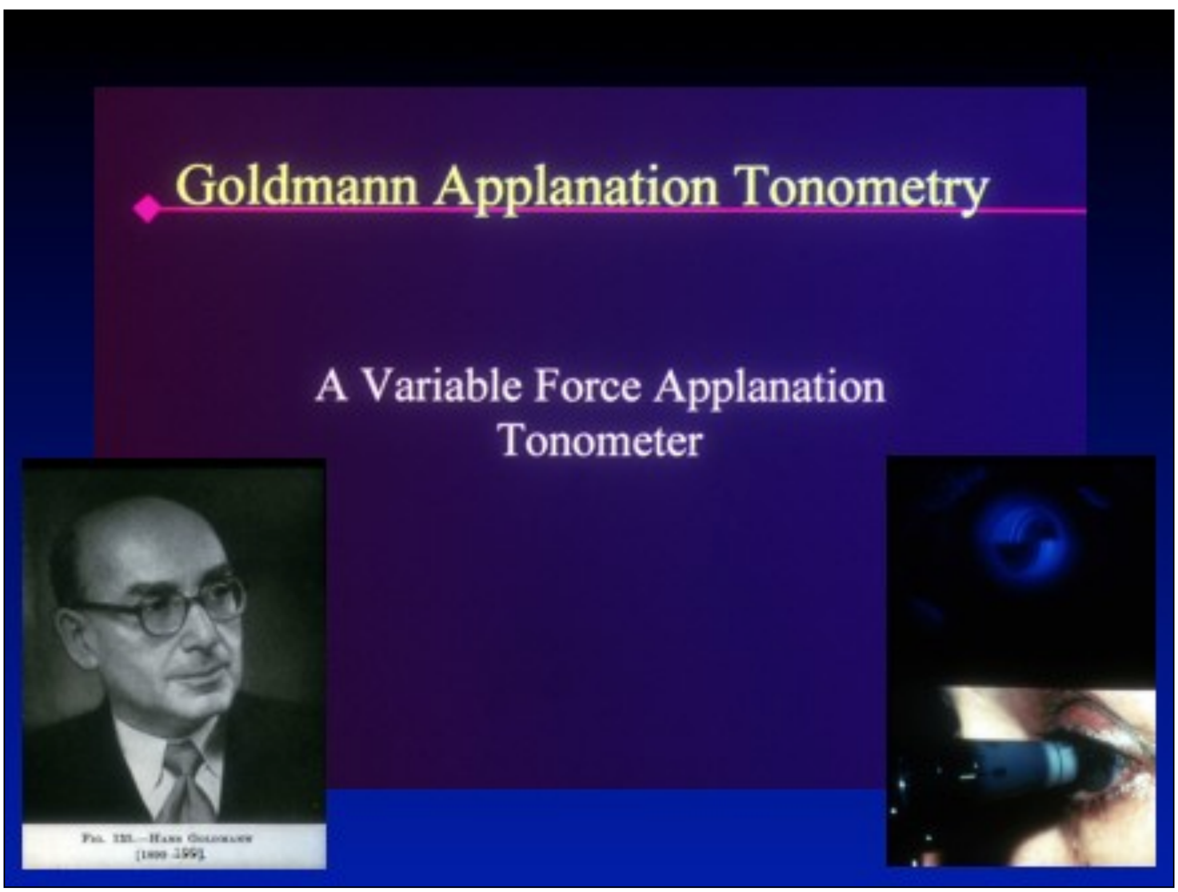
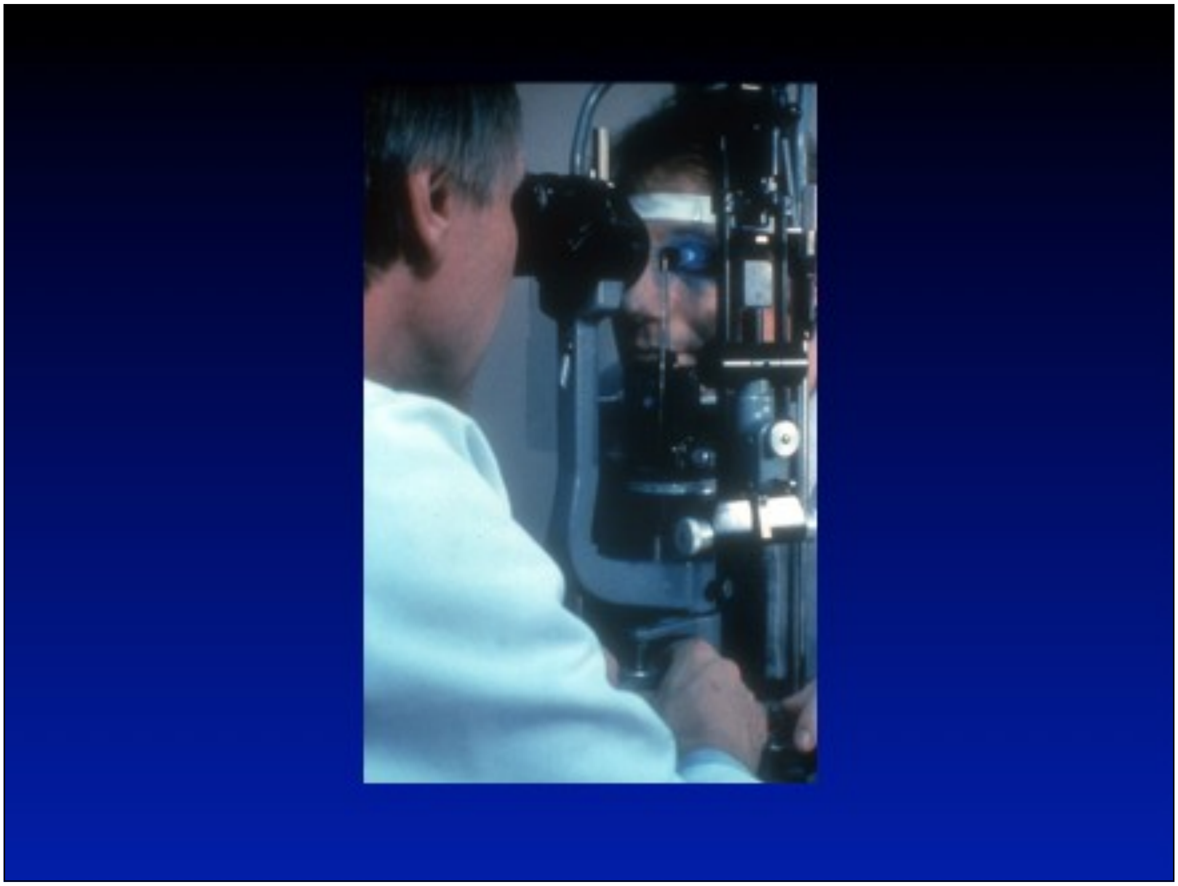
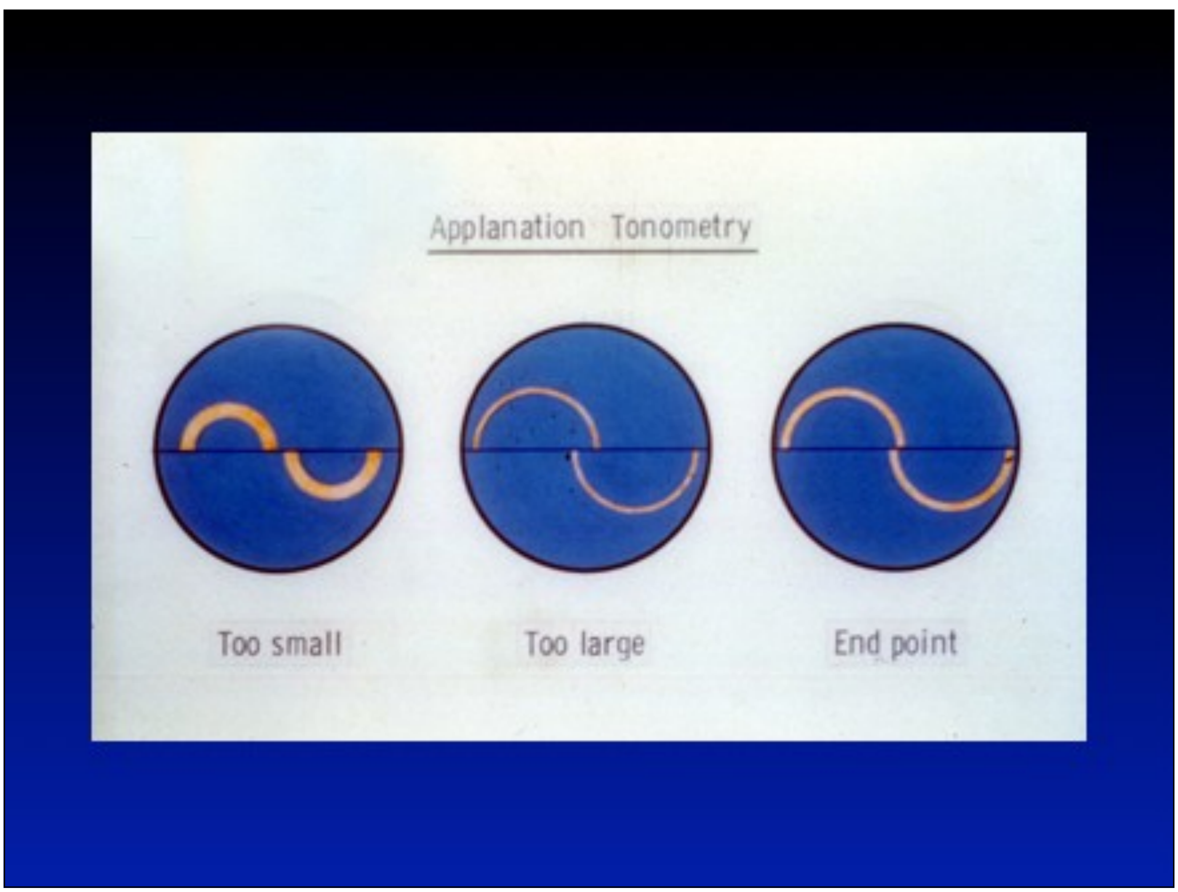
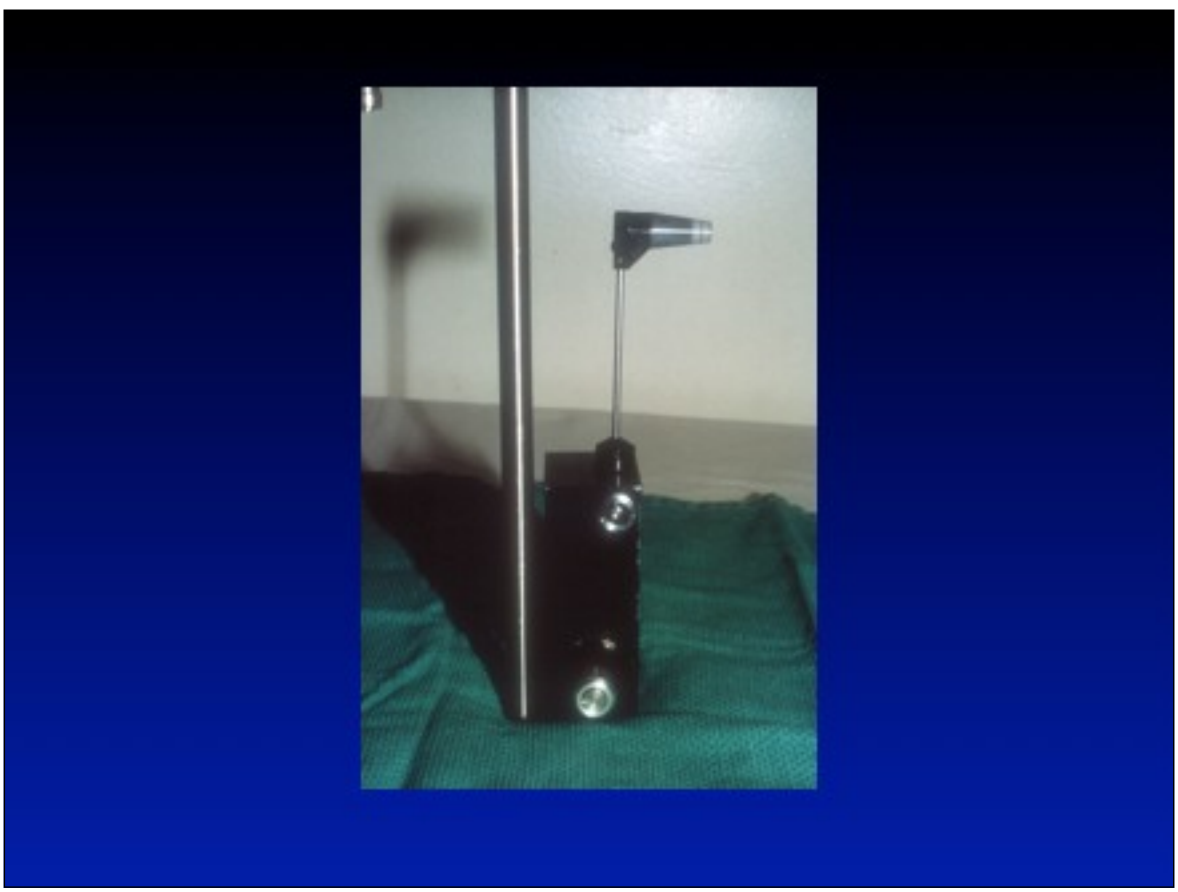
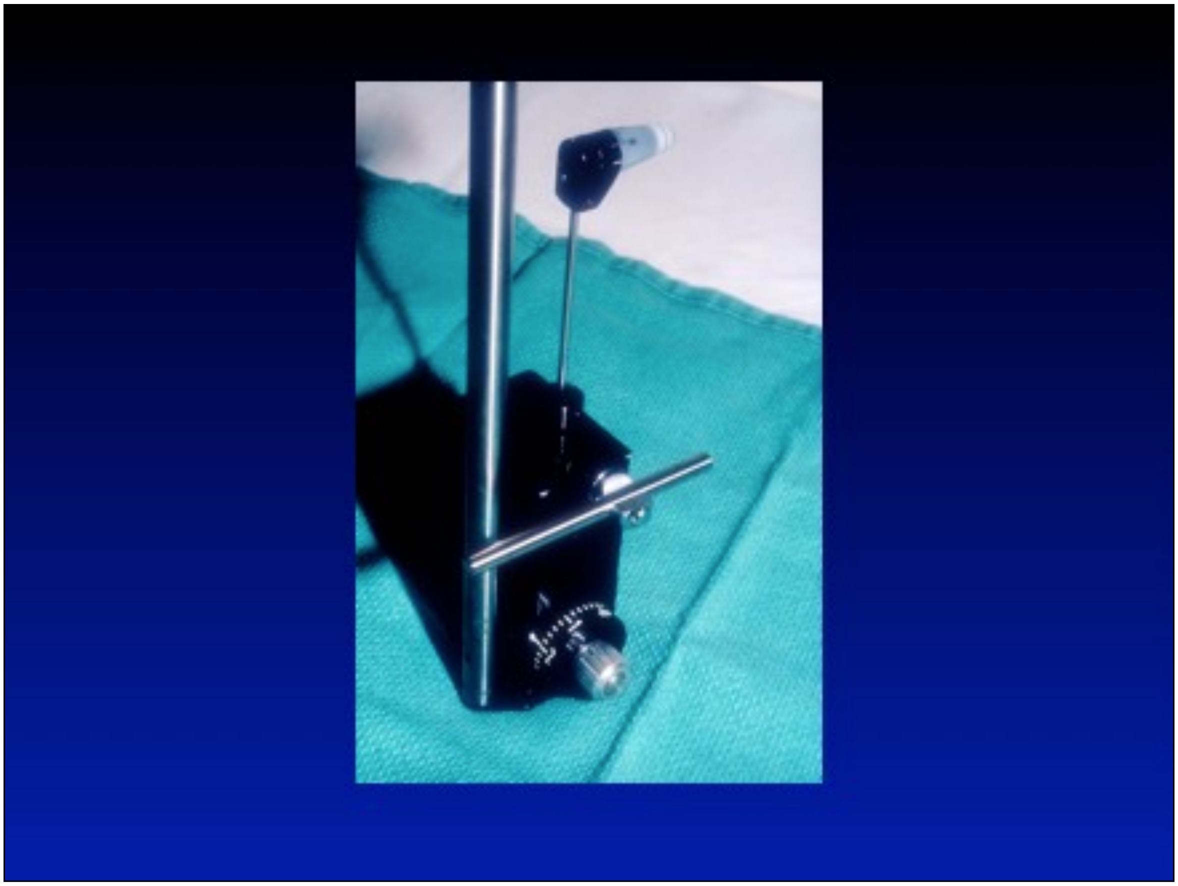

