AUXILIARY TESTING IN PRIMARY OPEN ANGLE GLAUCOMA

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INTRODUCTION

A wide range of procedures are available and necessary for the practitioner to do in order to assist in the detection, diagnosis and monitoring of glaucoma.

We will discuss the following principal procedures below.

- Gonioscopy
- Tonometry
- Pachymetry

GONIOSCOPY

The technique of gonioscopy is the only procedure readily available to the practitioner to visualize and assess the anterior chamber angle. The proficient use of a gonioscopy lens is absolutely essential for the diagnosis and management of glaucoma.

- Purpose of gonioscopy
    - To identify normal and abnormal angle structures and to estimate width of angle
- Optical principles

- Direct visualization of the angle is not possible because of total internal reflections in the cornea
- A gonioscopy lens replaces cornea-air interface by introducing a new interface with refractive index greater than that of cornea and tear film

STRUCTURES EXAMINED DURING GONIOSCOPY

The main anatomical landmarks that are visible using a gonioscopy lens are as follows (from anterior to posterior):

- **Schwalbe's Line (SL)**
  - Most anterior (shallow) structure of the anterior chamber angle
  - Condensation of connective tissue, end of the cornea (most peripheral aspect of the cornea)
  - Seen as a white band; may be pigmented (pigmentation line is called Sampaolesi's Line)
- **Trabecular Meshwork (TM)**
  - Two visible portions
    - Anterior: non-filtering portion (non-pigmented)
    - Posterior: overlies Schlemm's canal; therefore active in drainage of aqueous humor (pigmented)
    - Occasionally blood reflux from Schlemm's canal may be visible here
- **Scleral Spur (SS)**
  - Attaches the TM anteriorly and longitudinal muscle of CB posteriorly
  - If this structure is seen in gonioscopy it verifies the drainage is unobstructed
- **Ciliary Body (CB)**
  - Longitudinal muscle
  - Black, brown, grey, mottled, mixed with white

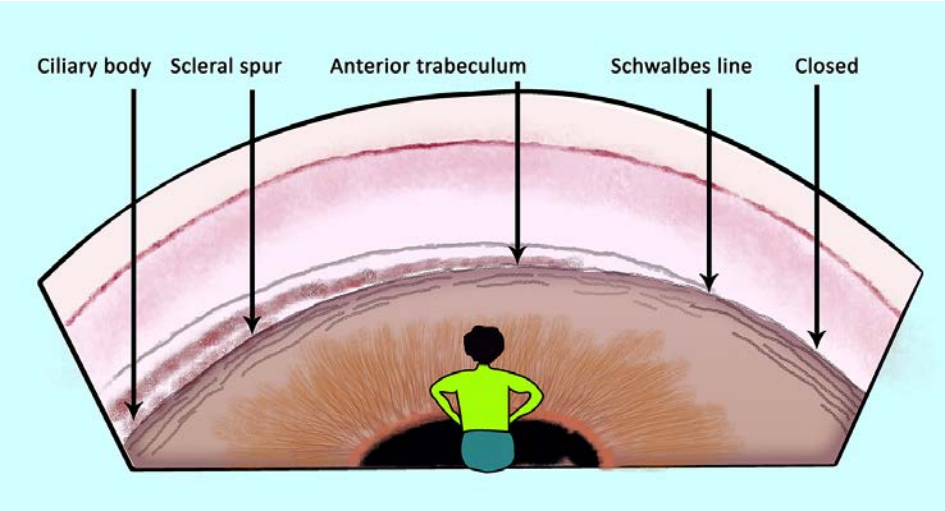

Figure 15.1: *Representation of a wide open angle (left) to a closed angle (right)*

