Tonometry

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DVOphthal MRCVS

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Whichever
Objectives

- To provide an overview of the theoretical basis and history of tonometry

- To promote discussion of the practical application of tonometry in clinical veterinary ophthalmology

- ...in less than 5 hours! 😊
Question 2

♦ What is the IOP cut-off point for differentiating glaucomatous from non-glaucomatous dogs with the TonoVet?
Questions 4 and 5

- I get a reading of 52mmHg in a Cocker Spaniel. Does this dog have glaucoma?

- I get a reading of 7mmHg in a Cocker spaniel. Can I rule out glaucoma?
“IOP” is a measurement **not** a diagnosis!

Glaucoma ↑

------------- 25 mm Hg

Normal ↓
Mercury Column
Manometry
the gold standard

Courtesy C. Delgado
IOP Measurement

DIRECT
- Manometry
  - invasive

INDIRECT (estimate)
- Tonometry
- Contact
- Non-contact
- Indentation
- Applanation
- Rebound
1622 AD: Richard Bannister England described the raised IOP as determined by palpation of the globe as a distinct sign of eye disease.

19th century – Europeans messing about in their basements

Schiøtz 1905

Goldmann 1954

2018 AD: Many dud tonometers fill the junkyard of history

Many "cool" (?) new devices

"is there an app for that"?
Question 3

- I’m feeling lucky! My Tono-pen calibrates “Good” this morning….first try! Without asking the tech for help!
- Does this mean that it will accurately measure IOP?
How to evaluate tonometers
and tonometry papers
Accuracy and Precision

• Target analogy

High accuracy, low precision
vs Low accuracy, high precision
How to evaluate tonometry papers...

- Are values compared to manometry?
- Accuracy
  - Is the correlation coefficient (r square) close to 1?
  - Is the slope of the regression line close to 1?
- Is the under-estimation or over-estimation linear and consistent over a clinically relevant range?
- Reproducibility and Precision
  - What is the scatter of data?
  - Are all data points presented or just the means?
  - Inter-observer variability?
- What is the magnitude of departure from “actual” IOP?
Fig 3—Comparison of in vitro measurements (mean ± SEM) of IOP in horses with eyes open, using a Tono-Pen tonometer vs direct manometry. The solid line represents an ideal 1:1 relationship.
Question 1

- What does tonometry measure?
IOP Measurement

DIRECT
- Manometry
  - invasive

INDIRECT (estimate)
- Tonometry
- Contact
- Non-contact
- Indentation
- Applanation
- Rebound
Indentation tonometry

- Digital “tonometry”
Indentation tonometry

- Variable indentation tonometers
  - Schiøtz
    - For a given weight applied, the greater the indentation, the lower the pressure
    - 1 scale unit approx = 0.05mm indentation
Schiøtz – Practical Use

- Topical anesthesia
- Zero using test block
- Corneal plane horizontal (!)
- Gently touch foot plate to axial cornea
- Plunger Assembly must be oriented vertically
- Add weights to plunger assembly if scale reading < 5, or inconsistent readings
- Avoid prolonged contact with eye
- Conversion table – eg Friedenwald 1955
- Disassemble and clean!
Other Factors
1) Conversion tables - At least 7 in veterinary medicine!
2) Tonometer standardization and maintenance
3) Surface area of indentation
4) Placement on the sclera or nictitating membrane
5) Duration of indentation (tonographic effect)
Schiøtz – “Practical” Use

↓ Force

- Gram weight
- Weight of plunger/instrument
- Tear film surface tension (pulls plunger towards eye)
- IOP

↑ Force

- Ocular (scleral) rigidity and corneal resistance to bending
- Steeper or thicker cornea
- Plunger/Tonometer sleeve friction (reduces effect of weight)
- Footplate/corneal friction (doesn’t let cornea relax to indent)
- Eyelid squeezing & / or Globe retraction
- Vascular congestion of the eye (jugular vein compression)
- Non-vertical placement - not all of weight applied to cornea

….What could possibly go wrong?!
Applanation tonometry

- Variable area – fixed weight/force
  - Maklakov type

- Fixed area – variable weight/force
  - Goldman type – optical detection of applanation point
  - Mackay-Marg type – electro-mechanical detection of applanation point
Imbert-Fick “law”

The force ($F$) required to flatten a circular area ($A$) of the surface of a container which has a relative internal pressure ($P$) is given as follows:

$$F = PA$$

Assumptions! The object is spherical, dry, perfectly flexible, infinitely thin and the container wall contributes nothing to the force equation.