Goldmann Applanation Tonometry
A Variable Force Applanation
Tonometer




Applanation Tonometry
Too small
Too large
End point





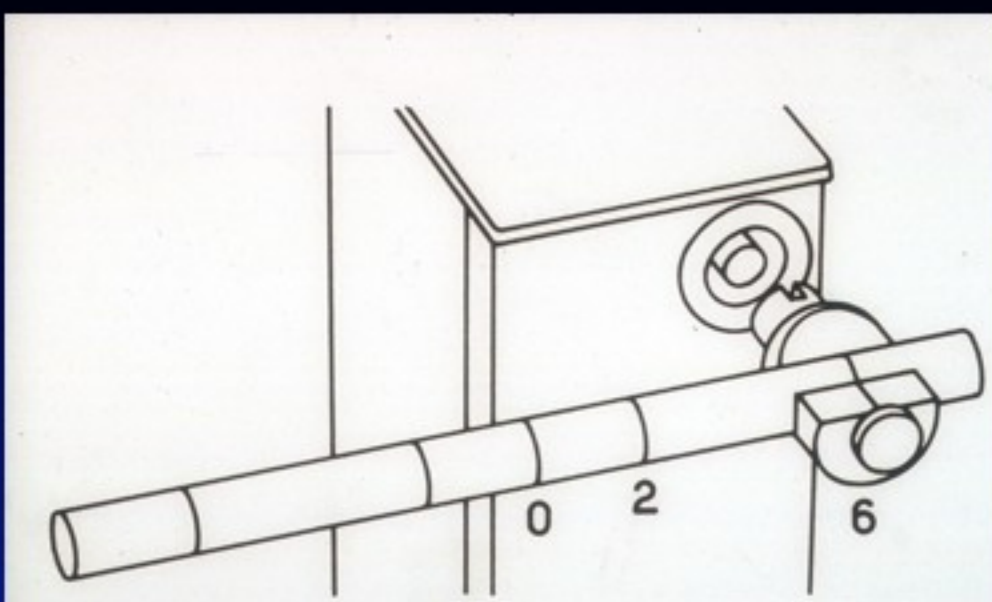


Fig. 15 Checking at drum position 6

Goldmann Applanation Tonometry

Principles of Action

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

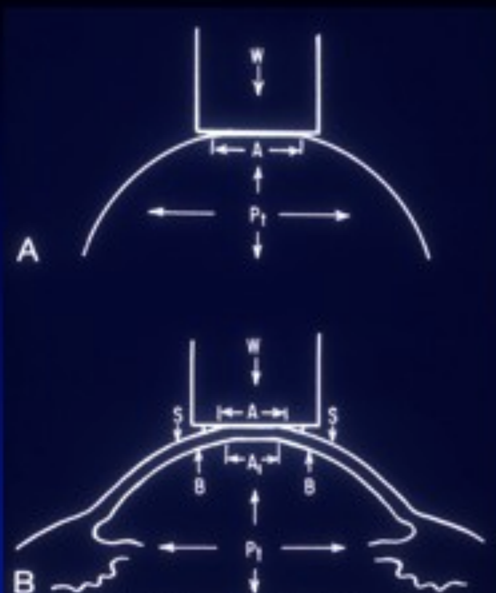


Figure 4.6. **A,** The Imbert-Fick Law ($W = P_t \times A$); **B,** Modification of Imbert-Fick Law for the cornea ($W + S = P_t \times A_t + B$).

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 $\geq$ 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