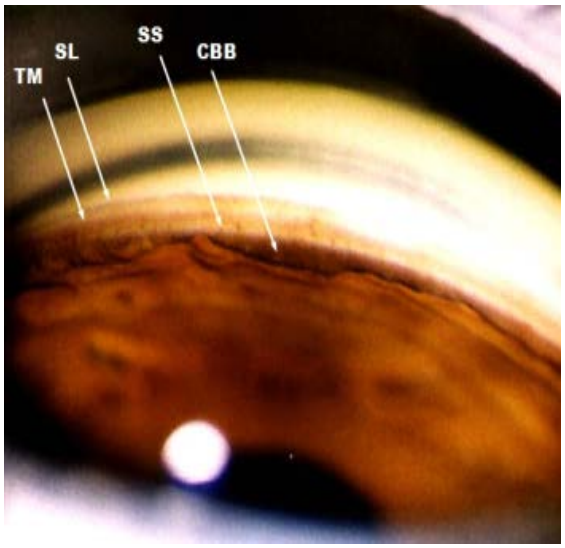

Figure 15.2: *Anatomical landmarks in the angle as seen with a gonio lens*

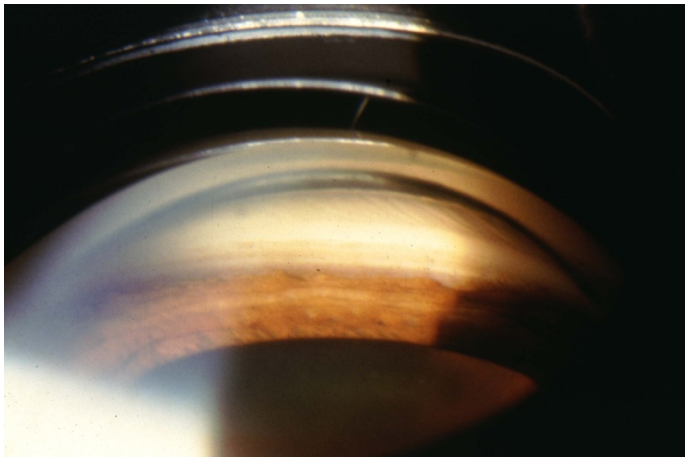

Figure 15.3: *Normal open angle with trace pigment*

Gonioscopy Findings and Associated Conditions	
Finding	**Associated Condition(s)**
High accumulation of pigment	*Pigmentary dispersion syndrome, exfoliation syndrome, trauma and surgery*
Peripheral anterior synechiae	*Intermittent or chronic angle closure attacks, trauma and chronic inflammation*
Hyphema	*Neovascularization of the angle, trauma*
Exfoliative material	*Exfoliation syndrome*
Wide ciliary band	*Angle recession*
Blood vessels	*Neovascularization, normal iris vessels*
Iris processes	*Normal finding, Axenfeld-Rieger syndrome*

Table 15.1: *Gonioscopy findings and associated conditions*

SUGGESTED ANATOMICAL RECORDING SYSTEM

Two examples of a method to record the anatomical observations made using a gonio lens in the four quadrants are shown in Figure 15.4.

More information on grading the anterior chamber angle can be found in the Clinical Optometric Procedures 2 chapter, *Gonioscopy*.