Hmmmmm........
Goldmann applanation tonometry

- Measures force required to flatten known area (diam = 3.06mm) of cornea.

- Resistance of cornea to deformation is balanced by attractive force of tear film.

- Corneas that are much thicker or thinner than average impact the reading

Gold standard for Physician ophthalmologists
Apply topical anesthetic and fluorescein

Cobalt blue light filter

Advance tonometer prism until close to the cornea & observe with table mounted slit lamp. Hemi-circles produced by the prism are brought into alignment by the operator.

When the inner edges of the hemi-circles contact, a circle of cornea 3.06mm in diameter is flattened (displacing ~0.5µl of aqueous humor).

Each 1gm of force applied to ocular surface corresponds to 10mmHg IOP, assuming an average corneal thickness...
Perkins hand held tonometer

• Endpoint operation of the instrument same as Goldmann

• Doubling prism used to observe two split semi-circles and thumbwheel used to align the fluorescein mires for an IOP measurement.

• An advantage of this tonometer is that it can be used in any position.
  • Calibrated for sheep, cattle, dogs and cats

• Relies on a clear regular cornea
• Maximal scale reading = 5 (maximal IOP ≤ 50mmHg)
Question 10

- I forgot to use proparacaine before obtaining IOP readings with the Tono-pen in one of my patients...and my boss told me not to bother. How will this affect IOP?
Question 7

The Tono-pen displays individual readings of 3, 18, 16 and 17mmHg but then displays a final reading of 17mmHg with <5% variance. Is it working properly?
Tono-pen

- Topical anesthesia required or IOP about 2 mmHg higher
- Calibrate by gravity
- Use a condom!
- Gently touch probe tip to cornea
- Applanation detected electromechanically – i.e. point when central plunger no longer bears force applied to cornea, then calculates an average from VALID readings
Question 8

- With my Tono-pen I get average readings of 26, 23 and 18mmHg, each with 5% variance. Is one reading more accurate than the others? Should I just average all three values to increase accuracy?
Tono-Pen vs Tono-Pen XL /VET

- Applanation tonometer with 3.2mm tip
- Both the Tono-Pen and Tono-Pen XL are known to underestimate IOP in CATS
  - Tono-Pen (slope = 0.73) central plunger 1.5mm
  - Tono-Pen XL (slope = 0.64) central plunger 1.02mm
  - Tono-Pen Vet / AVIA Vet (slope =0.62) central plunger - =1.02mm

McLellan, G et al (unpublished)
Minella et al (in review)

**Linear Regression Analysis, Tono-Pen AVIA**

\[ Y = 0.727X + 1.116 \]

\[ R^2 = 0.9532 \]

**Linear Regression Analysis, Tono-Pen VET**

\[ Y = 0.7271X - 0.1216 \]

\[ R^2 = 0.9765 \]

**Bland-Altman: TP AVIA vs. Manometry**

\[ Y = -0.2962X + 0.6858 \]

\[ R^2 = 0.6566 \]

**Bland-Altman: Tono-Pen Vet vs. Manometry**

\[ Y = -0.3062X - 0.4369 \]

\[ R^2 = 0.8055 \]

Minella et al (in review)
Question 17

- You are feeling pretty nervous about that Shih Tzu referred for suspected glaucoma .....so you repeat your measurement of IOP by applanation tonometry before sending the dog home.
- This time the IOP has gone up from 16-22mmHg....what the heck is going on , and why did the IOP go up?
Clinical considerations for Tono-pen tonometers

