Goldmann Applanation Tonometry

A Variable Force Applanation Tonometer
**Goldmann Applanation Tonometry**

**Principles of Action**

- $W =$ Force to flatten part of cornea (grams)
- $A =$ Area of cornea flattened ($\text{mm}^2$)
- $S =$ Attractive surface tension (.415 gm)
- $B =$ Repulsive Corneal Inflexibility (.415 gm)
- Imbert-Fick Law: $W = Pt \times A$
- Imbert-Fick (modified): $W + S = Pta + B$

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**Figure 4.6.** A, The Imbert-Fick Law ($W = Pt \times A$); B, Modification of Imbert-Fick Law for the cornea ($W + S = Pta + B$).
Goldmann Applanation Tonometry

Sources of error

- Too much, too little fluorescein
- Improper vertical alignment (erroneously elevated)
- Corneal thickness:
  - thin-low
  - thick-high (collagen)/low (edema)
- Corneal curvature
- Prolonged contact
- Calibration

Goldmann Applanation Tonometry

Sources of error

- Fluorescein
- No fluorescein underestimates by ≥ 5mmHg
- Ideal fluorescein concentration = 0.125% to 0.25%
- Low concentration underestimates IOP 1.5 to 9 mmHg
- High concentration overestimates IOP slightly
- Quenching: low pH, local anaesthetics
Goldmann Applanation Tonometry

Sources of error

- Corneal Thickness (Goldmann assumed 0.52mm)
- Thin corneas underestimate IOP
- Thick corneas overestimate IOP (edema underestimates)

Goldmann Applanation Tonometry

Sources of Error

- Corneal Thickness
- CCT in Normal, Glaucomatous and Ocular Hypertensive Eyes
  - Herndon et al, Arch Ophth. 1997;115:1137-1141
- CCT ocular hypertensives $0.606 \pm 0.041$ mm
- CCT glaucomatous eyes $0.561 \pm 0.022$ mm
Goldmann Applanation Tonometry

Sources of error

- Corneal Curvature
- 1 mm Hg for each 3 diopters of corneal curvature
- IOP underestimated for wtr astigmatism
- IOP overestimated for atr astigmatism
- 1 mm Hg for each 4 diopters of astigmatism
- Compensate with averaging or biprism rotation
Other Variable Force Applanation Tonometers

- Perkins
- Mackay-Marg
- Pneumotonometer
- Tonopen
Mackay-Marg Tonometry (1962)

Principles

- 1.5 mm Plunger/transducer
- Extends 10 μm beyond rubber sleeve
- Analogue tracing
Comparison of Tonometers with Goldmann

Pneumatonometer

- Close correlation with Goldmann
- Useful in scarred, irregular, edematous corneas
Tonometry

Classification of Contact Tonometers

- Indentation (Schiotz1905)
- Applanation
  - Variable Force e.g. Goldmann(1954), Mackay-Marg
  - Variable Area (Maklakov 1885)
Comparison of Tonometers with Goldmann

Schiøtz

- Significant disagreement
- Influence of ocular rigidity
- Indicates IOP range only
- Limited value even for screening purposes
Schiøtz Tonometry

Technique
- Calibrate
- Supine
- Topical anaesthetic
- Fixation Target
- Weights (gm)
  5.5, 7.5, 10.0, 15.0
- Friedenwald's Tables

Schiøtz Tonometry

Principles
- Po versus Pt
- Coefficient of Ocular Rigidity = E (Friedenwald's tables)
- E = 0.0245 (1948)
- E = 0.025 (1955)
Fig. 5-2. Friedenwald nomogram.

Table 28-2. Calibration scale for Schiotz tonometers, P₀ (mm Hg), revised 1955

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<th>5.5 grams</th>
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<td>10.9</td>
<td>16.5</td>
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**Schiotz Tonometry Sources of Error**

**Low E (falsely low IOP)**

- High myopia
- Elevated IOP
- Osteogenesis imperfecta
- Miotic therapy
- Vasodilator therapy
- Retinal detachment surgery: cryo, buckle, vitrectomy, gas

**High E (falsely high IOP)**

- High hyperopia
- Extreme myopia
- Long-standing glaucoma
- ARMD
- Vasoconstrictor therapy
IOP = F/C + EVP
Comparison of Tonometers with Goldmann

Noncontact tonometer

- High variability
- Difference of > 5 mm Hg in 8% of readings
- May tend to read lower at high IOP
Noncontact Tonometer

Principles

- Puff of air flattens cornea
- IOP proportional to time required to flatten cornea
- Cardiac cycle is a significant variable
- 3 measurements within 3 mm Hg recommended to minimize error from momentary IOP fluctuations in glaucoma patients
Corneal Biomechanical Properties are more important to IOP measurement than just Thickness

* Corneal Resistance
* Corneal Structure
* Corneal Elasticity
* Corneal Harmony (String-Like Response)

**Corneal Hysteresis

What is Corneal Hysteresis?
If Cornea is pushed by air impulse, an advanced electro-optical system can record 2 applanation pressure measurements: one while the cornea is moving inward and the other as the cornea returns.
The difference between these 2 measurements is Corneal Hysteresis (CH)
Comparison of Corneal Hysteresis distribution of normal, keratoconic, and Fuchs’ subjects

Corneal Hysteresis of 15 eyes pre- and post-LASIK
Tonometry in Adults and Children

A Manometric Evaluation of Pneumatanometry, Applanation, and TonoPen In Vitro and In Vivo

Dan L. Eisenberg, MD,1 Brian G. Sherman, MD,2 Craig A. McKeown, MD,1 Joel S. Schuman, MD1

Objective: The purpose of the study was to determine the accuracy of applanation tonometry, pneumatanometry, and TonoPen tonometry in adults and children and the effect of age on tonometer error.