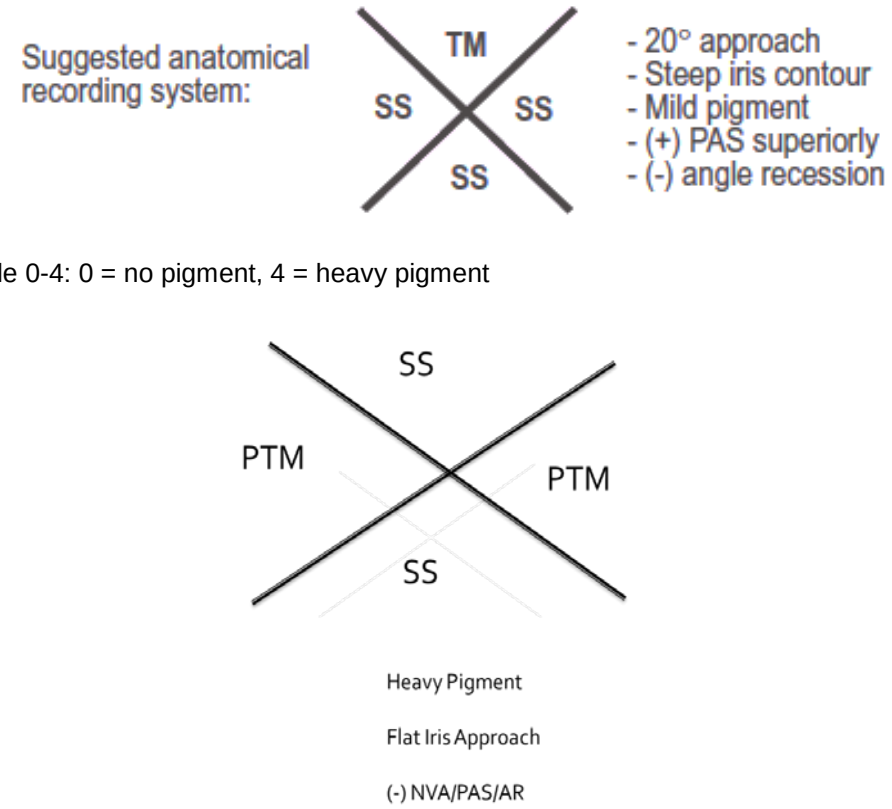

Figure 15.4: *Examples of how to record the angle observation made in four quadrants*

TONOMETRY

The clinical measurement of intraocular pressure (IOP) is an important component of the detection, diagnosis and monitoring of glaucoma. The Goldmann Applanation Technique measures the force required to applanate (flatten) the cornea and is considered the gold standard procedure.

Some of the techniques used for measuring the IOP are shown in Table 2.

Applanation	Indentation	Features of both
Goldmann Non-contact Perkins	Schiotz	Tono-Pen

Table 15.2: *Methods for measuring the IOP*

GOLDMANN APPLANATION TONOMETRY

Goldmann applanation tonometry (GAT) assumes central corneal thickness (CCT) of 500 - 520 microns (µm).

- GAT over-estimates or under-estimates IOP by as much as 5 mm Hg for every 70 µm of CCT difference from ~520 µm

The principles of GAT are depicted in Figure 15.5.

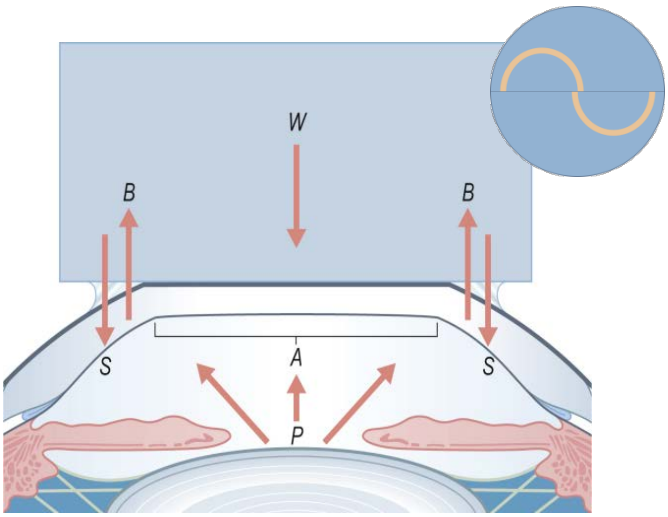

Figure 15.5: *Forces acting during applanation tonometry*
W = tonometer force; S = surface tension of precorneal tear film; P= intraocular pressure; A = area of applanation; B = corneal rigidity/resistance to bending.

Area of applanation = 3.06 mm
1 g of force to applanate = 10 mm Hg of IOP

FACTORS AFFECTING IOP MEASUREMENT

Many factors affect the result when measuring IOP. The ones listed here are for consideration and should be taken into account when considering any SINGLE reading. After all, a single IOP reading takes only a few seconds and there are 84,600 seconds in a day!