- Performance varies by model
  - Highly accurate and precise over normal physiological range
  - Less so at extremes of IOP
  - Overestimates low IOPs, underestimates high IOPs

- Less affected by corneal disease than other types
- Artifactual under-estimation of IOP unlikely – so take the lowest reliable reading
- **Viscosity of tear film** affects the readings (increasing them by about 15% or more if methylcellulose)
- Off center application doesn’t significantly affect readings
Pneumotonometer

Column of air replaces central plunger as central sensing device. Silastic membrane contacts eye. Not to be confused with air puff tonometer!
Air-puff tonometry

Non-contact device
flattens the cornea using a jet of air
Optical receiver detects when and how fast the cornea has been flattened to a predetermined degree.
Converts the amount of time it takes for applanation to occur into mmHg

Advantages:
Topical anesthetic is not required
potential cross-contamination prevented

Disadvantages:
not as accurate as Goldmann or Tonopen type tonometers (esp. at high IOP).

“Patient movement” a problem!!
Question 6

- I don’t get it!
- What’s the difference between a pneumotonometer and an air-puff tonometer?
“At least they don’t have the machine that blows air in your eye.”
“......Like most people, I was taken off guard the first time I took the test (so quick a test, I can’t believe it warrants a story … but it does). The technician had me lower my chin onto the base, and said to stare straight ahead without blinking. Seemed easy enough. But soon a burst of air traveling at Mach 2 shot into my cornea, and sent me hurtling backward against the wall, nothing but a heap of cowardly shivers and peed pants to show for it.

All the affectations of manhood that took years to build up quickly fell away, and were further defeated when she said, “you blinked,” no shit, “we’re going to have to do it again.”

Look, there’s just no licking the damn thing. I’ve flinched like a spaz during every single test, always in front of a cute girl administrating (sic) it. They’ll tell you that everyone flinches. They’ll say it’s a perfectly natural response. They’ll say whatever makes you feel better. But I know that somewhere out there is a man, oh yes, there is a man, with stiffened sinews and hardened breath and widened eyes, who releases nary a flinch, not even a blink.

That man is my hero, and yet, at the same time, I kind of hope he has glaucoma. Fucking tough guy.”
Corneal Biomechanics

- Applanation tonometry assumes:
  - cornea offers no resistance to deformation, infinitely thin, completely dry
- 0.1-0.7 mmHg increase in IOP with 10 μm increase CCT
- What about corneal stiffness?

<table>
<thead>
<tr>
<th>Table 1. GAT and Tono-Pen Readings at Various True IOP Levels in Canine Eyes</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOP&lt;sub&gt;Man&lt;/sub&gt; (mm Hg)</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>40</td>
</tr>
</tbody>
</table>

Effect of Corneal Stiffening on Goldmann Applanation Tonometry and Tono-Pen Measurements in Canine Eyes

Corneal thickness affects tonometer accuracy

Goldmann realized that corneal thickness and rigidity were important and might influence measurement of IOP.

Instrument was optimized for an “average” human cornea of 520 µm (underestimated! 540 - 550 µm.)

People who have thin corneas have IOP measurements which are lower than true IOP.

People with thick corneas tend to have an IOP measurement higher than true IOP.
THE RELATIONSHIP BETWEEN CCT AND IOP READINGS

...others report no linear correlation between CCT and IOP, why?
models are dependent on:
- population characteristics
- presence/absence of ocular hypertension
- number and type of surgical interventions
- ethnic groups
- pachymetric technique used
- tonometric technique used
  each can over or under estimate IOP

for every 100 µm increase in CCT, IOP increased by 1 and 2 mmHg by the TonoPen XL and TonoVet, respectively
So should we correct for corneal thickness?

Tofflemire et al. *Vet J* (2017) 224, 7-10
Question 18

- How do I measure IOP in mice?
Schematic for measuring IOP in mice with an induction-impact (I/I) tonometer, which operates on the rebound principle. Tonometer components and the eye are not drawn to scale.

