TONOMETRY/ INTRAOCULAR PRESSURE (IOP) ASSESSMENT

AQUEOUS PRODUCTION MECHANISMS

- Active secretion
- Ultrafiltration

CONTROL OF AQUEOUS PRODUCTION

- Active secretion → control carbonic anhydrase
  - Carbonic anhydrase inhibitors (CAIs)
- Ultrafiltration → control IOP/BP pressure balance
  - Control by lowering BP in capillaries of the ciliary processes
  - This strategy is really not used clinically due to the concomitant lowering of blood flow to the optic nervehead (ONH) which can worsen glaucoma
  - Homeostatic mechanism: increased IOP → ↓ rate of ultrafiltration

GROSS ANATOMY OF THE CILIARY PROCESSES

- Formed in ciliary processes
- Posterior chamber (PC)
- Through lens - iris diaphragm
- Anterior chamber (AC)
NORMAL AQUEOUS FLOW
TRABECULAR OUTFLOW PATHWAY

AQUEOUS CONVECTION
CURRENTS IN AC

- Aqueous is warmer in deep AC
- Warm aqueous rises
- Approaches peripheral AC
- Aqueous cools in peripheral AC
- Aqueous drifts downward in the more anterior AC

AQUEOUS OUTFLOW PATHWAYS

- Trabecular outflow (65 - 80%)
- Uveoscleral outflow (20 - 35%)

TRABECULAR OUTFLOW PATHWAY
Illustration from Shields MB. Textbook of Glaucoma

- Anterior chamber
- Uveal TM
- Corneoscleral TM
- Juxtacanalicular tissue
- Schlemm’s canal
- Aqueous veins
- Episceral venous plexus
- Superior and inferior ophthalmic veins
- Concomitant sinus
- Jugular veins

TRABECULAR OUTFLOW PATHWAY
From Shields MB. Textbook of Glaucoma

Most high IOP and open angle glaucoma particularly chronic open angle glaucoma (COAG) is caused by an obstruction in the trabecular outflow pathway.
Glaucoma: Too much aqueous vs too slow outflow

Most high IOP and open angle glaucoma particularly chronic open angle glaucoma (COAG) is caused by an obstruction in the trabecular outflow pathway.

EPISCLERAL VENOUS PRESSURE AND IOP

- 1 to 1 relationship in pressure change → 1 mmHg ↑ in episcleral pressure → 1 mmHg ↑ in IOP
- Causes of ↑ episcleral venous plexus pressure:
  - Valsalva
    - Increase in intrathoracic pressure
    - Possible Valsalva maneuvers:
      - Take a breath and hold it → do not let your patient do this during tonometry!!
      - Lifting, straining, coughing
  - Gonioscopy
  - Carotid cavernous fistula
  - Sturge-Weber syndrome

UVEOSCLERAL OUTFLOW PATHWAY

- Iris face
  - ↓ Iris stroma
  - ↓ Ciliary body / uveal tract
  - ↓ Suprachoroidal space
  - ↓ Choroidal veins

UVEOSCLERAL OUTFLOW vs TRABECULAR OUTFLOW

- Uveoscleral not pressure (IOP) dependent; trabecular outflow is pressure dependent
- Ciliary muscle contraction causes ↑ TM outflow but ↓ uveoscleral outflow

OVERVIEW OF ACTIONS OF DPAs & GLAUCOMA MEDS RELATION TO AQUEOUS FLOW

- Anticholinergics (DPAs)
- Glaucoma meds
  - Cholinergics
  - Sympathomimetics
  - Sympatholytics (beta blockers)
  - Carbonic anhydrase inhibitors (CAIs)
  - Prostaglandin analogs

ANTICHLINERGICS USED CLINICALLY

Weakest to strongest

- Tropicamide
  - Good, fast mydriasis of short duration
  - Weak cyclopexia
- Cyclopentolate
- Scopolamine
- Homatropine
- Atropine
Which is an anticholinergic?