Some of the factors that affect the IOP are as follows:

PHYSIOLOGICAL FACTORS

- CCT
- Diurnal variation / hydration
- Arterial (pulse) pressure
- Posture
- Blood Flow
- Exercise
- Accommodation
- Axial length / refractive error

- Corneal dystrophies

EXTRANEOUS INFLUENCES

- Eye rubbing
- Necktie
- Obesity and positioning of slit lamp
- Head position
- Fluid intake
- Medications

ASSUMPTIONS IN THE INITIAL INSTRUMENT DESIGN

Goldmann applanation tonometry (GAT) is considered the gold standard for IOP measurement. It was introduced nearly 60 years ago and was based on CCT of about 500 - 520 µm. There were other assumptions that influenced the present instrument, as well. These simplifications have often been overlooked when presuming that the applanation reading is "absolute."

- Imbert-Fick applies to:
  - Infinitely thin membranes
  - Surrounding perfect spheres of uniform elastic properties
  - GAT is based on CCT of 500 to 520 µm

Other considerations that should be taken into account when measuring the IOP are as follows:

1. **Corneal biomechanics, hysteresis**
   a. Cornea is NOT perfectly thin and elastic
   b. Imbert-Fick law does not always apply

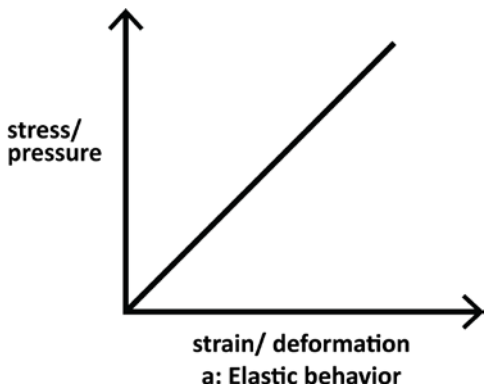

Figure 15.6: *Effect of elastic behaviour on the Goldmann IOP measurement*

2. **Corneal thickness greater or lesser than normal (measured by pachymetry)**

   a. Variation not linear
   b. In general, CCT thinner than 520 µm will result in underestimation of IOP while in cases of CCT > 520 µm, Goldmann reading represents an overestimation of IOP. An exact correction method to account for CCT is not possible.

3. **Corneal curvature**

4. **Squeezing eyelids, holding breath, obesity or straining to reach slit lamp**
5. **Corneal scarring or corneal irregularity**
6. **Excessive or inadequate amount of fluorescein**
7. **Inaccurately calibrated tonometer**

Understanding the shortcomings of these assumptions, the influences of corneal biomechanics and, more quantitatively, the CCT, some adjustment of the IOP measurement is recommended for accuracy.

OTHER TONOMETERS

Several studies have underlined the shortcomings of Applanation Tonometry - mainly its dependence on the biomechanical properties of the cornea. Goldmann Tonometry, we now realize, provides an estimate rather than a real measurement of IOP.

Other methods of measuring IOP are listed here. These alternatives may have greater or lesser influence from CCT but they have their own limitations.

- Indentation* (Schiøtz tonometer)
- Dynamic Contour Tonometry (DCT)
- Ocular Response Analyzer* (ORA)
- Pneumo-tonometer
- MacKay-Marg tonometer
- Tono-Pen

*Allows for corneal rigidity effects

OCULAR RESPONSE ANALYZER (REICHERT)

The Ocular Response Analyzer (ORA) aims to provide an IOP reading that is free of the influence of corneal biomechanical factors.

- Two applanation readings are measured (initial applanation and rebound)

