  – Easily integrated into slit lamp exam

• Disadvantages
  – Requires smooth corneal surface
  – Requires patient to be seated at slit lamp
  – Can transmit pathogens if not cleaned properly between patients
Pascal Dynamic Contour Tonometer

- Third-generation, digital, contact tonometer that measures pulsatile IOP directly and continuously
- Contour surface that cradles the cornea without applanation
- Built-in microprocessor determines the IOP
Pascal Dynamic Contour Tonometer

• Manometric IOP measured in 16 freshly enucleated human cadaver eyes in an “open and closed stopcock” set up and compared to DCT, GAT, and PTG

• DCT values measured 0.58 mm Hg higher than true IOP; GAT measured 4.01 mm Hg lower than true IOP; PTG measured 5.09 mm Hg lower than true IOP

OPA

• Ocular Pulse Amplitude (OPA)
  – Difference in IOP between systole and diastole
  – May be a marker for overall ocular rigidity
  – Varies not only with the amount of blood transported to the eye during systole, but also depends on choroidal vascular rigidity as well as scleral rigidity
Clinical Utility of OPA

• 55 eyes of 32 patients included
• GAT, TAT, DCT measured to determine significance of relationship to predictor variables, such as age, CCT, BP, AGIS score, C/D ratios
• Increased OPA related to decreased severity of glaucoma

Reichert Ocular Response Analyzer

• Utilizes a bi-directional applanation process to present a new measurement called corneal hysteresis

• Hysteresis is a measure of the “viscoelastic” properties of the cornea
Static vs. Dynamic Measurement

• Goldmann tonometers make ‘static’ measurements. That is they derive IOP from the force measured during a steady state applanation of the cornea.

The Ocular Response Analyzer is based on Non-Contact Tonometer (NCT) technology. NCT’s make ‘dynamic’ measurements. That is, they derive IOP from the movement of the cornea in response to a rapid air impulse.
Definitions

**Hysteresis** Hys`te*re*sis, n. [NL., fr. Gr. to be behind, to lag.] (Physics)
The phenomenon was identified, and the term coined, by Sir James Alfred Ewing in 1890.

Hysteresis is a property of physical systems that do not instantly follow the forces applied to them, but react slowly, or do not return completely to their original state.

**Corneal Hysteresis** Cor’ne·al Hys`te*re*sis, n. [NL., fr. Luce.] (Physics)
Identified by David Luce, Ph.D., Corneal Hysteresis is the difference in the inward and outward pressure values obtained during the dynamic bi-directional applanation process employed in the Ocular Response Analyzer, as a result of viscous damping in the cornea.
Applanation Signal Plot

Signal Plot

Applanation Pressure 1

Hysteresis

Applanation Pressure 2

"In" Signal Peak

"Out" Signal Peak

Time - msec

Pressure / Signal

0 10 20 25

0 200 400 600 800 1000 1200
Normal CH values

Summary of published results

<table>
<thead>
<tr>
<th>Authors</th>
<th>Ave CH</th>
</tr>
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<tbody>
<tr>
<td>Kirwan, O’Keefe (Ireland)</td>
<td>10.8 ± 1.5</td>
</tr>
<tr>
<td>Shah et al. (UK)</td>
<td>10.7 ± 2.0</td>
</tr>
<tr>
<td>Ortiz (Spain)</td>
<td>10.8 ± 1.5</td>
</tr>
<tr>
<td>Hager et al. (Germany)</td>
<td>10.6 ± 2.3</td>
</tr>
<tr>
<td>Touboul et al (France)</td>
<td>10.26</td>
</tr>
<tr>
<td>Lam et al. (China)</td>
<td>10.9</td>
</tr>
<tr>
<td>Fontes, et al (Brazil)</td>
<td>10.17 ± 1.82</td>
</tr>
<tr>
<td>Ehongo (Belgium)</td>
<td>10.9 ± 1.3</td>
</tr>
<tr>
<td>Gonzalez-Meijome (Portugal)</td>
<td>11.4 ± 1.5</td>
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<tr>
<td>Kamiya (Japan)</td>
<td>10.2 ± 1.3</td>
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<td>Carbonaro (UK)</td>
<td>10.24 ± 1.24</td>
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<tr>
<td>Montard (France)</td>
<td>10.25 ± 1.6</td>
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<tr>
<td>Kida et al (USA 50-80 adults)</td>
<td>10.4 ± 1.1</td>
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<tr>
<td>Kida et al (USA Young Adults 20-26)</td>
<td>11.8 ± 1.6</td>
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<tr>
<td>Song (Chinese Children)</td>
<td>10.7 ± 1.6</td>
</tr>
<tr>
<td>Lim et al (Singaporean Children)</td>
<td>11.8 ± 1.55</td>
</tr>
<tr>
<td>Kirwan, O’Keefe 2008 (Irish Children)</td>
<td>12.5 ± 1.35</td>
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Glaucoma

CH can help differentiate normal from Glaucomatous eyes

![Graph showing the percentage of eyes at different corneal hysteresis values for normal and glaucomatous eyes.](image)
ORA

• 230 subjects underwent measurement of CCT and ORA to correlate with glaucoma progression
• Lower CH, not CCT, was assoc with VF progression
• Thinner central corneas associated with state of glaucoma damage

» Congdon NG, et al AJO 2006;141:868-875
CH predicts Laterality in Asymmetric Glaucoma

CH had a higher odds ratio of predicting asymmetric glaucoma damage than GAT, CCT, or Myopia and the best sensitivity and specificity.
CH and VF progression

• 153 eyes (patients) followed prospectively for 5 years
• Mean global rate of change was -.34 +/- .7 dB/yr. 25 eyes reached progression endpoint
• Progressing eyes had lower CCT and CH
• Only peak IOP, age, and CH remained statistically significant by multivariate analysis
  • De Moraes CG, et al J Glaucoma. 2012
Rebound tonometer

• Dekking and Coster introduced the term rebound tonometry in 1967 to describe a form of dynamic tonometry that used a “ballistic tonometer”
• The device was initially validated by manometry using rodent models
• Has been used extensively in veterinarian medicine to measure IOP in a variety of rodents, birds, large mammals, and non-human primates
Rebound tonometer

• Portable tonometer that measures the IOP based on processing the rebound movement of a rod probe, resulting from its interaction with the eye

• Probe is repelled horizontally by magnets and the bounced probe induces a voltage which is converted to a digital signal
iCare tonometer

- The iCare tonometer (iCare Finland, Helsinki, Finland) is the only commercially available rebound tonometer approved for use in humans. It was approved for clinical use in Germany in 2003 and in the United States in 2007.
iCare tonometer
iCare tonometer

• In adults, measurement of IOP with iCare rebound tonometry has been reported to be about 1 mmHg to 2 mmHg higher than measurements with applanation tonometry.

• The difference is greater in myopic patients and in patients with higher IOP. In addition, the difference between iCare rebound tonometry and GAT increases with increasing corneal central thickness.


iCare tonometer

• In children, iCare rebound tonometry has potential to improve the feasibility and accuracy of IOP assessment without anesthesia

• Increasingly being used by to assess IOP in young children. It seems to be well tolerated by young children and can reduce the need for examination under anesthesia

  • Flemmons MS, et al. JAAPPOS, 2011
Summary

- Goldmann applanation tonometry is flawed
- New tonometers may get at true IOP, and start to address question of viscoelastic properties of eye
- Future studies needed to correlate CH with laminar/posterior sclera susceptibility
- Further research is needed to assess the correspondence between rebound and applanation tonometry in young children