OCULAR ACTIONS OF ANTICHOLINERGICS

- Block ciliary muscle → cycloplegia
- Block pupillary sphincter → pupil dilation

ANTICHOLINERGICS CAN CAUSE ELEVATED IOP IN A OPEN ANGLE POSSIBLE MECHANISMS

- Cycloplegia (relax longitudinal ciliary muscle fibers) → no tonus on scleral spur & TM → pore size in TM is decreased???. rate of aqueous outflow?
- Pigment release into the AC
- Phenylephrine more likely
- Plateau iris
  Angle was actually not wide open but appeared open on the pre-dilation angle evaluation.

CILIARY MUSCLE TONE AND IOP CHOLINERGICS VS. ANTICHOLINERGICS

- Increased tone (ciliary spasm) can increase aqueous outflow rate via trabecular pathway → ↓ IOP
  Cholinergics (pilocarpine) cause this
- Decreased tone (cycloplegia) can decrease aqueous outflow rate via trabecular outflow path → ↑ IOP
  Anti-cholinergics (tropicamide, cyclopentolate, homatropine etc.) can cause this

CILIARY MUSCLE & THE TRABECULAR MESHWORK

CLINICAL SIGNIFICANCE OF POST-DILATED IOP RISE

- Significant IOP spike in a susceptible patient (elderly, vascular disease, carotid occlusive dz., prior CRVO or BRVO etc.) can cause CRVO / BRVO
- Indicates very fragile IOP balance
- Must rule out angle closure in all cases → gonioscopy
- Usually ↑ IOP is transient but occasionally IOP does not return to normal
DIFFERENTIAL DIAGNOSIS (DDx) OF POST-DILATED IOP SPIKE

- Angle closure (narrow angle)
  Usually takes hours
- Plateau iris
  Can take minutes
- Cycloplegic effect of the mydriatic agent
- Pigment release into AC

PATHOGENESIS OF ANGLE CLOSURE BY PUPILLARY BLOCK MECHANISM

Mid-dilated pupil
↓
Relative pupil block
↓
↑ IOP in posterior chamber
↓
Iris bombe`
↓
Angle closure
(only in pre-existing narrow angles)

POST-DILATED TONOMETRY

WHO SHOULD HAVE IT?

- Glaucoma patients
- Glaucoma patients on a miotic agent
  Always check post-dilated IOP
- Narrow angles
  Usually angle closes hours later if due to pupillary block
- Pigmentary dispersion syndrome / pigmentary glaucoma
- Pseudoexfoliation / pseudoexfoliative glaucoma
- Glaucoma suspects

ANGLES AT RISK OF PUPIL BLOCK ANGLE CLOSURE

- Only those with a narrow angle are at risk of angle closure
- Angles at risk:
  - Grade 1 <1/4
  - Grade 2 ≥1/4

PERIPHERAL IRIDOTOMY
1. How do you set up this view?
2. Where should the optic section be focused?
3. What do you record in the patient’s record?
4. What grade is this angle?
5. What is the risk of angle closure?
6. What is the risk of primary open angle (POAG)?

PLATEAU IRIS ANGLE CLOSURE

GLAUcoma MEDS – EFFECT ON AQUEOUS FLOW
Cholinergics (pilocarpine)
  Causes ciliary spasm – increases aqueous outflow through TM
Sympathomimetics (epinephrine and dipivefrin)
  Stimulate B2 sites in TM – increases aqueous outflow in TM pathway
Sympathomimetics (bromidine and apraclonidine)
  Stimulate alpha 2 sites in ciliary body – decreases aqueous formation; also increases uveoscleral outflow
Sympatholytics (beta blockers – timolol, levobunolol, carteolol etc.)
  Block B2 sites in ciliary body – decreases aqueous formation
CAIs (dorzolamide, brinzolamide)
  Block carbonic anhydrase in ciliary body – decreases aqueous formation via active secretion
Prostaglandin analogs (latanoprost, travaprost, bimatoprost)
  Loosen the extracellular matrix in ciliary muscle – increases uveoscleral outflow rate