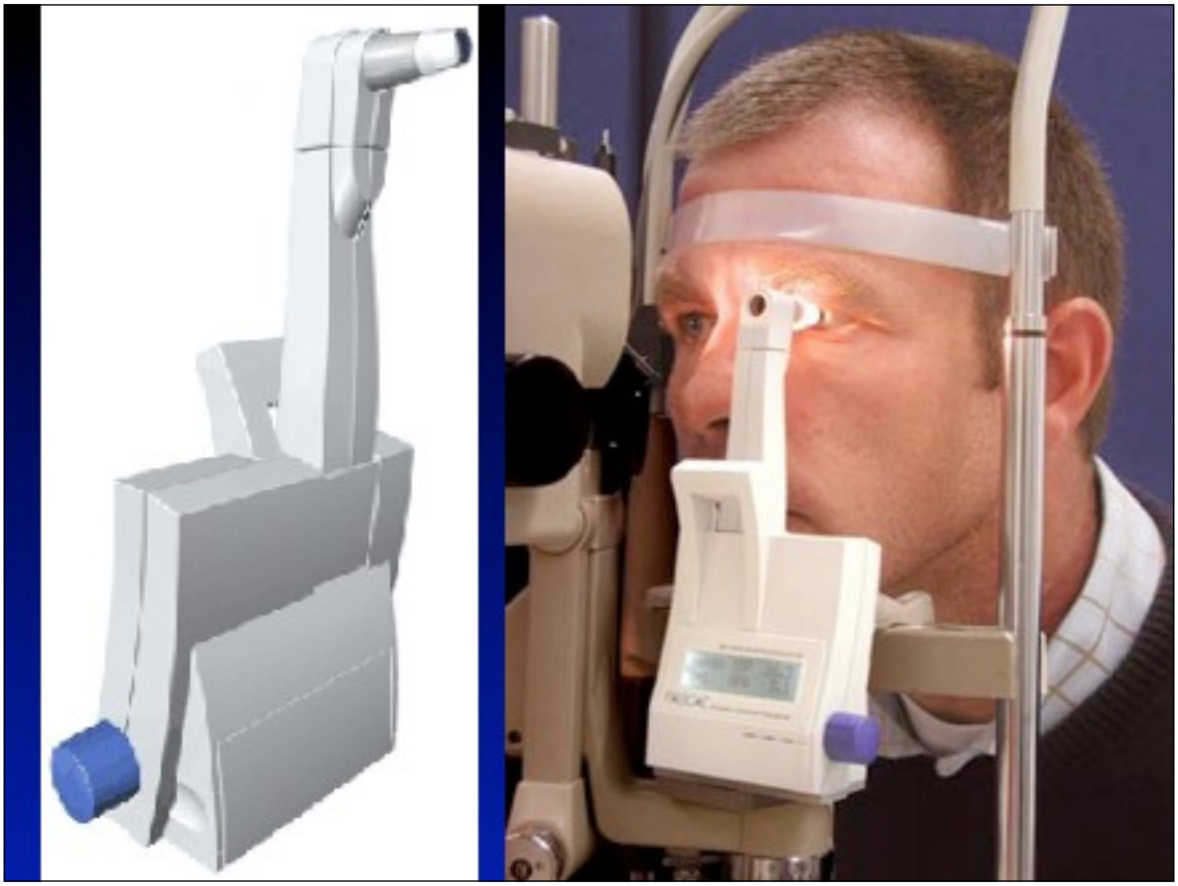
Sources of Error

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

Goldmann Applanation Tonometry

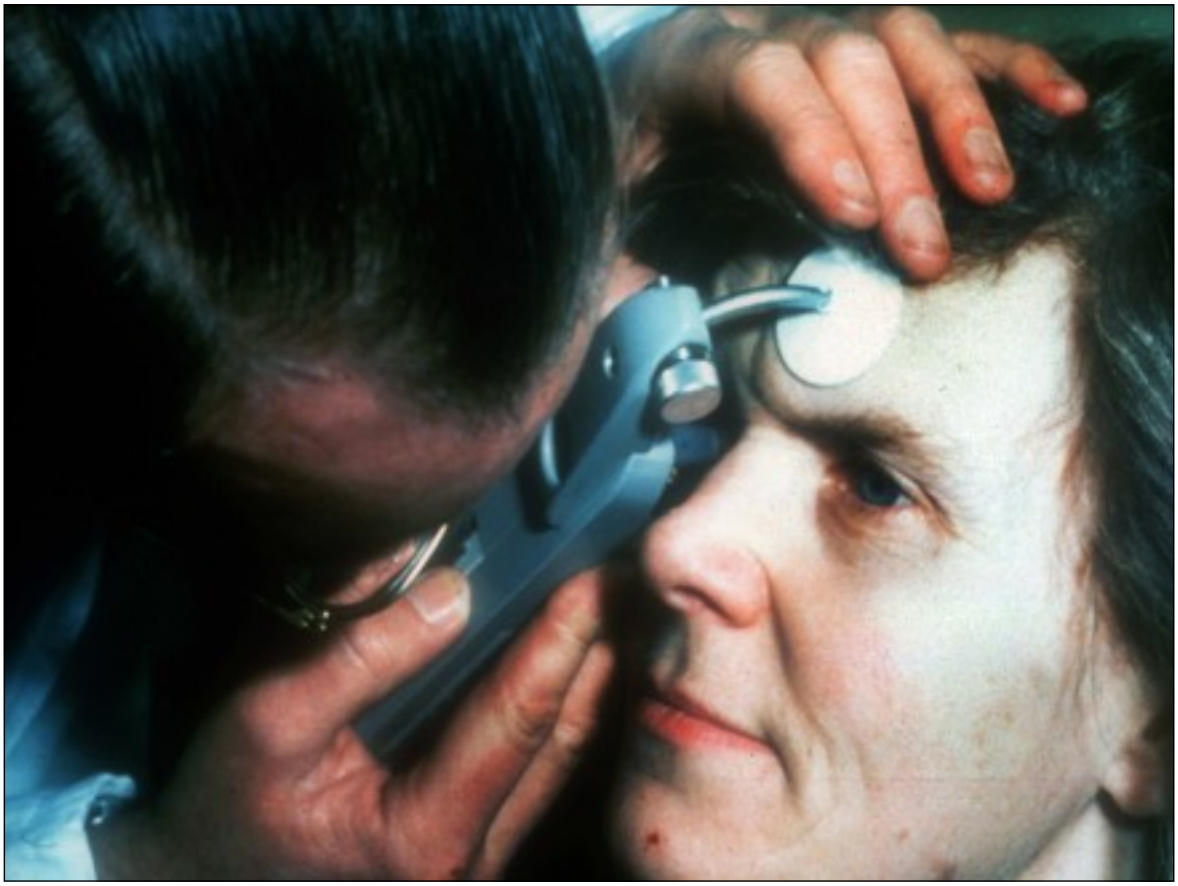
Sources of error

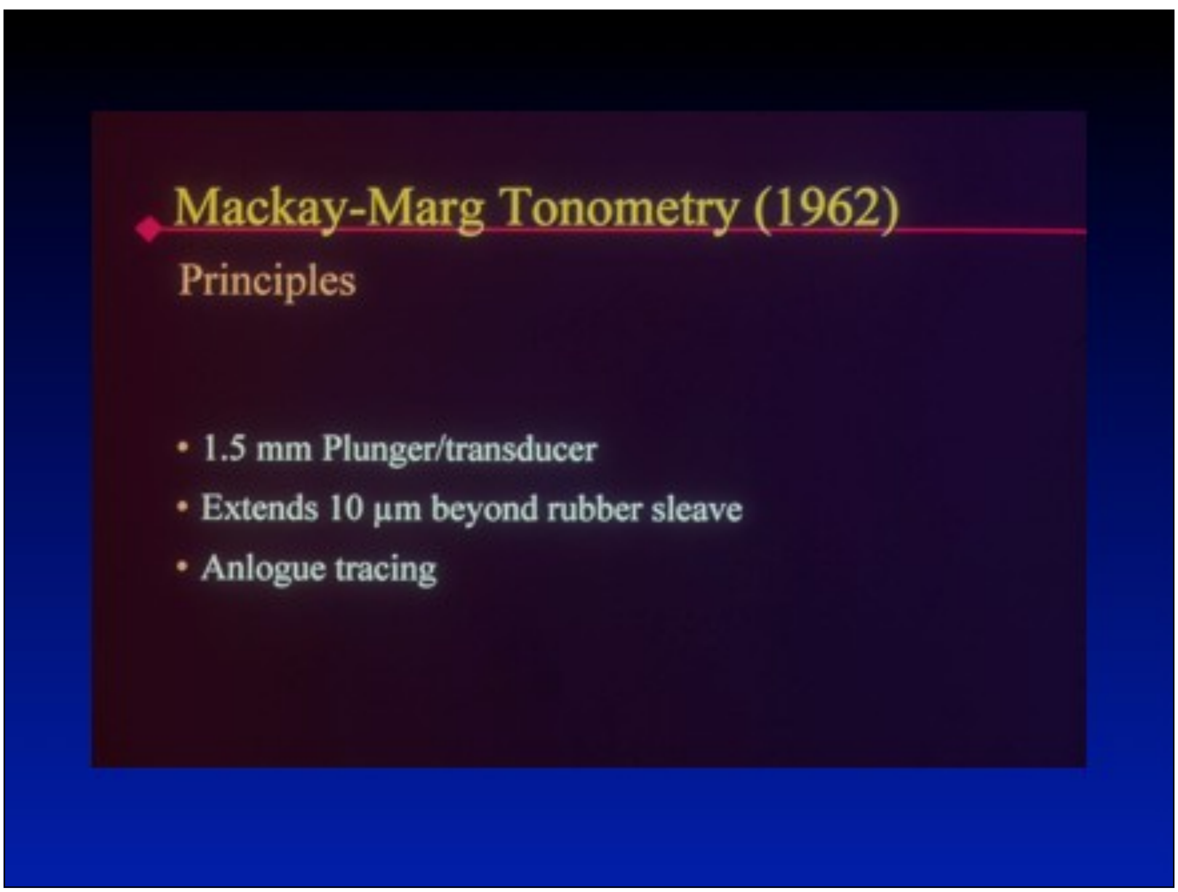
- Corneal Curvature
- 1 mm Hg for each 3 diopters corneal curvature
- IOP underestimated for wtr astigmatism
- IOP overestimated for atr astigmatism
- 1 mm Hg for each 4 diopters of astigmatism
- Compensate with averaging or biprism rotation



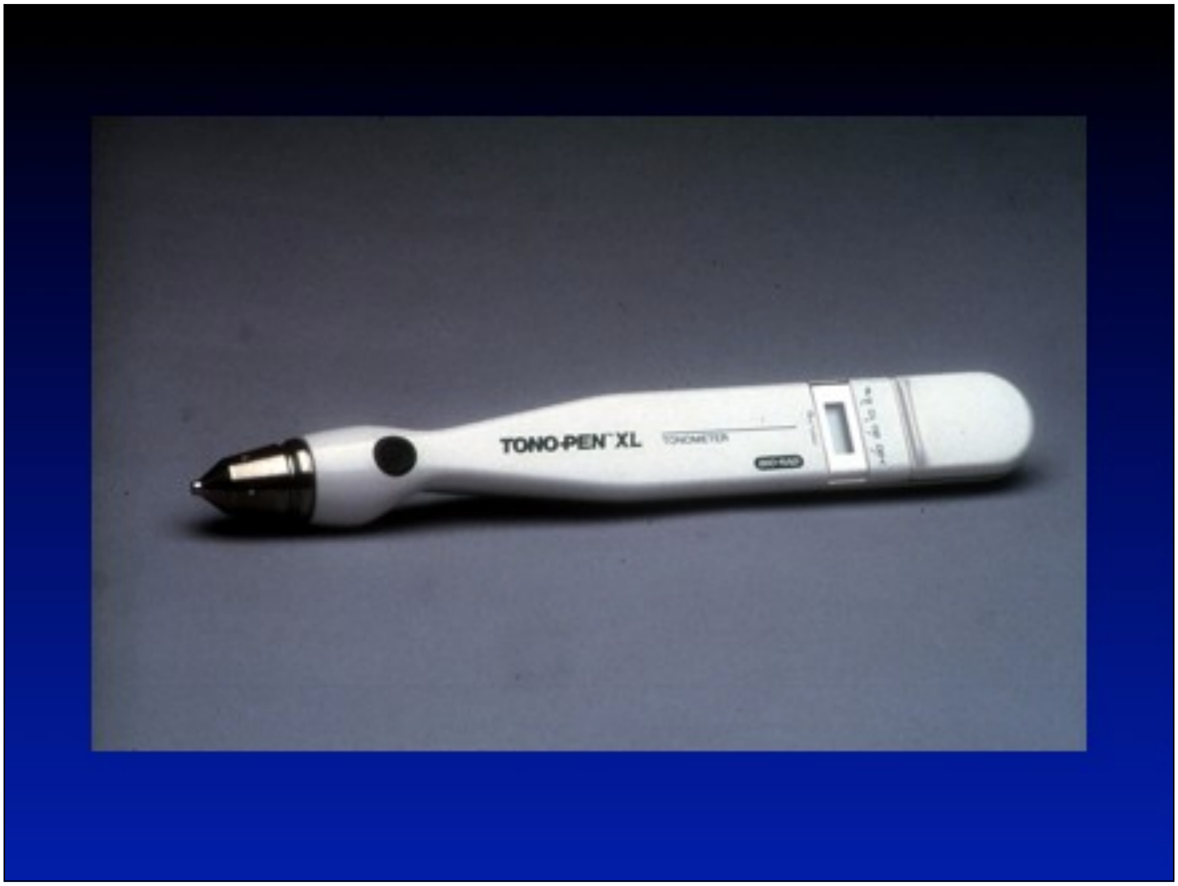
Other Variable Force Applanation Tonometers

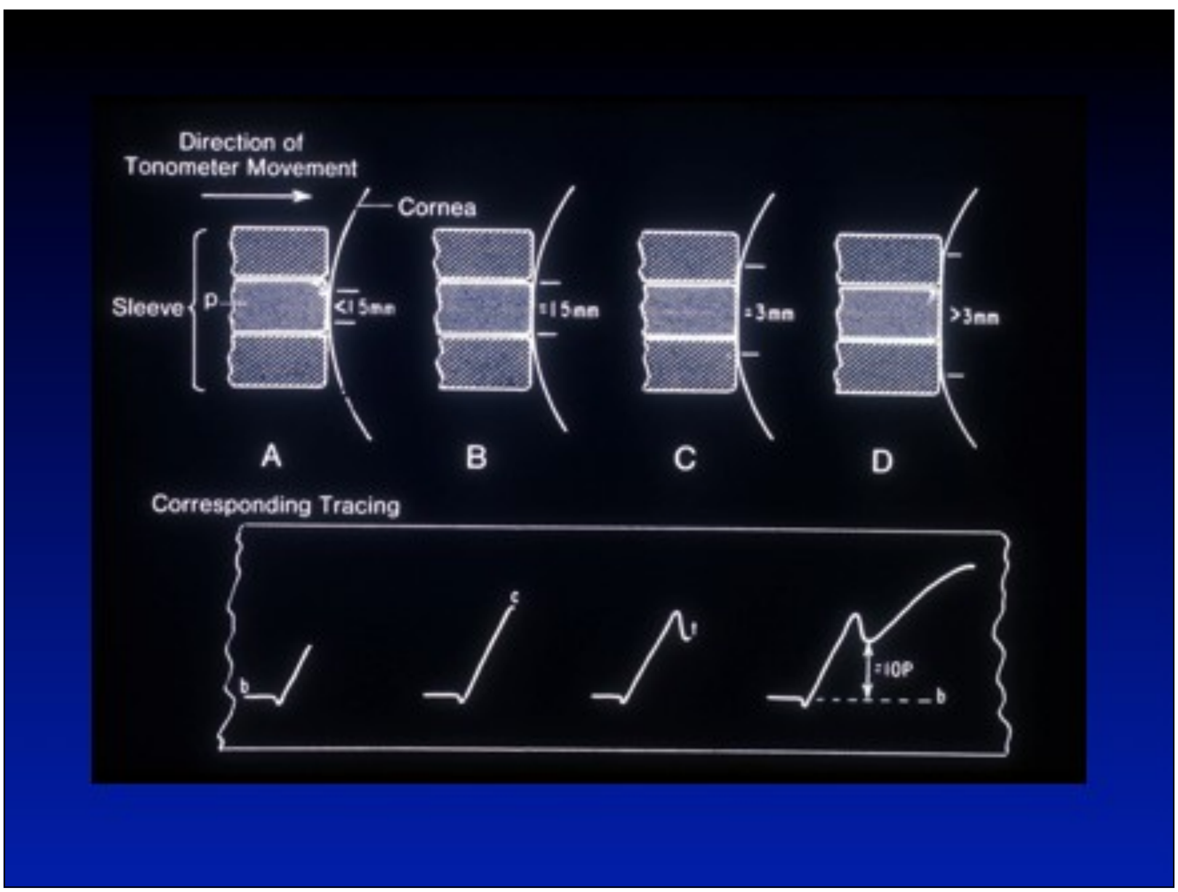
- Perkins
- Mackay-Marg
- Pneumotonometer
- Tonopen





Mackay-Marg Tonometry (1962)
Principles
• 1.5 mm Plunger/transducer
• Extends 10 µm beyond rubber sleave
• Anlogue tracing


TONO-PEN™ XL
TONOMETER


Direction of
Tonometer Movement
Cornea
Sleeve
P
<1.5mm
=1.5mm
=3mm
>3mm
A
B
C
D
Corresponding Tracing
b
c
t
=IOP
b