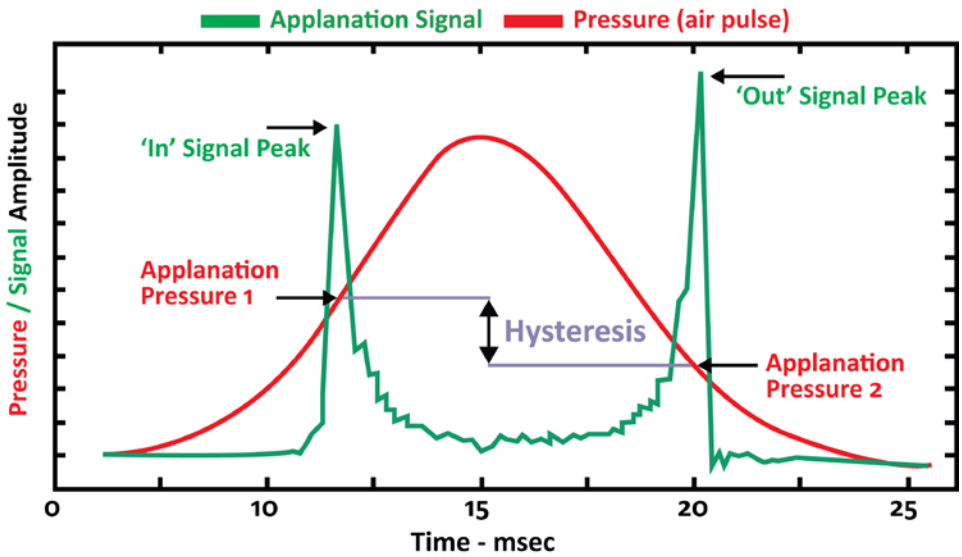

Figure 15.7: *Ocular Response Analyzer recording*

The cornea resists the dynamic air puff causing delays in the inward and outward applanation events, resulting in two different pressure values (Figure 15.7). The second value is lower than the first due to the viscoelastic (dampening) properties of the cornea.

This instrument also gives a measurement of corneal hysteresis (Figure 15.8). This measurement demonstrates the corneal biomechanical property of viscoelasticity.

- The difference is Corneal Hysteresis (CH)

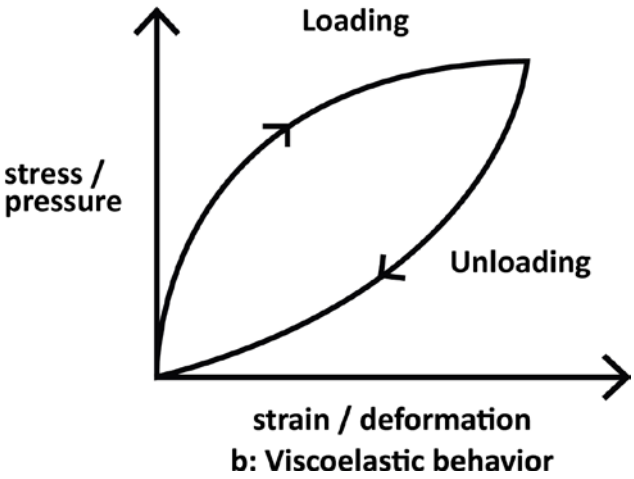

Figure 15.8: *Corneal hysteresis*

The ORA measurements generate the following information:

- Corneal-Compensated Intraocular Pressure (IOPCC)
    - Less affected by corneal properties than GAT
- Corneal Resistance Factor (CRF)
    - An indicator of the overall "resistance" of the cornea

The ORA generates a corneal-compensated IOP as well as a resistance factor. The full meaning of the resistance is not known. It may be that a more resistant cornea means a more resistant sclera and a lesser likelihood of developing glaucoma.

- Lower CH (corneal elasticity / distensibility) may be associated with glaucomatous progression

DYNAMIC IOP MEASUREMENT - DYNAMIC CONTOUR TONOMETRY (DCT)

Making good use of state-of-the-art digital technology, it is easily possible to record the pressure detected by the sensor not only once at a more or less arbitrary point in time, but continuously at a high sampling rate of, say, 100 Hz.

IOP is not a static property of the eye but a dynamic quantity modulated by cardiac activity and other physiological processes. It is possible to clearly distinguish diastolic and systolic IOP measurements.

The Dynamic Contour Tonometer (Figure 15.9) permits accurate measurement to ± 0.5 mm Hg. It is important not to ignore the cardiac modulation, which amounts to 2 - 3 mm Hg on average and can easily reach 7 mm Hg and more in some cases.

The Dynamic Contour Tonometer records a time-resolved ocular pulse curve and continuously reads the diastolic and systolic values of the Ocular Pulse Pressure curve.