USES OF TONOMETRY
- Assess risk of glaucoma – important in glaucoma diagnosis
- Assists in glaucoma management

INDICATIONS FOR TONOMETRY

ALL comprehensive exams of all patients who can tolerate tonometry

GLAUcoma - DEFINED
A group of disorders where progressive damage occurs to the retinal ganglion cell axons and is clinically evident in the optic nerve and retinal nerve fiber layer (RNFL).
The damage may be in part due to intraocular pressure (IOP) in some cases
CLINICAL EVIDENCE OF GLAUCOMA

- Damage to the ONH and RNFL – structural damage
- Functional damage
  - Visual field (VF) loss
  - Color vision (tritan defect)
  - Pattern ERG (PERG)
  - Pattern VER
  - Flash VER
  - Contrast sensitivity
  - Other

IOP AND GLAUCOMATOUS DAMAGE

- The ONH and RNFL damage is directly due to retinal nerve fiber (ganglion cell axon) death
- Exact cause is not known. *May be due to IOP which is too high in some cases*
- Significant individual variation in ability of axons to withstand various levels of IOP

GLAUCOMA – TYPES & DEFINITIONS

- Open Angle Glaucoma (COAG or POAG)
  - No clinically evident aqueous outflow obstruction on gonioscopy.
  - Characteristic glaucomatous damage in ONH or RNFL or VF.
  - IOP may or may not be “high”.
- Angle Closure Glaucoma (ACG)
  - A clinically evident aqueous outflow obstruction to the trabecular meshwork → iris root covers the trabecular meshwork &/or pupillary block.
  - Definitive diagnosis - gonioscopy

PUPILLARY BLOCK ANGLE CLOSURE

LOW TENSION GLAUCOMA / NORMAL TENSION GLAUCOMA

- A form of open angle glaucoma characterized by glaucomatous damage yet IOP is never over 21 mm Hg - IOP is always statistically normal.
- Key is to detect the damage in the ONH, RNFL and VF.
- Tonometry is not helpful in detection.

OCULAR HYPERTENSION

- A condition where the IOPs are statistically high (>21 mmHg) yet at the present no structural or functional evidence of glaucoma exists.
- These patients are at some risk of developing glaucomatous changes though most do not. Key is to detect the damage or increased risk.
NORMAL VS. ABNORMAL IOP

CLINICALLY NORMAL IOP

- Clinical examination reveals no structural or functional damage.
- A very critical examination of structure (ONH, RNFL) and function (VF at least) is necessary to detect early glaucomatous damage.
- The best method of detecting *early* glaucomatous damage is by detecting *change* in the structure or function with time.

NORMAL VS. ABNORMAL IOP

STATISTICAL ASPECTS

- Statistical information on the range of IOP in normal patients and in glaucomatous patients is *minimally* useful in the diagnosis of glaucoma due to the large overlap of IOPs in these groups.
- Statistical info is most useful in assessing the present or future *risk* of glaucoma.
- IOPs ALONE CANNOT BE USED TO DIAGNOSE OR TO RULE OUT GLAUCOMA

TONOMETRY AND GLAUCOMA DETECTION

- Sensitivity 50%
- Specificity 70-90%

GLAUCOMA

Patients with IOP > 21 mmHg (in black)

vs

Patients with IOP < 21 mmHg (in white)

PATIENT EDUCATION - TONOMETRY

- Measures the pressure inside the eye
- Helpful in detecting glaucoma
- We do SEVERAL tests for glaucoma
  - Case history, IOP, VF, ONH/RNFL evaluation
- There is not ONE test for glaucoma; no one test is adequate to detect glaucoma by itself

IOP IN NORMAL PATIENTS

LEYDHECKER’S STUDY - 1958

- 10,000 “normal” patients
- Ages: 10 to 69
- Instrument: Schiotz tonometer
- Mean: 15.5 mmHg
- Standard deviation: 2.57 mmHg
IOP IN NORMAL PATIENTS
LEYDHECKER’S STUDY - 1958

- Flaws in methodology / data analysis
  - Schiotz tonometer used
  - IOPs over 21mm Hg were considered glaucomatous
  - Found a skewed distribution with
    second peak in low 20s → these were excluded as glaucoma. This resulted in
    a standard, bell shaped distribution.