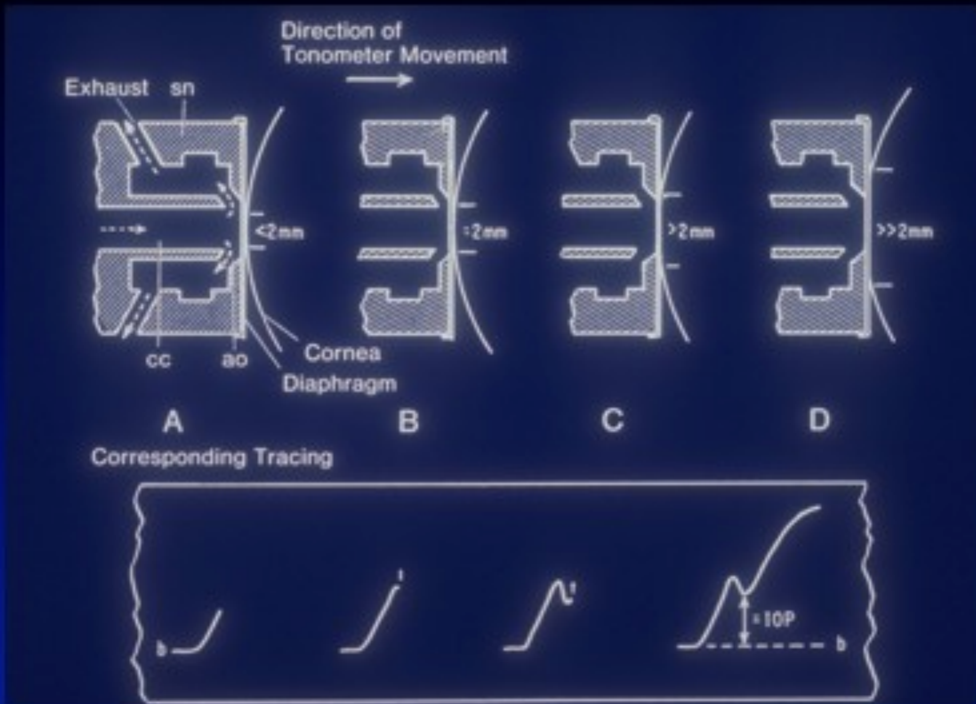

OCU-FILM
MENTOR O&O
TONO-PEN XL
TONOMETER


BIO-RAD
mm. Hg
>20 20 10 5 %

Comparison of Tonometers with Goldmann

Pneumatonometer

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



Tonometry

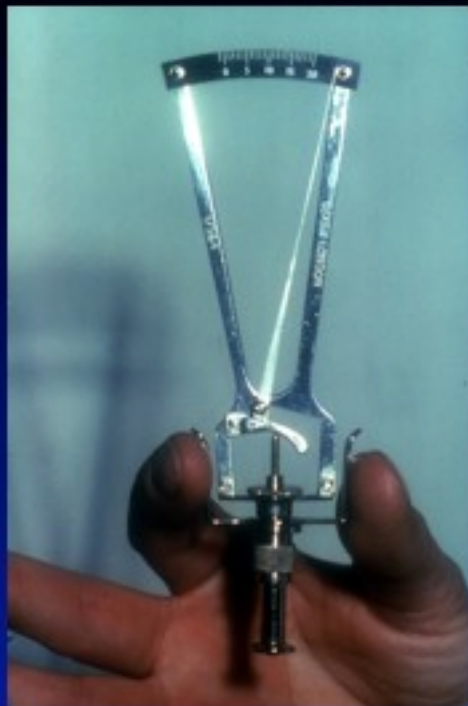
Classification of Contact Tonometers

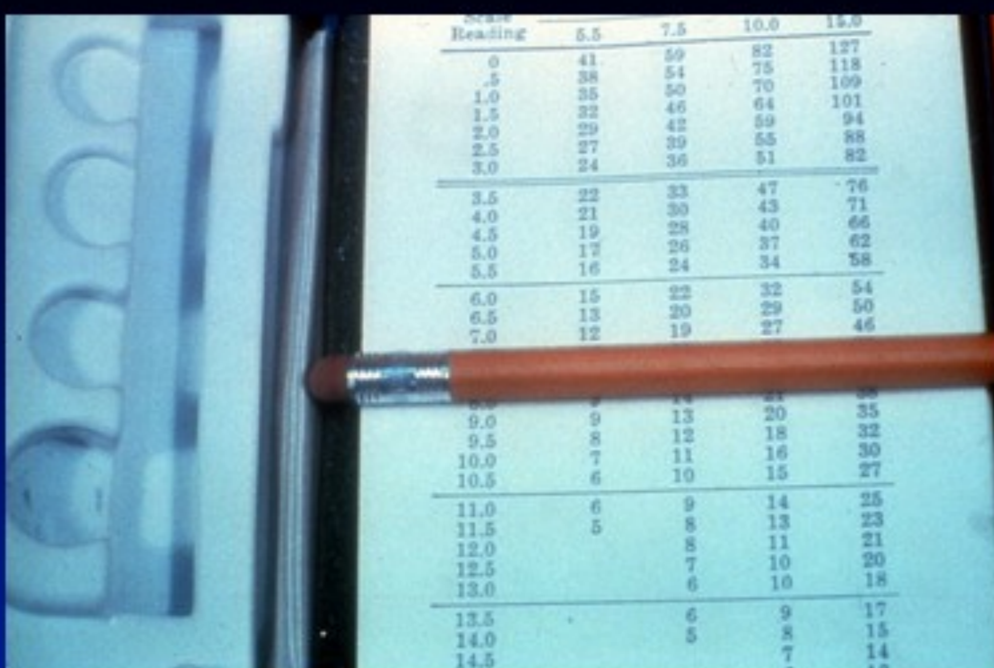
- Indentation (Schiøtz1905)
- Applanation
  - Variable Force e.g. Goldmann(1954), Mackay-Marg
  - Variable Area (Maklakov 1885)

Comparison of Tonometers with Goldmann

Schiøtz

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





Reading	5.5	7.5	10.0	15.0
0	41	59	82	127
.5	38	54	75	118
1.0	35	50	70	109
1.5	32	46	64	101
2.0	29	42	59	94
2.5	27	39	55	88
3.0	24	36	51	82
3.5	22	33	47	76
4.0	21	30	43	71
4.5	19	28	40	66
5.0	17	26	37	62
5.5	16	24	34	58
6.0	15	22	32	54
6.5	13	20	29	50
7.0	12	19	27	46
9.0	9	13	20	35
9.5	8	12	18	32
10.0	7	11	16	30
10.5	6	10	15	27
11.0	6	9	14	25
11.5	5	8	13	23
12.0		8	11	21
12.5		7	10	20
13.0		6	10	18
13.5		6	9	17
14.0		5	8	15
14.5			7	14

FIG. 272.—HJALMAR AUGUST SCHIØTZ
[1850–1927].

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)

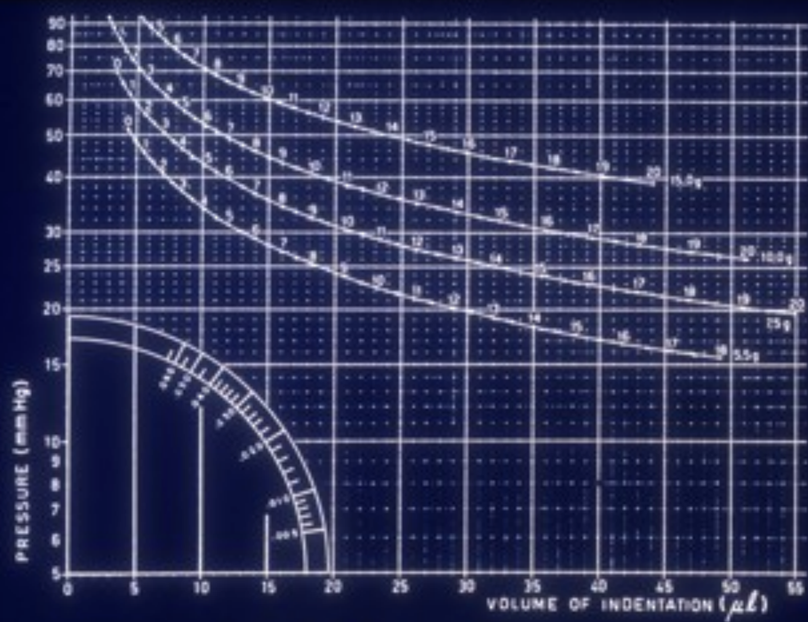
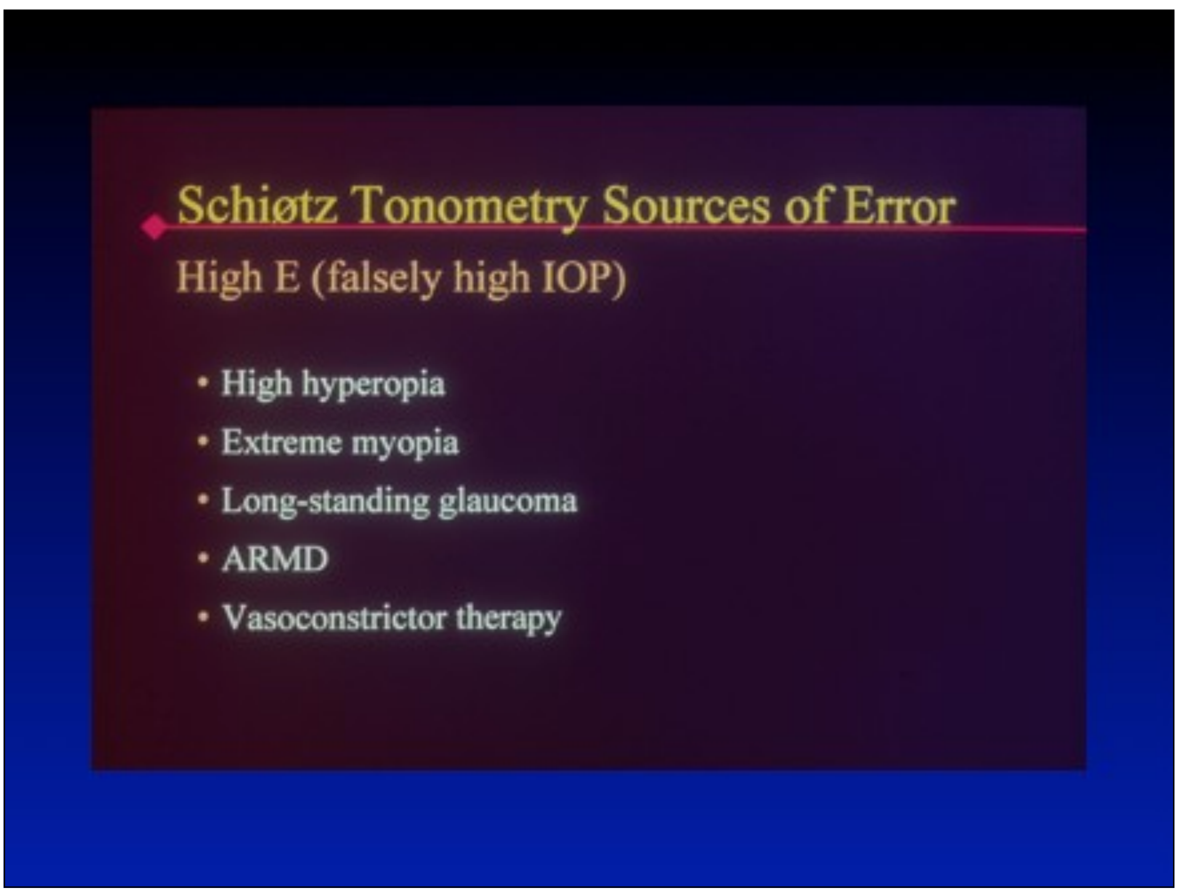


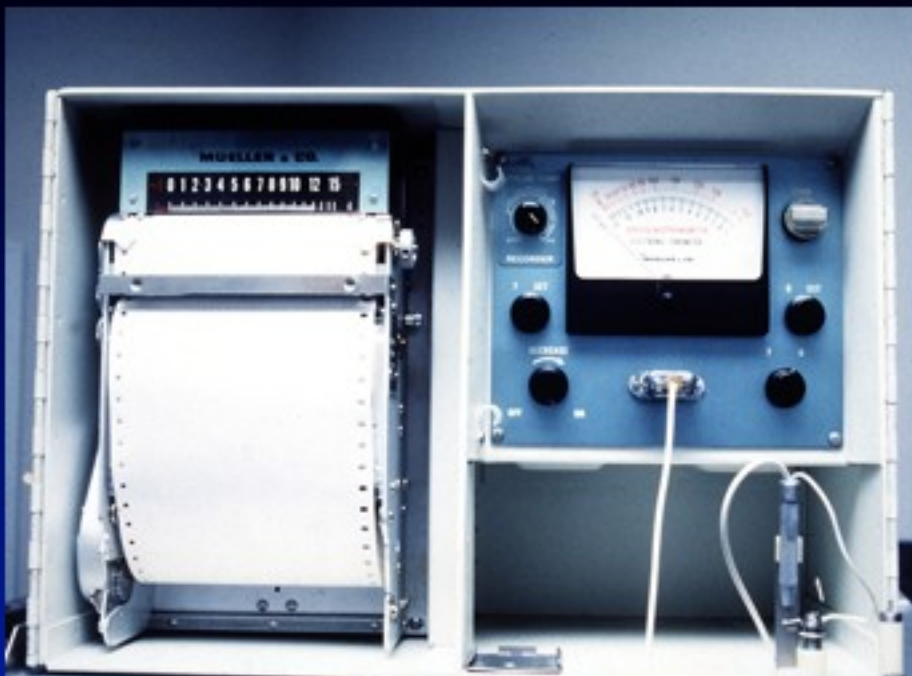
Fig. 5-2. Friedenwald nomogram.

Table 28-2. Calibration scale for Schiøtz tonometers, P_0 (mm Hg), revised 1955

Scale reading	Plunger load			
	5.5 grams	*7.5 grams*	*10 grams*	*15 grams*
3.0	24.4	35.8	50.6	81.8
3.5	22.4	33.0	46.9	76.2
4.0	20.6	30.4	43.4	71.0
4.5	18.9	28.0	40.2	66.2
5.0	17.3	25.8	37.2	61.8
5.5	15.9	23.8	34.4	57.6
6.0	14.6	21.9	31.8	53.6
6.5	13.4	20.1	29.4	49.9
7.0	12.2	18.5	27.2	46.5
7.5	11.2	17.0	25.1	43.2
8.0	10.2	15.6	23.1	40.2
8.5	9.4	14.3	21.3	38.1
9.0	8.5	13.1	19.6	34.6
9.5	7.8	12.0	18.0	32.0
10.0	7.1	10.9	16.5	29.6


Schiøtz 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


Schiøtz Tonometry Sources of Error
High E (falsely high IOP)
• High hyperopia
• Extreme myopia
• Long-standing glaucoma
• ARMD
• Vasoconstrictor therapy



IOP = F/C + EVP

Comparison of Tonometers with Goldmann

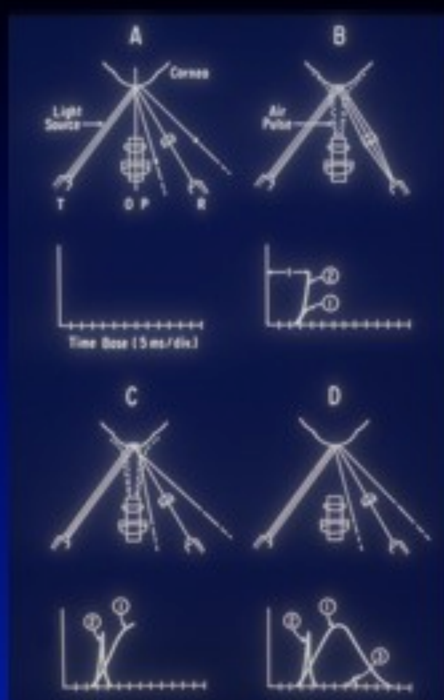
Noncontact tonometer

- 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

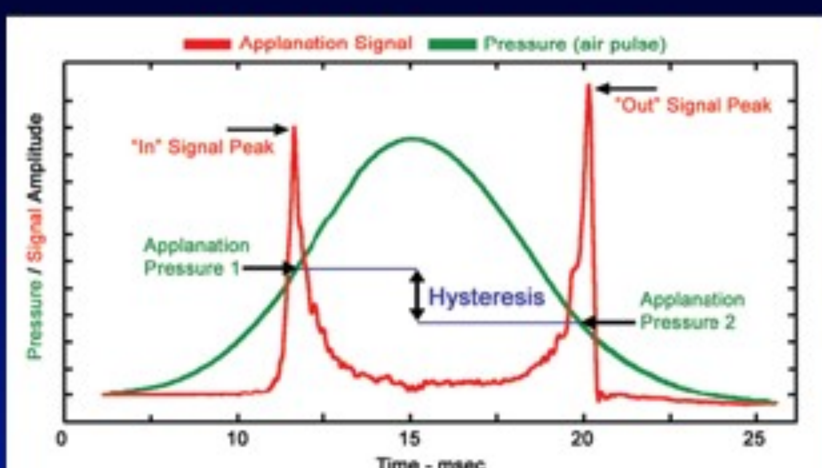
What is Corneal Hysteresis?