Dania et al. (Investigative Ophthalmology and Visual Science. 2003;44:1138-1141.)
Rebound tonometry

- Probe rebounds faster as IOP increases
- Higher IOP - shorter duration of impact.
- Does not require topical anesthesia.
- Similar reliability to Tono-Pen XL and better accuracy
- Systematic overestimation or underestimation of IOP
- Further assessment of rebound tonometry in populations with higher IOP and corneal disease, is needed.
TonoVet

- Studies in:
  - Pigs, Humans, Dogs, Horses, Rabbits, cats, Chinchillas.....
  - Birds (but slopes = 0.8 to 1.6 depending on species)
  - TonoLab (rodents)
- Highly accurate (slope close to 1) in dogs, cats, horses, rabbits and some avian species
- Species differences noted – needs calibration/validation by species (don’t use ‘p’ setting!)

Ma et al Scientific Reports | 6:35187 | DOI: 10.1038/srep35187
Wang,WH et al (2005) IOVS ; 46, 4617-4621

Question 19

- Which tonometer should I use to measure IOP in cats?
Question 13

- A cat with conjunctivitis has an IOP reading of 27mmHg in the affected eye. Does this cat have glaucoma?
Clinical issues impacting tonometric IOP

- Pressure on eyelids
- Restraint (including collars)
- Blepharospasm and eye movement
- Patient posture and head position
- Sedation, other drugs administered
- Duration of tonometry / multiple measurements
- Time of Day
- Inter-operator variability
- Tonometer type (use consistently)
- The patient - e.g. corneal biomechanical properties
Question 12

- My resident-mate tends to get IOP measurements that are 2-3mmHg higher than mine. Which one of us is right?
Stress & the "White Coat Effect"
Question 16

- A very diligent general practitioner measures IOP with his Schiøtz in a 7 year old Shih Tsu during a routine physical exam prior to vaccination. The IOP is 35mmHg so he applies a drop of pilocarpine and sends the dog to you immediately. Your Tono-pen reading is 16mmHg and you find only mild pectinate ligament dysplasia on gonioscopy, and he has a smallish pupil but otherwise the ophthalmic exam is normal.

- WTF is going on?
Effects of Eyelid Pressure & Restraint

Restraint vs. no restraint

<table>
<thead>
<tr>
<th>N=12 animals</th>
<th>Mean (mmHg)</th>
<th>SD (mmHg)</th>
<th>Range (mmHg) (avg 3 readings)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck restraint</td>
<td>16.4</td>
<td>6.9</td>
<td>8-33</td>
</tr>
<tr>
<td>Head restraint</td>
<td>10.2</td>
<td>1.9</td>
<td>7-16.5</td>
</tr>
<tr>
<td>No restraint</td>
<td>10.1</td>
<td>0.8</td>
<td>9-13</td>
</tr>
</tbody>
</table>

**P value**

<table>
<thead>
<tr>
<th>Comparison</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck vs. head</td>
<td>0.00015</td>
</tr>
<tr>
<td>No restraint vs. head</td>
<td>0.73</td>
</tr>
<tr>
<td>No restraint vs. neck</td>
<td>0.0014</td>
</tr>
</tbody>
</table>

Question 9

- In an equine patient, I get averaged readings of 48, 32, 33 and 26mmHg, each with 10% variance. Is there something wrong with the Tono-pen? What could be causing these widely differing values?
Effect of head / body position on IOP in horses

Komáromy et al
*Am J Vet Res*
2006;67:1232-5

Effect of body position on intraocular pressure in dogs without glaucoma

(IOP most consistent in sternal)
Twenty-four-hour patterns of mean IOP in healthy young adults in the sitting (•) and supine (○) positions
Question 11

Should I use the Tono-pen or TonoVet to check for ocular hypertension 2 hours after phacoemulsification surgery?
Comparison of a rebound tonometer with an applanation tonometer in dogs with glaucoma