Figure 15.9: *Dynamic Contour Tonometer*

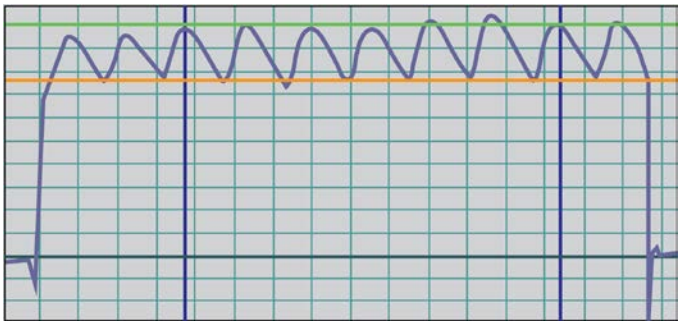

Figure 15.10: *Ocular pulse pressure curve*

THE PASCAL SENSORTIP TONOMETER

Another attempt to circumvent CCT is the PASCAL tonometer (Figure 15.11) that uses choroidal pulse to generate the IOP reading. In addition, it reads the ocular pulse amplitude. The device has a built-in pressure sensor with a contour matched concave tip surface. The transparent tip permits a view of the cornea interface (Figure 15.12) for centering and instrument control.

The IOP measurement is based on mean choroidal diastolic IOP, however the readings are not interchangeable with the Goldmann Applanation results.

The SensorTip (Figure 15.11) highlights the contoured, concave contact surface. The built-in pressure sensor appears as an opaque spot in the center of the contact surface. The electrical contacts which fit into the Main Unit‘s tip carrier are seen on the bottom of the image.

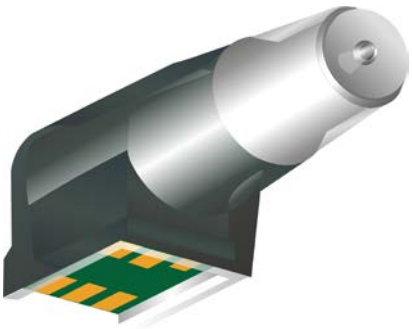

Figure 15.11: *The Pascal Tonometer*

The SensorTip interface, as seen through the slit-lamp microscope at moderate magnification, is shown in Figure 15.12. In the center of the view, the pressure sensor obstructs the view of the iris. Around the opaque spot, the circular contact area is seen as a darker area in the color of the patient‘s iris. The surrounding area, where there is no contact with the cornea, appears lighter. In this picture, the contact area is not perfectly centered. However, it is sufficiently centered to provide a correct pressure reading.

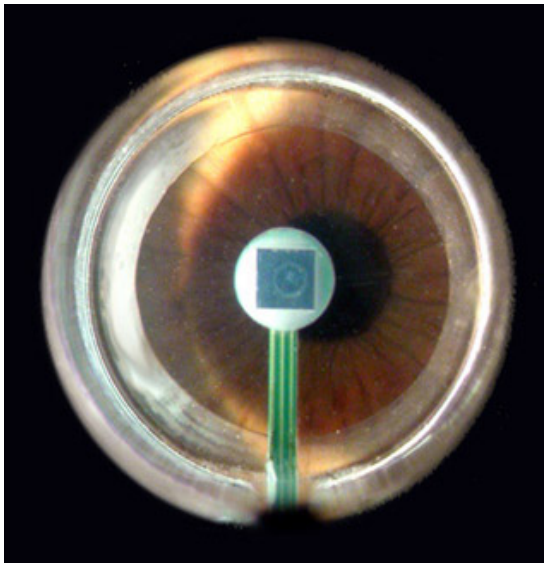

Figure 15.12: *The view through the Pascal Tonometer*

PASCAL SENSORCAPS

The SensorCap (Figure 15.13) protects the tip of the device and also the cornea of the patient.

Figure 15.13: *The Pascal Tonometer SensorCap*

Figure 15.14: *The PASCAL Tonometer mounted on the slit-lamp's central axis*

The LCD displaying IOP and OPA (Ocular Pulse Amplitude), in mm Hg is shown in Figure 15.15. The Quality factor (Q) provides an assessment of the quality of the pulse curve segment used for computation. If a poor Q value is displayed, this suggests the user perform a repeat measurement to verify the result obtained. Poor data may be obtained if the patient is not cooperative, or if the device is unable to establish proper contact with the cornea.