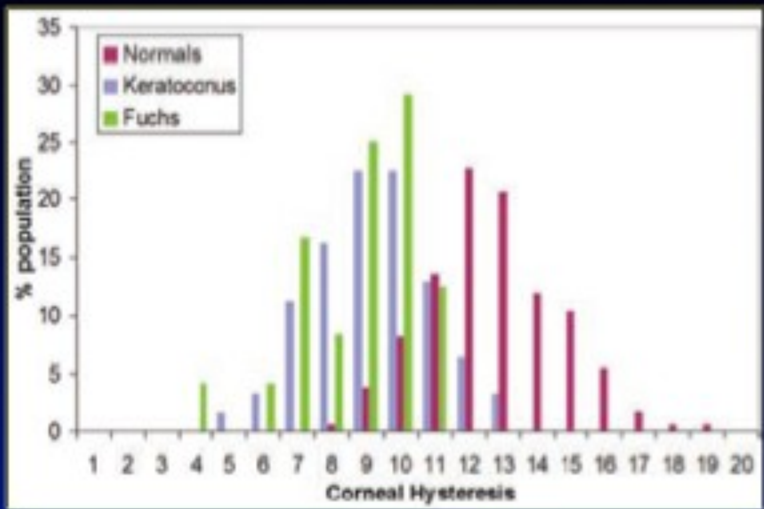
If Cornea is pushed by air impulse, an advanced electro-optical system can record 2 applanation pressure measurements: one while the cornea is moving inward and the other as the cornea returns.

The difference between these 2 measurements is Corneal Hysteresis (CH)

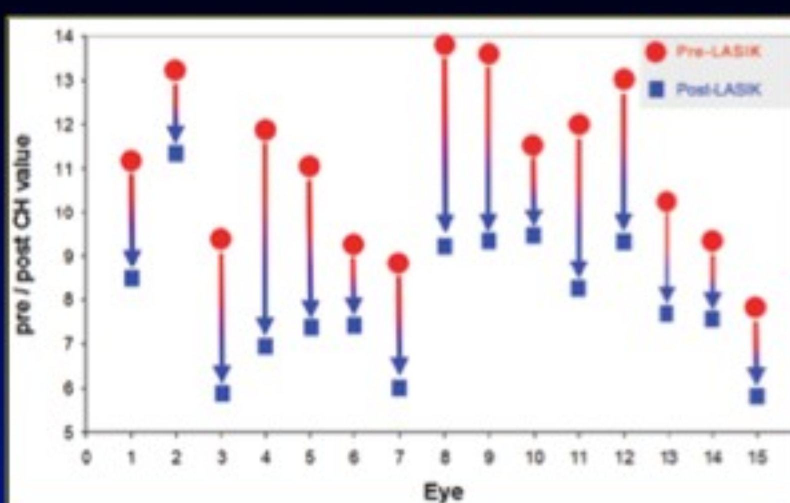
Ocular Response Analyzer

Corneal Hysteresis





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 Pneumatonometry, 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, MD[1]

Objective: The purpose of the study was to determine the accuracy of applanation tonometry, pneumatonometry, 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 Ta = 0.71 age(years) + 10 up to age 10. Applanation tonometry under anesthesia differs from pneumatonometry by an average of −8.6 mmHg and is age related by the equation Ta = Tpn + 2.6 log(age) − 10.3. The TonoPen was the most accurate instrument for enucleated eyes, and the pneumatonometer 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 pneumatonometer performed the best clinically and the best overall. *Ophthalmology 1998;105:1173–1181*

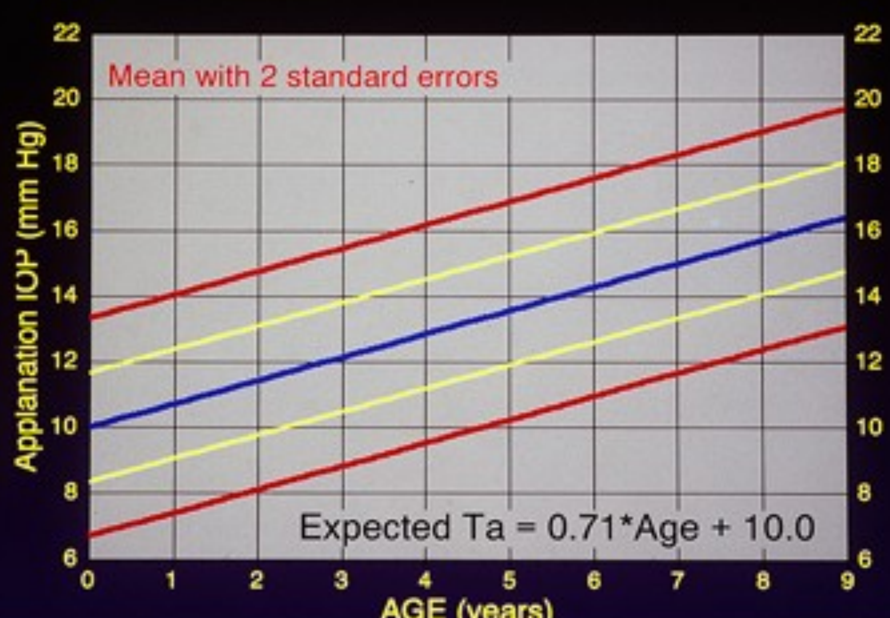
Tonometry in Adults and Children

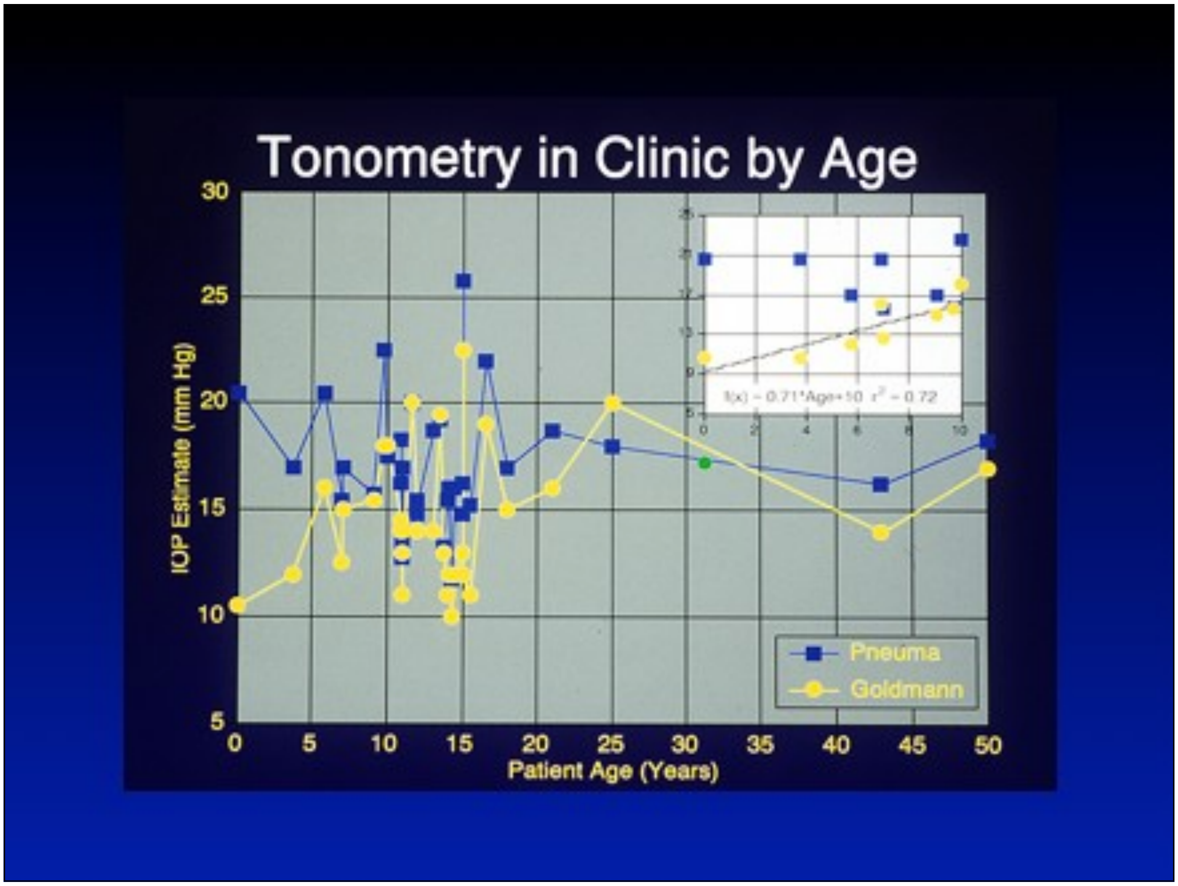
- Part I: Goldmann vs Pneuma in Clinic
- Part II: Perkins vs Pneuma in OR (EUA)
- Part III: Perkins vs Pneuma vs TonoPen vs Manometer in Vitro
- Part IV: Perkins vs Pneuma vs TonoPen vs Manometer in Vivo

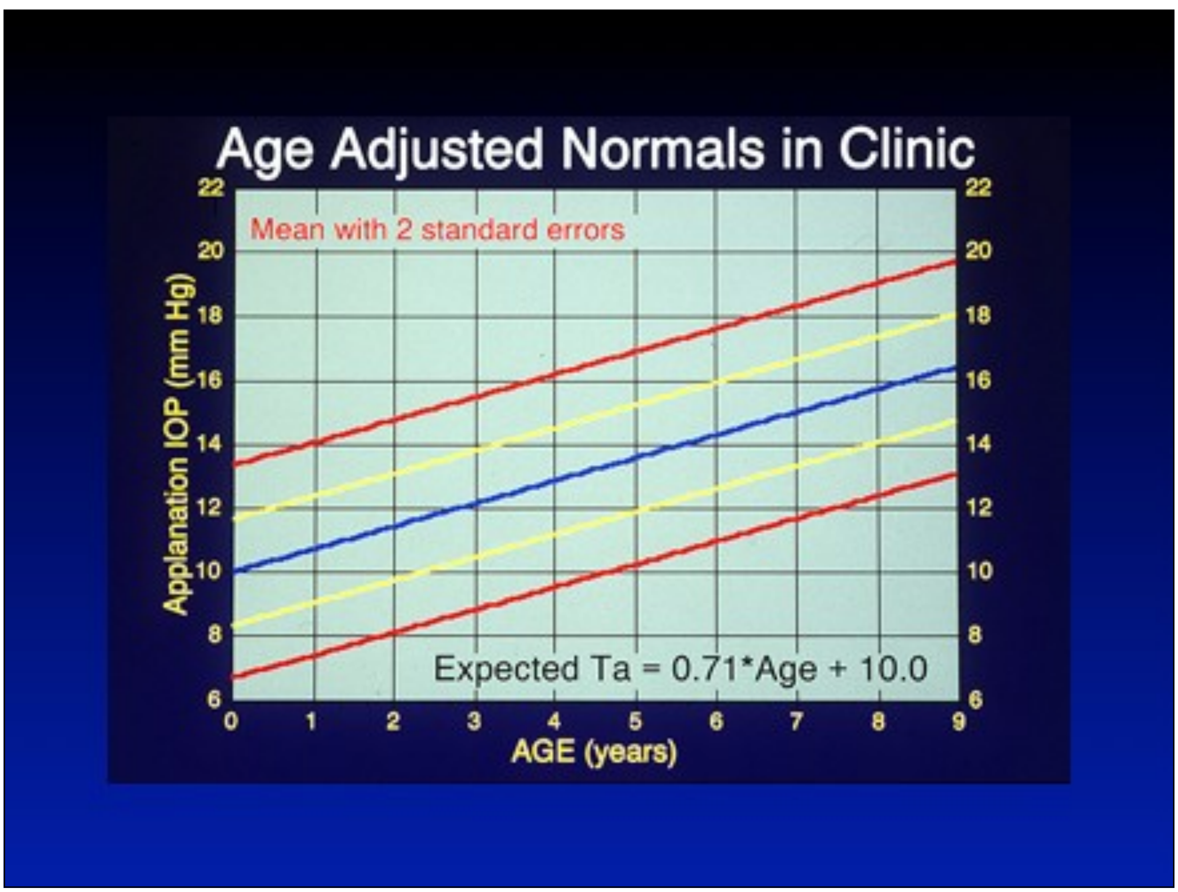
Methods Part I

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

Age Adjusted Normals in Clinic




Tonometry in Clinic by Age
IOP Estimate (mm Hg)
30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
50
Patient Age (Years)
Pneuma
Goldmann