<table>
<thead>
<tr>
<th></th>
<th>Tono-Pen XL</th>
<th>TonoVet</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>13.31 ± 4.57</td>
<td>12.85 ± 6.08</td>
<td>P = 0.632</td>
</tr>
<tr>
<td>OS</td>
<td>11.73 ± 4.05</td>
<td>11.36 ± 4.23</td>
<td>P = 0.676</td>
</tr>
<tr>
<td>Glaucoma</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>40.57 ± 9.68</td>
<td>48.29 ± 14.02</td>
<td>P = 0.015*</td>
</tr>
<tr>
<td>OS</td>
<td>40.92 ± 16.91</td>
<td>47.25 ± 13.82</td>
<td>P = 0.031*</td>
</tr>
</tbody>
</table>

Asterisks denote statistical significance. Average difference between instruments = 6.7 mm Hg; (P = 0.0025)
OD Right eye, OS Left eye

Slack, Stiles & Moore Vet Rec (2012)
Influence of ocular disease on tonometry values

Question 14

- A cat has chronic severe stromal keratitis related to FHv-1 infection but also has chronic uveitis and secondary glaucoma is a concern. Should I choose the Schiøtz, Ton-pen or TonoVet
“Depending on the type and degree of corneal pathology, the deviation in IOP resulting from measurements on altered cornea ranged from -6 to 16 mmHg for the TonoVet(®) and -7 to 20 mmHg for the Tono-Pen Vet(®), respectively. On average, the effect of corneal disease on IOP measurements was lower for the TonoVet(®) by 1.14 mmHg.”

Question 15

- I am worried about secondary glaucoma in a dog after retinal reattachment surgery yesterday. I have already placed a therapeutic soft contact lens to improve comfort as he has a superficial corneal ulcer as well. Do I need to take out the contact lens to check the IOP?
Contact Lenses

Does rebound tonometer probe misalignment affect readings obtained?

de Oliveira et al Open Vet J (2018);8 (1): 68-76
“Deviation from the manufacturer's recommendations on handling the Tonovet® during the measurement significantly affected the results obtained. Compared to the reference measurement, directing the Tonovet® onto the peripheral cornea (approximately 1.5 mm from the limbus) as well as reducing the measuring distance to <4 mm resulted in slightly elevated IOP readings. Substantial underestimation of IOP occurred with angular deviation of the measuring axis.”

Linear Regression Analysis, TonoVet Plus

Y = 0.9215*X - 1.587
R^2 = 0.9835

Bland-Altman: TonoVet Plus vs. Manometry

Y = -0.0737*X - 1.907
R^2 = 0.2469

Minella et al (in review)
Question 20

- I am monitoring IOP in a dog that I am treating for glaucoma. At the last visit, IOP was 14mmHg but today it is 18mmHg – is IOP less well controlled?
Is this pressure range physiologically relevant?

Sigle, KJ et al. (2011) Vet Ophthalmol 14; 48-53
The Proview eye pressure monitor

Uses a psychophysical test based on the entoptic phenomenon of pressure phosphenes, a sensation of light elicited by nonphotic stimuli, to evaluate IOP.

Not very accurate!!

Diaton tonometer also measures IOP through the eyelid. Tends to underestimate IOP.
Telemedicine and Continuous IOP Monitoring

- Will allow continuous remote measurement of IOP
- IOP variability and fluctuations are “worse” than we think!
- All of the devices thus far tested have their “limitations”
- Watch this space!
Direct Telemetric Measurement of IOP

Downs, JC et al, 2011. IOVS
New Frontiers in Continuous IOP measurement

Implantable – intraocular or extraocular Contact Lens

The SENSIMED Triggerfish® Sensor is a soft disposable silicone contact lens with a micro-sensor strain gauge that captures spontaneous circumferential changes in the cornea with IOP fluctuation (1).

An adhesive antenna, placed around the eye, receives information from the contact lens. (2)

Data are transmitted through a thin flexible cable from the Antenna to the portable recorder, worn by the patient, that stores acquired data. (3,4)

At the end of the 24hr recording period, the data are transferred via Bluetooth from the recorder to computer software for review.

www.sensimed.ch
Implanted during cataract surgery
In clinical trials
....and yes, there will soon be an app for that
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