LEYDHECKER’S FINDINGS

- Mean IOP 15.5 mmHg
- Standard deviation 2.57 mmHg
- Distribution was NOT actually a standard (Gaussian or normal) distribution though
  Leydhecker presumed that IOPs > 21 were
  glaucomatous. Distribution of IOPs in normal patients is
  actually skewed into the 20s as Leydhecker
  found but did not recognize.
- Based on Gaussian statistics: 2 standard
  deviations from mean would be 15 mmHg +
  2(2.5 mmHg) = 20.5 mmHg

WHERE DID THE 21 MM HG COME FROM?

- Leydhecker’s Study - mean (15.5) plus 2
  standard deviations (2.5) = ~21 mmHg
- Other studies show a mean of 15.5 to
  17mm Hg and standard deviation of 2.5 to
  3.5

STUDIES ON IOP IN THE GENERAL POPULATION
SHIELDS, MB. TEXTBOOK OF GLAUCOMA TABLE 3-1

<table>
<thead>
<tr>
<th>Investigators</th>
<th>Number of Individuals</th>
<th>Age (men)</th>
<th>IOP (mm Hg)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Tested With Schiötz Tonometers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Johnson (1960)</td>
<td>7,577</td>
<td>&gt;40</td>
<td>15.6</td>
<td>2.63</td>
<td></td>
</tr>
<tr>
<td>Sjögren &amp; Savic (1960)*</td>
<td>15,995</td>
<td>&gt;80</td>
<td>15.0-15.5</td>
<td>2.5 (women)</td>
<td></td>
</tr>
<tr>
<td>B. Tested With Applanation Tonometers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arnal (1955)</td>
<td>2,890</td>
<td>20-79</td>
<td>15.8</td>
<td>3.14*</td>
<td></td>
</tr>
<tr>
<td>Pennisi (1960)</td>
<td>2,890</td>
<td>&gt;40</td>
<td>15.0-15.5</td>
<td>2.5 (men)</td>
<td></td>
</tr>
<tr>
<td>Lowen, et al. (1960)</td>
<td>4,664</td>
<td>8-99</td>
<td>15.0-15.5</td>
<td>2.5 (men)</td>
<td></td>
</tr>
<tr>
<td>Report on IOP, (1948)</td>
<td>6,092</td>
<td>5-84</td>
<td>15.0-15.5</td>
<td>3.45</td>
<td></td>
</tr>
</tbody>
</table>

* Computed from data reported according to sex and age groups.

WHAT IS THE CUT OFF BETWEEN THE IOP IN NORMALS AND IN GLAUCOMA?

- Due to the large overlap of the IOP
distribution in normals and glaucoma
  there is NO appropriate cutoff IOP
- Tonometry alone cannot be used to
differentiate glaucoma from normal
- Higher IOPs are associated with a
  higher risk of glaucoma
Tonometry: A Single IOP Measurement
Sensitivity and Specificity

Tonometry: Sensitivity / Specificity

<table>
<thead>
<tr>
<th>Intraocular pressure cutoff</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;17 mm Hg</td>
<td>80.1%</td>
<td>51.8%</td>
</tr>
<tr>
<td>&gt;19 mm Hg</td>
<td>63.9%</td>
<td>72.9%</td>
</tr>
<tr>
<td>&gt;21 mm Hg</td>
<td>47.1%</td>
<td>92.4%</td>
</tr>
<tr>
<td>&gt;24 mm Hg</td>
<td>27.2%</td>
<td>96.4%</td>
</tr>
<tr>
<td>&gt;26 mm Hg</td>
<td>20.4%</td>
<td>98.1%</td>
</tr>
</tbody>
</table>

Tulsch (Tielsch JM. Transactions of the New Orleans Academy of Ophthalmology, Keagle Amsterdam, 1993.)