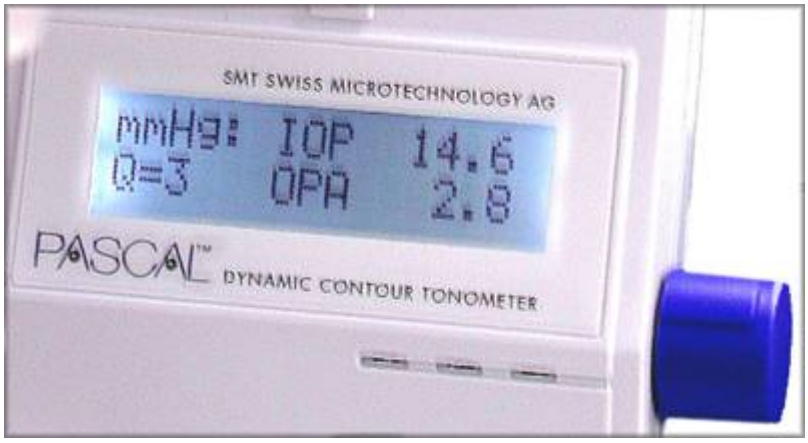

Figure 15.15: *Display of the IOP result*

PACHYMETRY

Pachymetry is an important part of the workup for a glaucoma suspect.

- Clinical measurement of central corneal thickness (CCT)
- A thinner than normal cornea is at higher risk of progressing to glaucoma (independent risk factor)
- Thicker than normal cornea is at less risk of progressing to glaucoma

SIGNIFICANCE OF A THIN CORNEA

The Ocular Hypertension Treatment Study (OHTS) established the significance of a thin central cornea as a risk for conversion from ocular hypertension (OHT) to glaucoma.

- *OHTS results suggested that CCT is a "powerful risk factor" for developing POAG (2002)
- A 71% increased risk per 40 µm less CCT (than mean of 555 µm)
- IOP will be UNDERESTIMATED with thinner CCT (Goldmann based on 520 µm)
    - Thicker cornea equals higher measured pressure, whereas thinner cornea leads to lower measured pressure
- Thinner CCT may be reflected as weaker laminar resistance to ↑IOP; ↓ Ocular blood flow to ONH

But, the biggest role for CCT is as an independent risk factor for developing glaucoma. A thin central cornea was identified in the ocular hypertension treatment study (OHTS) as a "powerful risk factor" for conversion from OHT to glaucoma. Underestimation of IOP due to a thin CCT may influence the categorization of some normal-tension glaucoma diagnoses.

Risk Factor	For Every	Relative Risk for Glaucoma Increased
Age	10 year ↑	22%
IOP	1 mm Hg ↑	10%
CCT	40 µm ↓	71%
Horizontal C/D ratio	0.1 ↑	27%
Vertical C/D ratio	0.1 ↑	32%
Pattern standard deviation	0.2 dB ↑	27%

Table 15.3: *Relative risk for glaucoma with various risk factors*

Adapted from Gordon et al. Archives of Ophthalmology 2002 120:714-720.

IOP (mm Hg)	CCT < 555 µm	CCT 555-588 µm	CCT >588 µm
>26	**36%**	13%	6%
24-26	**12%**	10%	7%
<24	**17%**	9%	2%