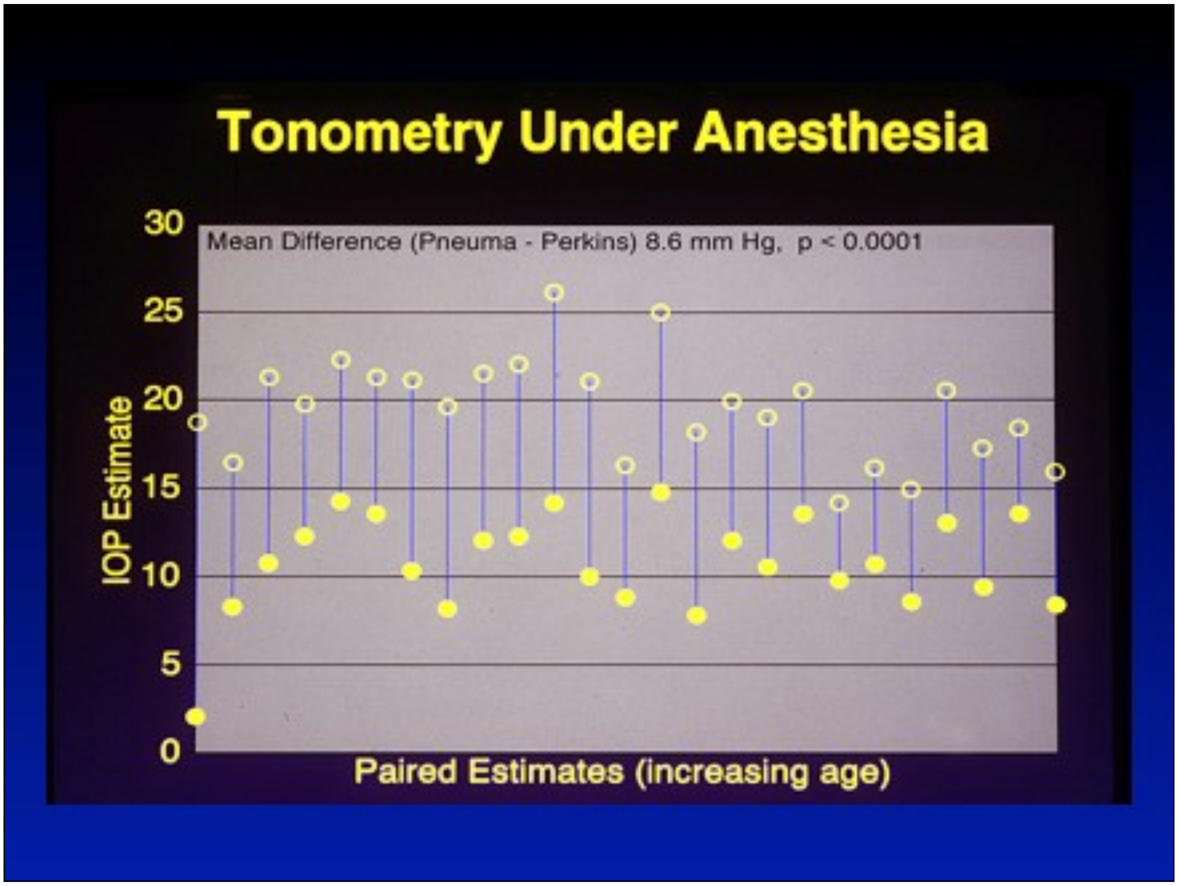

Age Adjusted Normals in Clinic
Mean with 2 standard errors
Applanation IOP (mm Hg)
22
20
18
16
14
12
10
8
6
0
1
2
3
4
5
6
7
8
9
AGE (years)
Expected Ta = 0.71*Age + 10.0

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*Log(Age)



Methods Part III

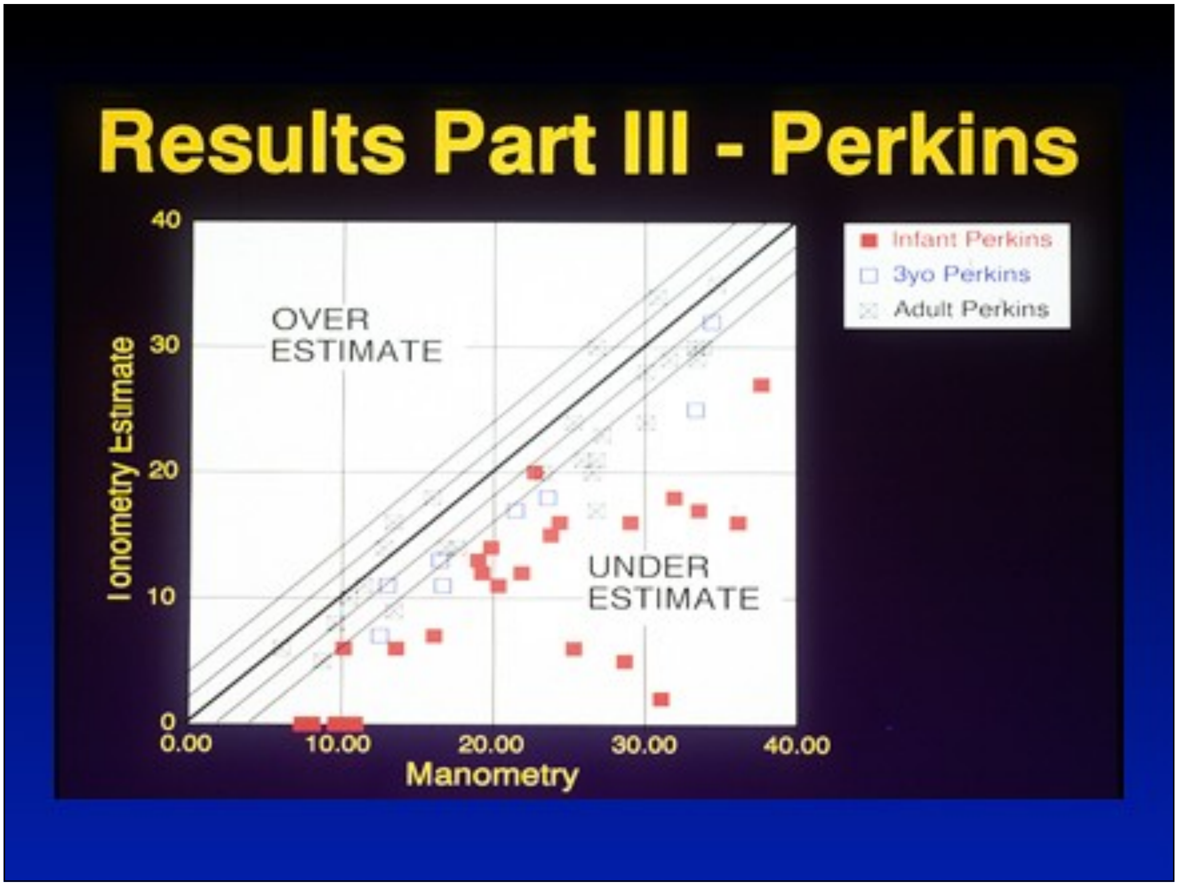
- Enucleated Human Eyes
- Enucleated globes, <24hrs post mortem
- Perkins, Pneuma, TonoPen by DLE
- MANOMETRIC reference
- Randomized IOP target (low, med, high)

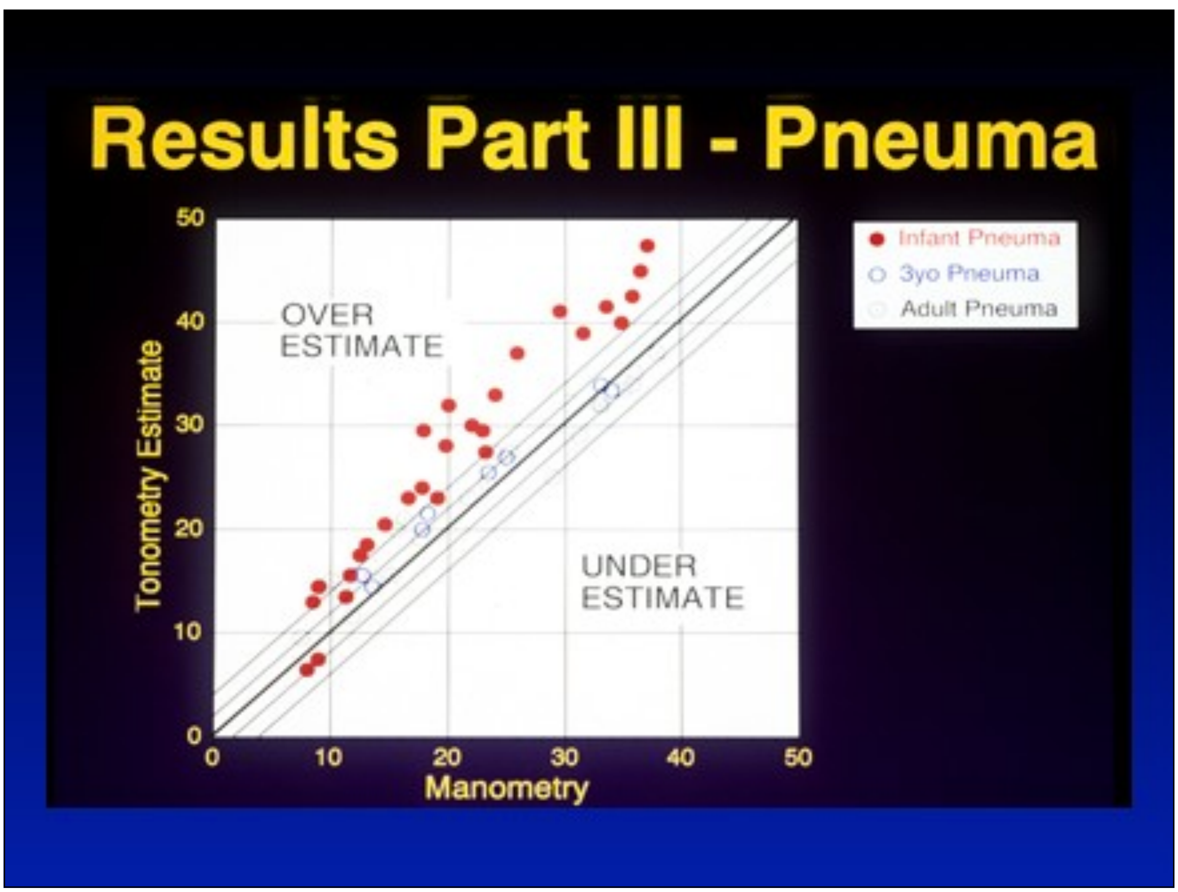
Demographics - Enucleated Human Eyes

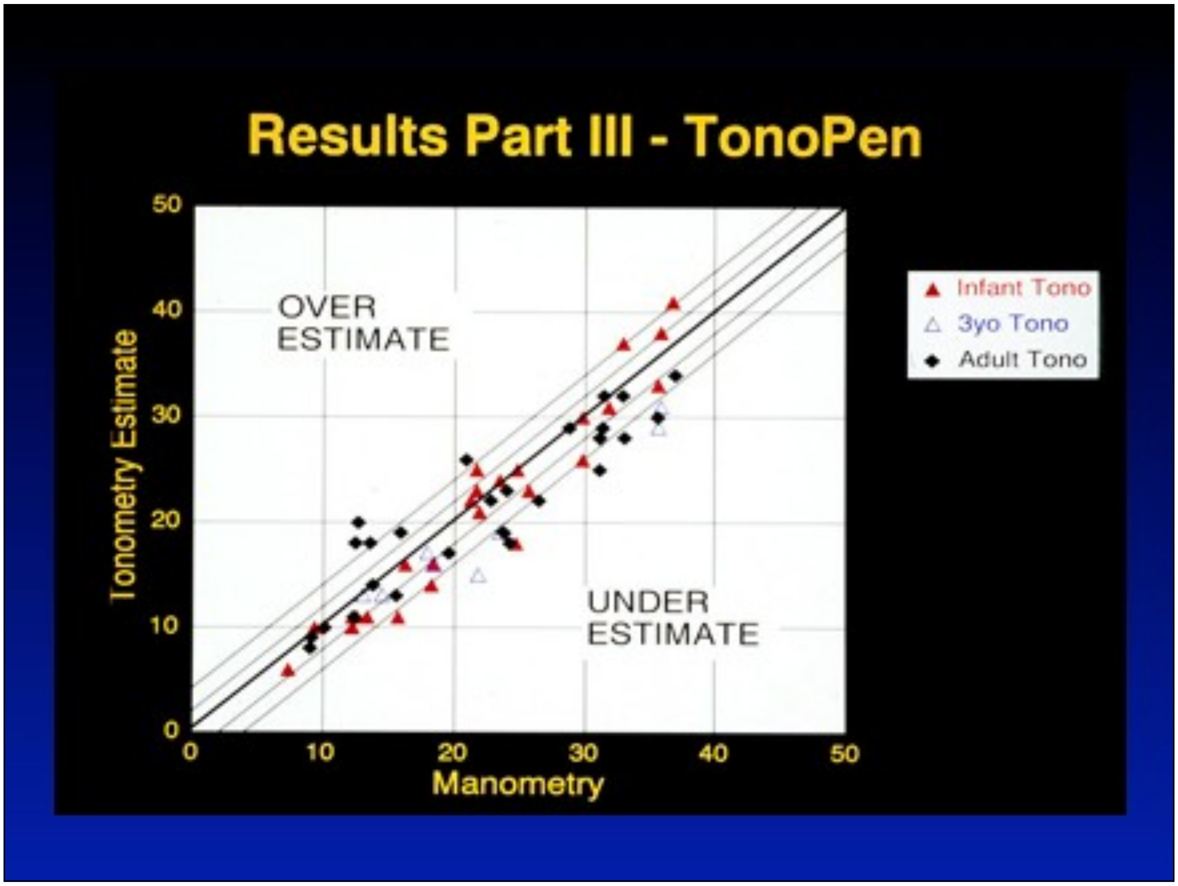
	Age(Years)	Gender	Eye
1	0.00	M	OU
2	0.01	F	OU
3	3.00	M	OU
4	82.00	M	OU
5	82.10	F	OU