Differentiation of normal from abnormal IOP

Differentiation cannot be made by tonometry alone
Tonometry should be used to evaluate risk
Glaucoma diagnosis depends on clinical examination

IOP in the Glaucoma Evaluation
Other factors in interpretation

- Highest level of IOP achieved (spike height)
- Variation in IOP
- Long term trend in IOP
- Interocular asymmetry

Long term factors affecting IOP

- Age
  - In US a very slow upward trend with age
- Race
- Sex
- Family history
- Refractive error

Factors causing transient IOP change

- Time of day (diurnal variation)
- Accommodation
- Posture
- Exercise
- Apprehension
  - Lid squeezing, holding breath
  - Co-contraction of EOMs
- Pressure on the globe
- Fluid intake
- Medications, pharmaceutical agents
- Cardiac cycle
- Trauma, inflammation
- Blood pressure

Diurnal IOP Variation

- Classic thought
  - Higher around 7:00 a.m. / lowest around 7:00 p.m.
- Liu’s recent studies at UCSD
  - Highest IOP in AM before arising ~5:00 AM
DIURNAL IOP VARIATION
GUIDELINES IN INTERPRETATION

- < 5 mmHg - normal
- 5-10 mmHg - abnormally high
- >10 mmHg - abnormal - very likely glaucomatous

ACCOMMODATION AND IOP

- Can decrease IOP very quickly (seconds to minutes)
- Do not use an accommodative target for tonometry; use a distant fixation target

POSTURE AND IOP

- Sitting to supine: average 2-3 mmHg IOP increase in normals
- Inversion >15 mmHg increase possible

EXERCISE AND IOP

- Prolonged exercise → can cause up to 30% ↓ in IOP but transient
- Straining, lifting (Valsalva movement) can increase IOP temporarily due to increased intrathoracic pressure

APPREHENSION AND IOP

- Lid squeezing or widening
- Co-contraction of the EOMs
- Holding the breath (Valsalva)

EXTERNAL PRESSURE ON LIDS AND IOP

- Often when holding lids for tonometry
- Can cause small (2-3 mm Hg) or large (>10) IOP increase
- May cause very large (>30) IOP increase
- Do not let patient hold their lids during tonometry
- If you hold the lids do NOT touch the globe
CARDIAC CYCLE AND IOP

- IOP varies by a small (1-5 mm Hg) amount due to the cardiac cycle.
- During systole → increased intraocular blood volume → increased IOP.
- During diastole → decreased intraocular blood volume → decreased IOP.
- This IOP change also causes spontaneous central retinal vein pulse.

BLUNT OCULAR TRAUMA AND IOP

- Initially trauma produces an iritis / anterior uveitis causing decreased aqueous production → decreased IOP.
- After several hours or days inflammatory debris can block the TM → increased IOP.
- Many years later (if angle recession has occurred) angle recession glaucoma may onset.
- Retinal detachment is usually accompanied by decreased IOP.

SYMPTOMS OF HIGH IOP

- Chronic ↑ IOP
  - Symptoms rare
- Acute ↑ IOP
  - Symptoms common

SYMPTOMS OF ELEVATED IOP FACTORS CAUSING SYMPTOMS

- Acuteness / rapidity of the IOP increase
- Magnitude of IOP increase / level of IOP
- Health of corneal endothelium, i.e., guttatae

SYMPTOMS OF ACUTE IOP INCREASE SUCH AS ANGLE CLOSURE

- Eye / head pain
- Nausea / vomiting
- Blurred, foggy, hazy vision
- Haloes
- Red eye
- Watery discharge (due to photophobia)
- Photophobia