Table 15.4: *Risk of progressing to POAG*

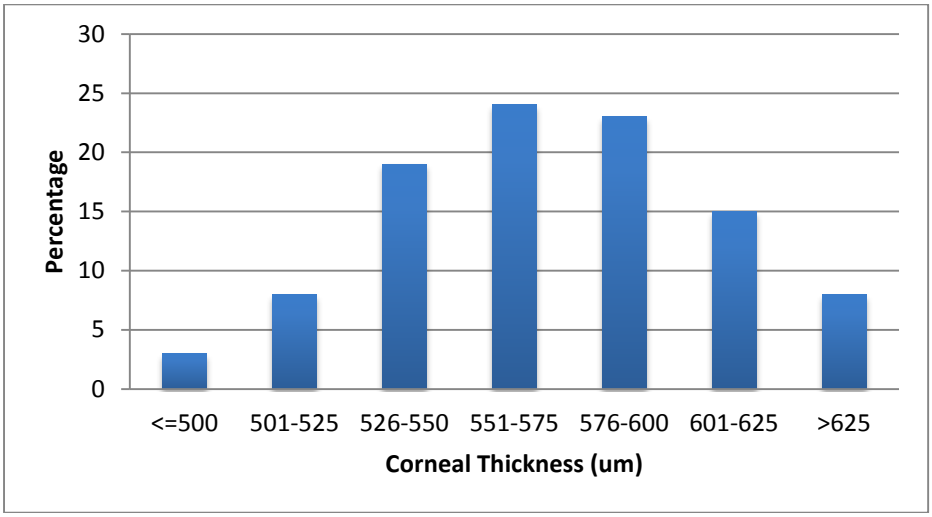

Figure 15.16: *Distribution of corneal thickness in the OHTS*

Gordon, M. O., et al. (2002) The ocular hypertension treatment study: baseline factors that predict the onset of primary open-angle glaucoma, Arch Ophthalmol, 120, 714-20.

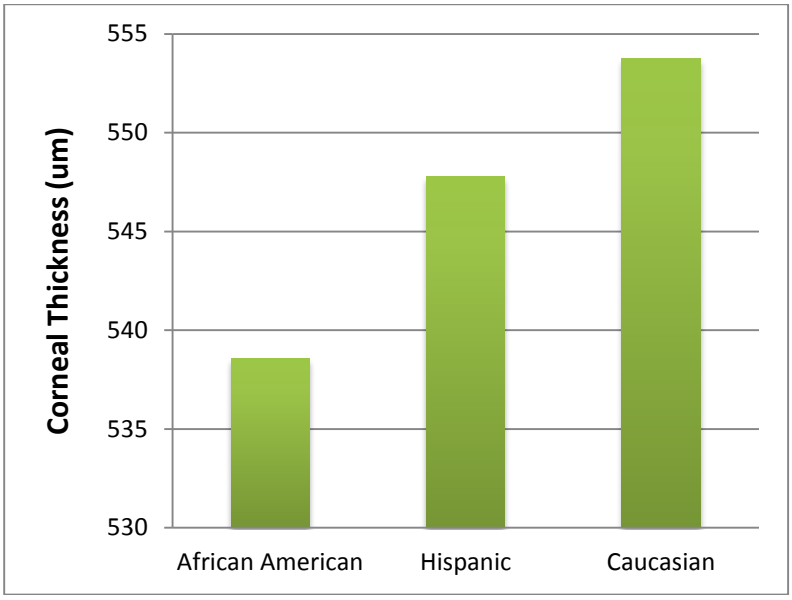

Figure 15.17: *Variation in central corneal thickness by race*

Gordon, M. O., et al. (2002) The ocular hypertension treatment study: baseline factors that predict the onset of primary open-angle glaucoma, Arch Ophthalmol, 120, 714-20.

VARIATIONS IN CCT

CCT measurement is stable in the majority of patients. In a small number of patients the CCT varies considerably from day to day and from measurement to measurement on the same day.

This variation is due to:

- Variations in corneal surface
- May vary by race
- Thins with aging (≈ 10 µm / decade)
- Varies by 40 µm at a 1-year interval in 5% of patients

- When variations are observed, use the first 2 measurements when readings are within 20 µm and the median of 3 when variation is greater than 20 µm.

As a result of the influence of CCT on Goldmann IOP readings, CCT should be considered as an independent risk factor for glaucoma. The perspective of CCT should be expanded to include risk and not only as a modifier of Goldmann IOP reading.

CCT poses a greater risk of conversion in OHT than other, perhaps better-known, features. For all ocular hypertension patients with IOP > 21 mm Hg, a thinner cornea increases the risk of developing glaucoma.