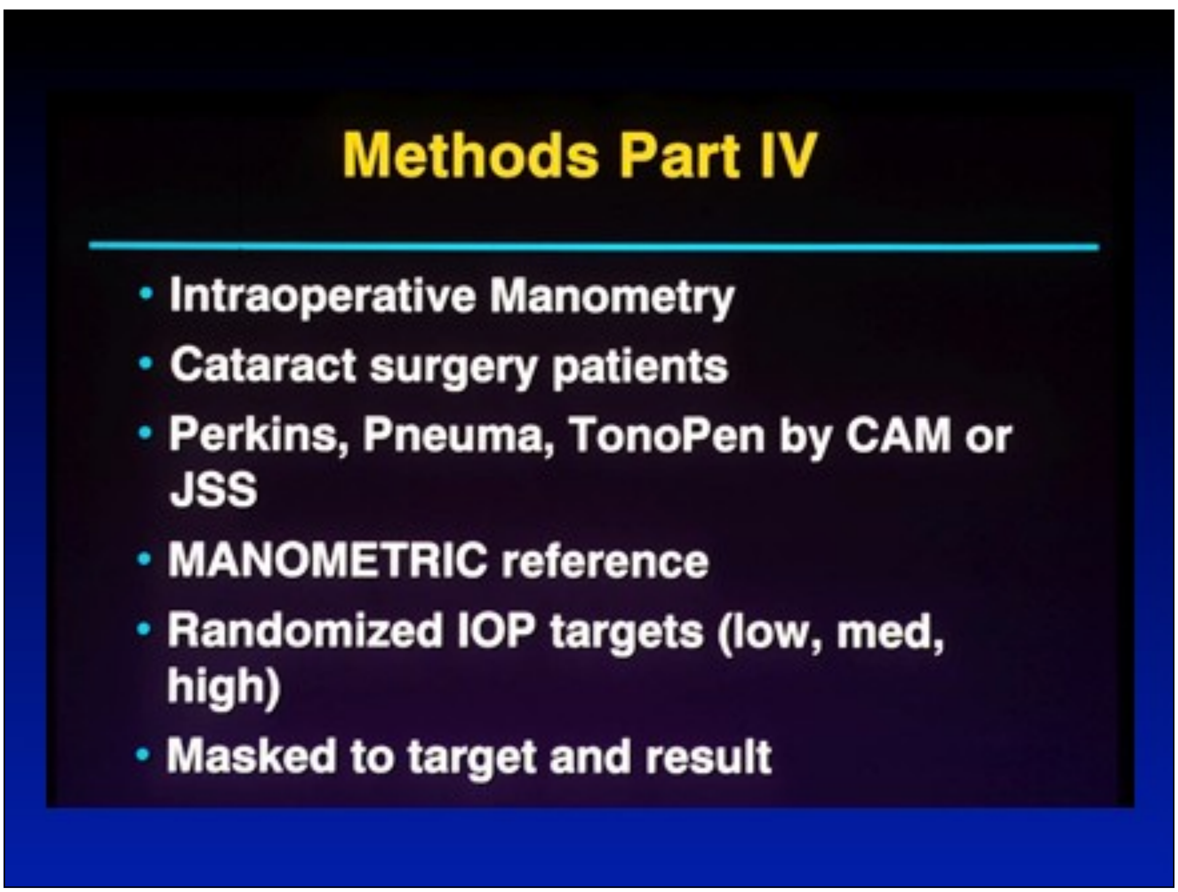
Results Part III

- Enucleated Human Eyes
- 2 newborn, 1 3 yo, 2 adult (10 eyes)
- Perkins: -7.6 + 0.040*Age, no IOP effect
- Pneuma: +5.6 -0.053*Age, no IOP effect
- TonoPen: -0.10*IOP, no Age effect


Results Part III - Perkins
OVER ESTIMATE
UNDER ESTIMATE
Infant Perkins
3yo Perkins
Adult Perkins
Tonometry Estimate
Manometry
0
10
20
30
40
0.00
10.00
20.00
30.00
40.00


Results Part III - Pneuma
OVER ESTIMATE
UNDER ESTIMATE
Infant Pneuma
3yo Pneuma
Adult Pneuma
Tonometry Estimate
Manometry
0
10
20
30
40
50


Results Part III - TonoPen
OVER ESTIMATE
UNDER ESTIMATE
Tonometry Estimate
Manometry
0
10
20
30
40
50
Infant Tono
3yo Tono
Adult Tono

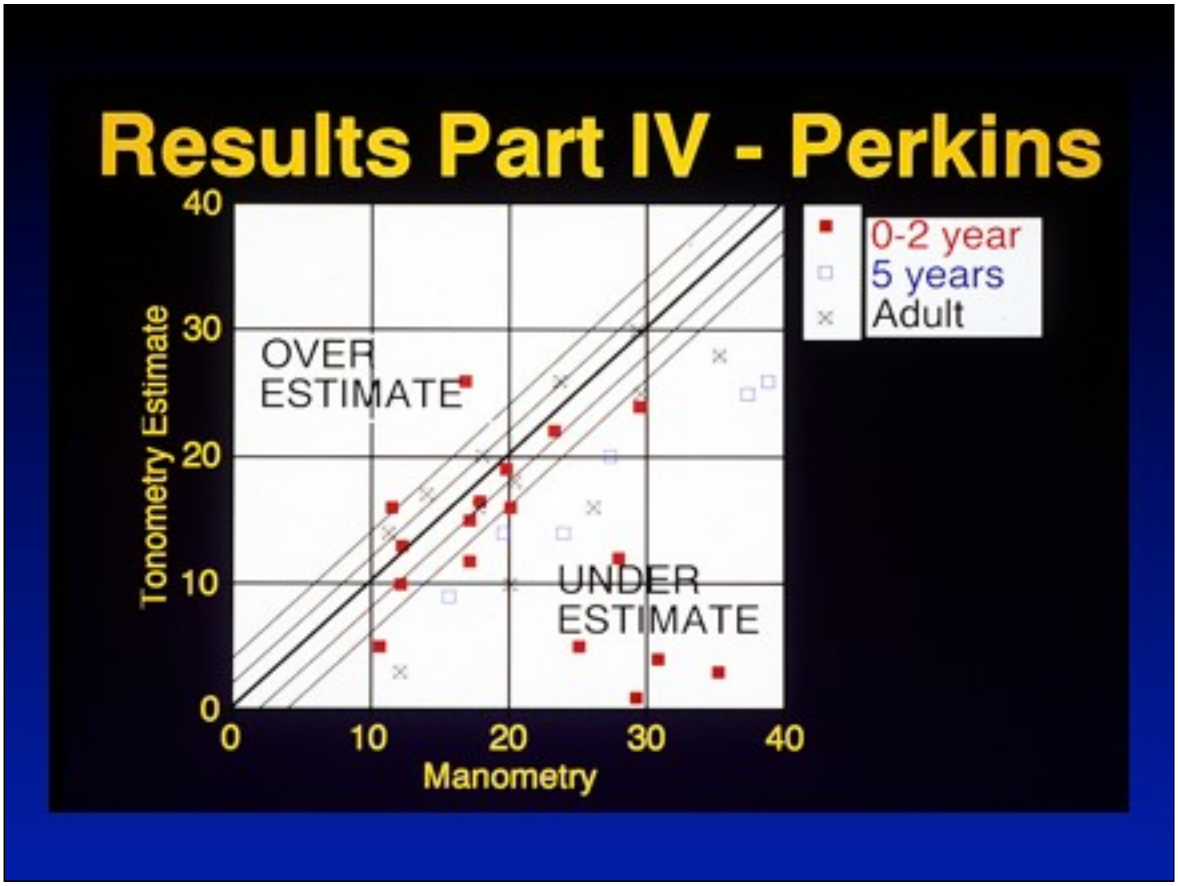

Methods Part IV
• Intraoperative Manometry
• Cataract surgery patients
• Perkins, Pneuma, TonoPen by CAM or JSS
• MANOMETRIC reference
• Randomized IOP targets (low, med, high)
• Masked to target and result

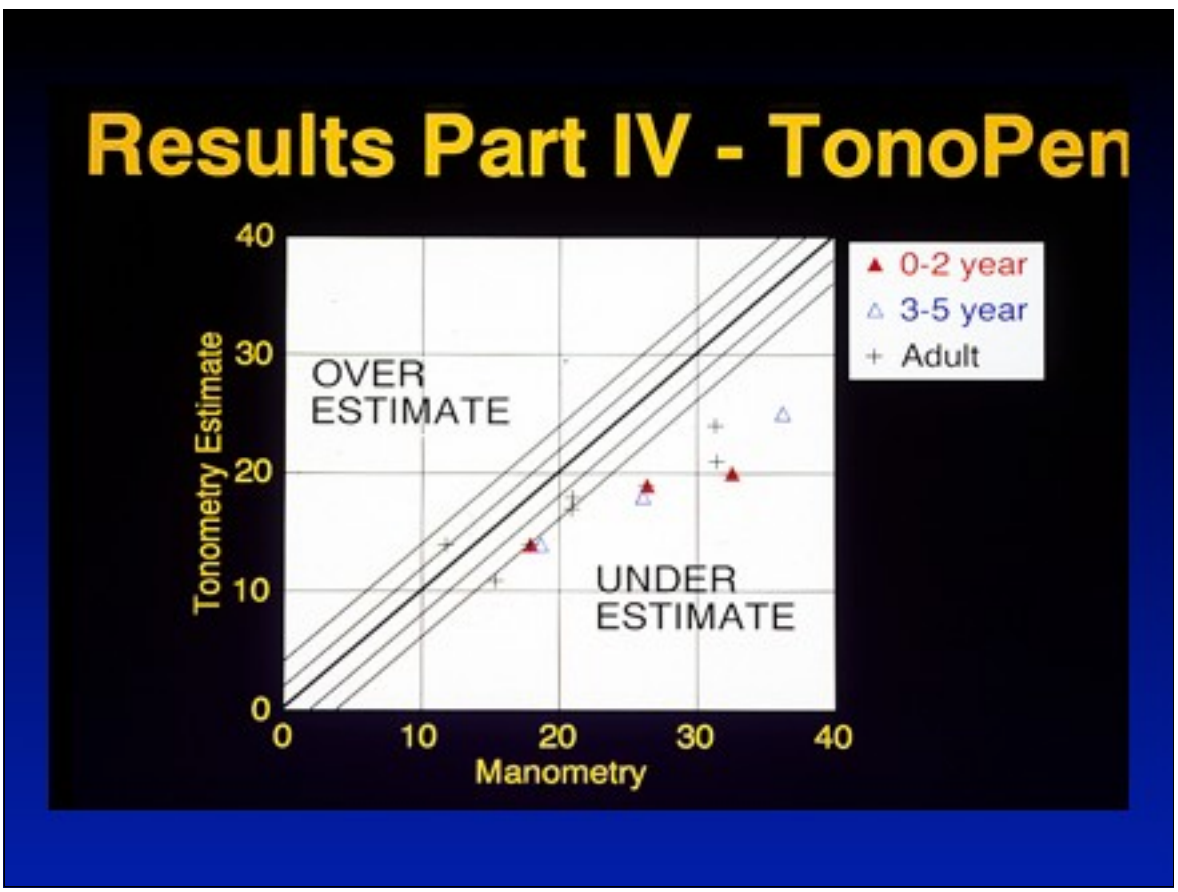
Demographics - Intraoperative Manometry

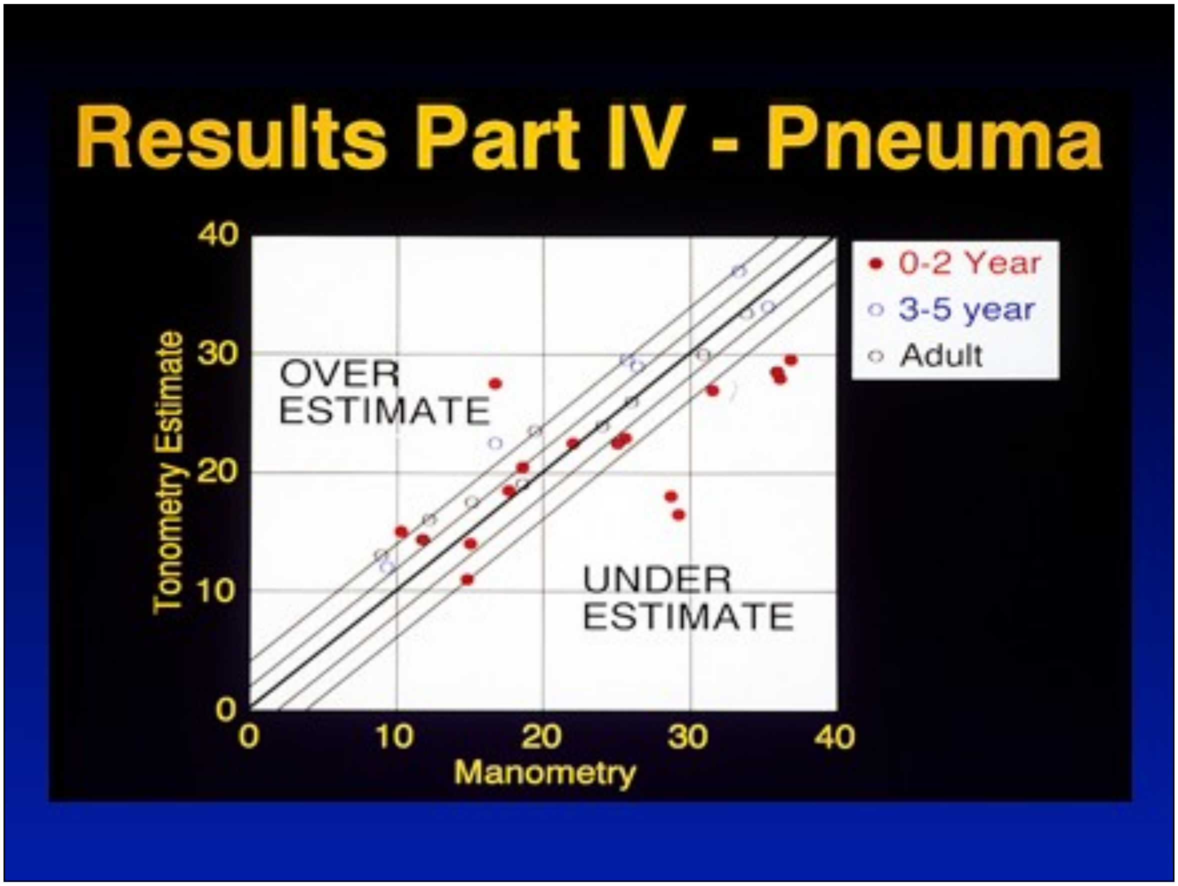
	Age(Years)	Gender	Eye
AL	0.10	F	OS
RS	0.23	M	OS
JB	0.75	M	OD
JB	1.00	M	OS
JM	1.75	F	OD
CF	4.90	F	OS
CF	5.00	F	OD
CL	50.20	F	OD
RD	68.00	F	OD
PD	78.30	F	OS
WO	85.00	M	OD