Design: The design was divided into four parts: part 1 was prospective and cross-sectional, and parts 2 through 4 were prospective, cross-sectional, and masked.

Participants: This study contained 72 patients representing 74 data points.

Intervention: Tonometry with simultaneous manometry was performed.

Main Outcome Measures: Intraocular pressure (IOP) and the tonometric estimate of IOP were obtained.

Results: The normal pediatric IOP follows the line: \( T_a = 0.71 \text{age(years)} + 10 \) up to age 10. Applanation tonometry under anesthesia differs from pneumatanometry by an average of −8.6 mmHg and is age related by the equation: \( T_a = T_p + 2.6 \log(\text{age}) - 10.3 \). The TonoPen was the most accurate instrument for enucleated eyes, and the pneumatanometer was the most accurate in anesthetized living eyes.

Conclusions: Applanation tonometry markedly underestimated IOP in young eyes. TonoPen tonometry performed well with enucleated eyes but was not adequately accurate for clinical use. The pneumatanometer performed best clinically and the best overall. Ophthalmology 1998; 105:1173–1181

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Tonometry in Adults and Children

- Part I: Goldmann vs Pneuma in Clinic
- Part II: Perkins vs Pneuma in OR (EUA)
- Part III: Perkins vs Pneuma vs TonoPen vs Manometer in Vitro
- Part IV: Perkins vs Pneuma vs TonoPen vs Manometer in Vivo
Methods Part I

- Tonometry in Clinic
- Normal eyes in Clinic
- Goldmann (few Perkins) and Pneuma by DLE or BGS
- Regression analysis

Age Adjusted Normals in Clinic

Mean with 2 standard errors

Expected Ta = 0.71*Age + 10.0
Methods Part II

- Tonometry Under Anesthesia
- Strabismus surgery eyes in OR
- Perkins and Pneuma by CAM
- Regression analysis of difference

Results Part II

- Tonometry Under Anesthesia
- 24 Patients, 0 to 68 years of age
- Ta significantly lower than Pneuma by 8.6 mmHg
- \( Ta = Pneuma - 10.3 + 2.6 \cdot \log(Age) \)
Tonometry Under Anesthesia

Mean Difference (Pneuma - Perkins) 8.6 mm Hg, p < 0.0001

Paired Estimates (increasing age)

Methods Part III

- Enucleated Human Eyes
- Enucleated globes, <24hrs post mortem
- Perkins, Pneuma, TonoPen by DLE
- MANOMETRIC reference
- Randomized IOP target (low, med, high)
### Demographics - Enucleated Human Eyes

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### Results Part III

- Enucleated Human Eyes
- 2 newborn, 1 3 yo, 2 adult (10 eyes)
- Perkins: $-7.6 + 0.040 \times \text{Age}$, no IOP effect
- Pneuma: $+5.6 - 0.053 \times \text{Age}$, no IOP effect
- TonoPen: $-0.10 \times \text{IOP}$, no Age effect
Results Part III - TonoPen

Methods Part IV

- Intraoperative Manometry
- Cataract surgery patients
- Perkins, Pneuma, TonoPen by CAM or JSS
- MANOMETRIC reference
- Randomized IOP targets (low, med, high)
- Masked to target and result
Demographics - Intraoperative Manometry

<table>
<thead>
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<th>Eye</th>
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Results Part IV

- Intraoperative Manometry
- 5 children, 4 adults (11 eyes)
- Perkins: 0.067*Age - 0.21*IOP
- Pneuma: +7.6 -0.36*IOP, no Age effect
- TonoPen:+5.2 - 0.50*IOP, no Age effect
Results Part IV - Pneuma

Error by Age Intraoperative Manometry

Pneuma
TonoPen
Perkins
Conclusions: Applanation Tonometry

- Age was an independent source of error
- IOP was an independent source of error
- The error was underestimation in both
- Younger patient age resulted in greater error
- Higher IOP resulted in greater error

Conclusions: TonoPen Tonometry

- No age effects
- IOP was an independent source of error in living eyes
- The error was overestimation at IOP below 11 mmHg and underestimation above
Conclusions: Pneumatonometry

- No age effects found in living eyes
- IOP was an independent source of error
- The error was overestimation at IOP below 20 mmHg and underestimation above

Summary

- Applanation significantly underestimated IOP
  - Effect possibly related to corneal thickness
- The Pneumatonometer was the most accurate in living eyes
- The TonoPen was the most accurate in enucleated eyes