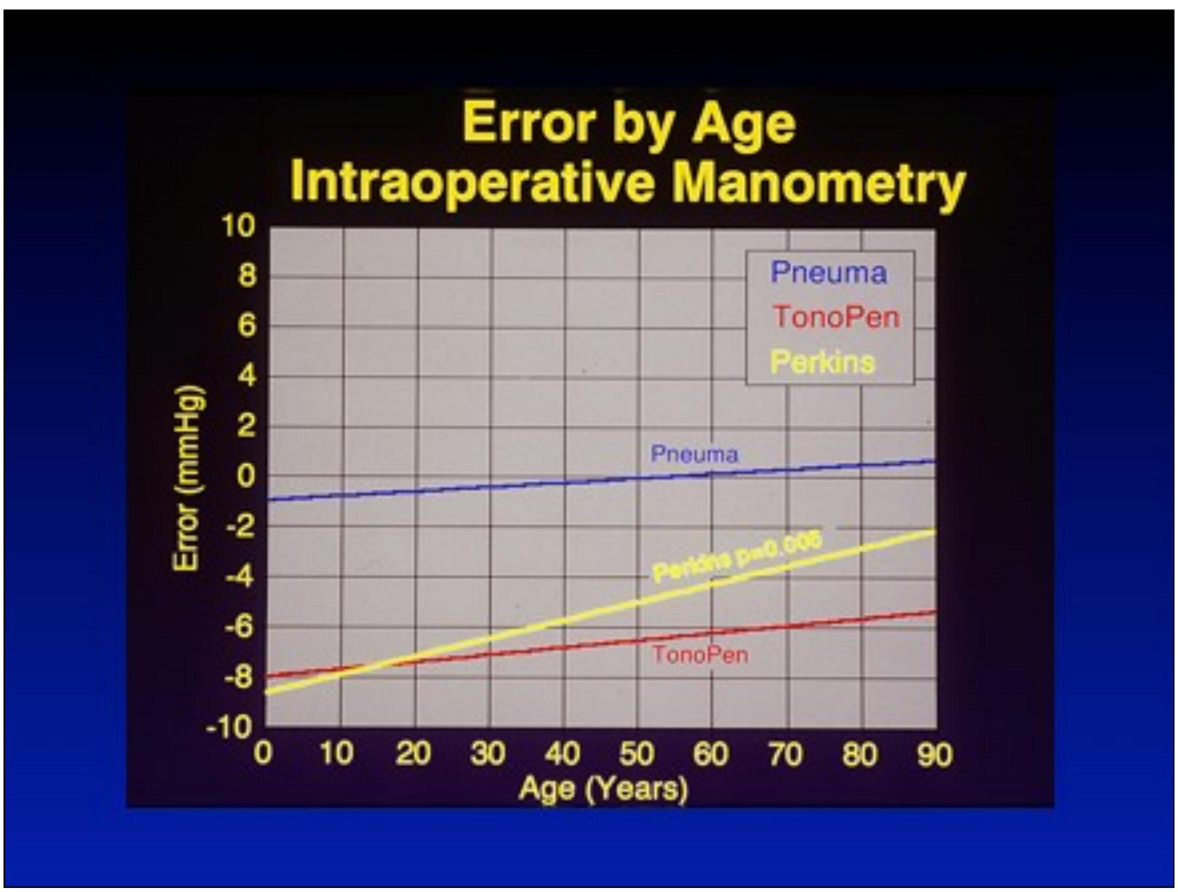
Results Part IV

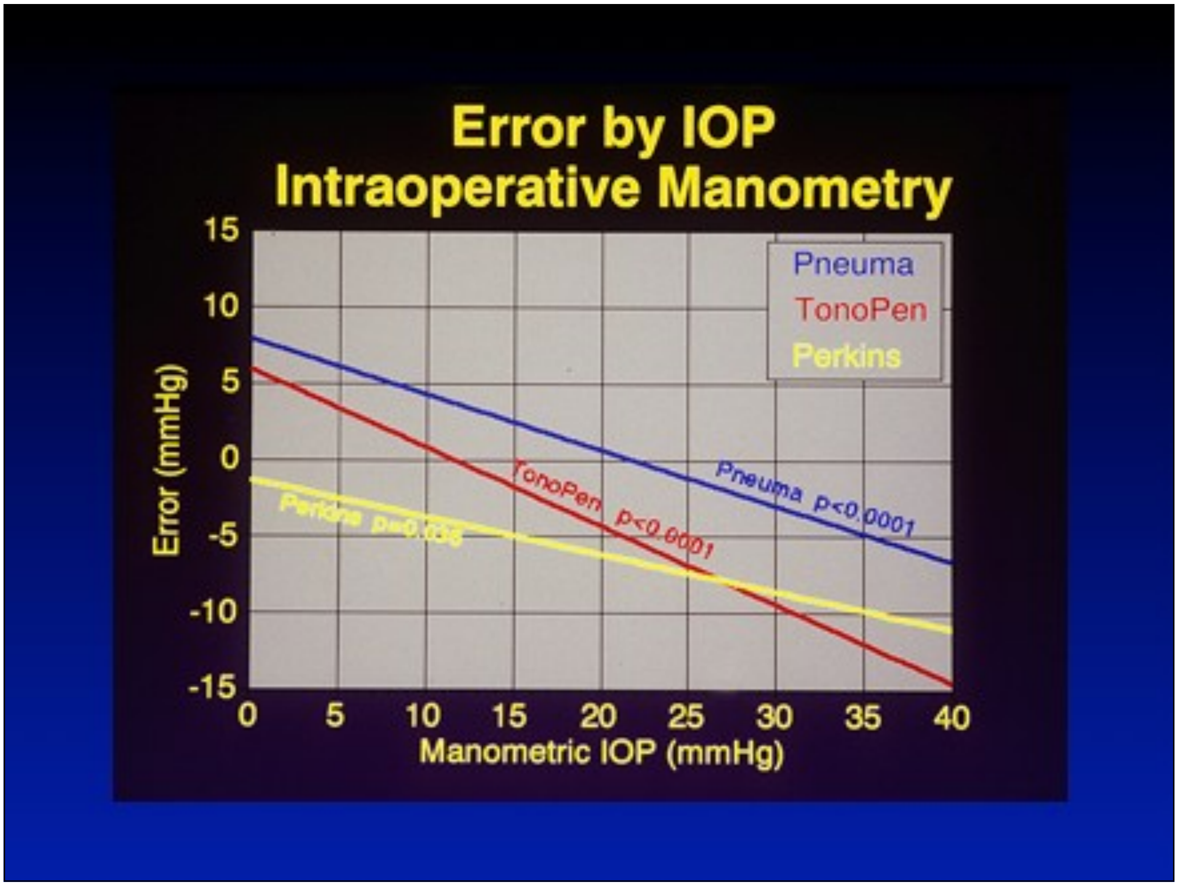
- Intraoperative Manometry
- 5 children, 4 adults (11 eyes)
- Perkins: 0.067*Age - 0.21*IOP
- Pneuma: +7.6 -0.36*IOP, no Age effect
- TonoPen:+5.2 - 0.50*IOP, no Age effect

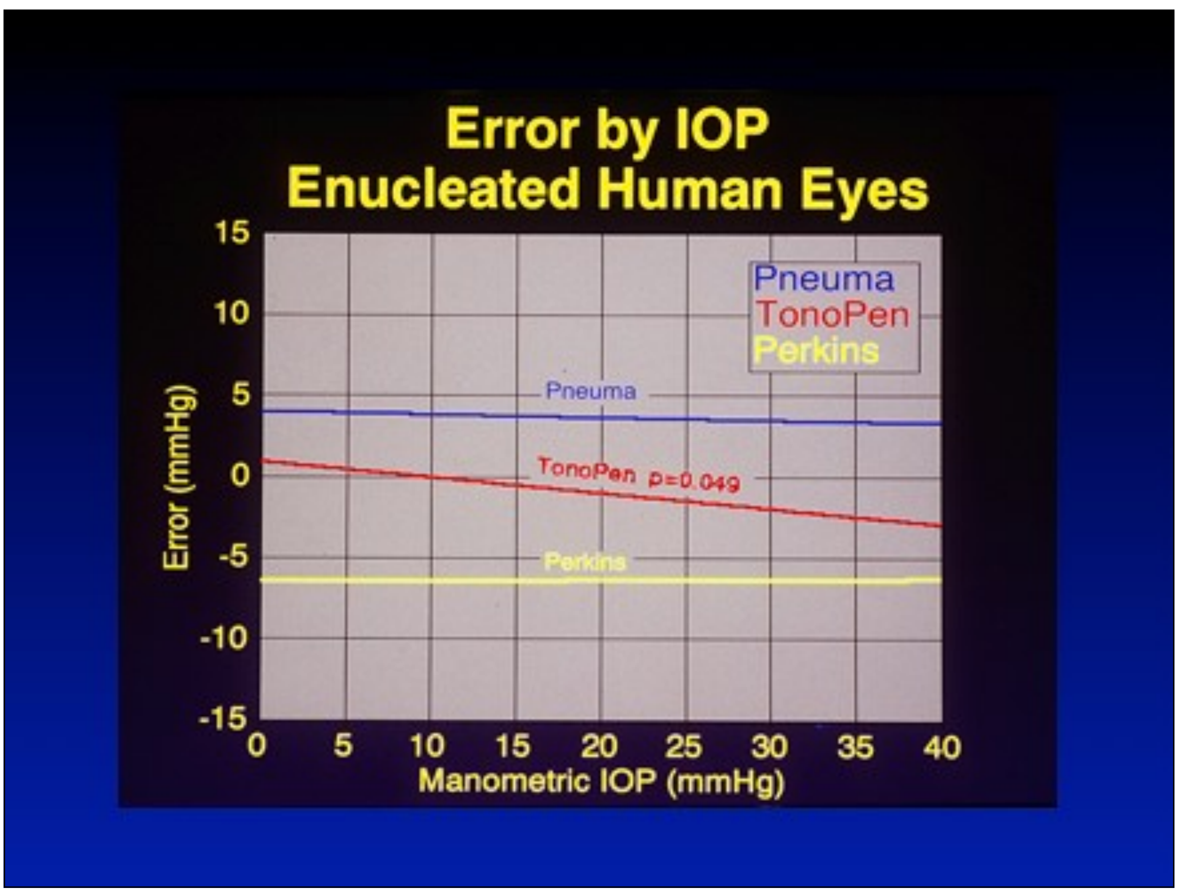

Results Part IV - Perkins
Tonometry Estimate
Manometry
OVER ESTIMATE
UNDER ESTIMATE
0-2 year
5 years
Adult
0
10
20
30
40


Results Part IV - TonoPen
Tonometry Estimate
Manometry
OVER ESTIMATE
UNDER ESTIMATE
0-2 year
3-5 year
Adult
0
10
20
30
40


Results Part IV - Pneuma
0-2 Year
3-5 year
Adult
OVER
ESTIMATE
UNDER
ESTIMATE
Tonometry Estimate
Manometry
0
10
20
30
40


Error by Age
Intraoperative Manometry
Pneuma
TonoPen
Perkins
Pneuma
Perkins p=0.005
TonoPen
Error (mmHg)
Age (Years)
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60
70
80
90


Error by IOP
Intraoperative Manometry
Pneuma
TonoPen
Perkins
Pneuma p<0.0001
TonoPen p<0.0001
Perkins p=0.036
Error (mmHg)
15
10
5
0
-5
-10
-15
0 5 10 15 20 25 30 35 40
Manometric IOP (mmHg)


Error by IOP
Enucleated Human Eyes
Pneuma
TonoPen
Perkins
Pneuma
TonoPen p=0.049
Perkins
Error (mmHg)
15
10
5
0
-5
-10
-15
0 5 10 15 20 25 30 35 40
Manometric IOP (mmHg)

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