

INTRODUCTION

With the emergence of modern surgical techniques, patients have increasingly higher refractive expectations. To achieve optimal refractive outcomes, accurate intraocular lens (IOL) power calculation is important.^(1, 2)

IOL power is calculated using preoperative biometric measurements such as axial length (AL), corneal power (K), anterior chamber depth (ACD) and an estimation of postoperative effective lens position (ELP).^(3, 4)

Historically, a positive correlation between axial length (AL) and anterior chamber depth (ACD) has been well documented.⁽⁵⁾ Recent studies have supported this finding.⁽⁶⁻¹⁰⁾ However, this correlation holds only for normal to long eyes.^(7, 11)

Hosny and his group, in 2000, first reported that there was no correlation or even a negative linear correlation between AL and ACD when AL was beyond 27 mm.⁽¹¹⁾

A decade later, Hoffmann and Hutz provided stronger evidence with a large population study of more than 23,000 eyes that concurred with the observations of Hosny et al.⁽⁷⁾

They concluded in their studies that intraocular lens (IOL) calculation formulas may need updating due to the differences in extremely long eyes (>27 mm) and normal to long eyes.

Chang and Lau have concluded in their study that AL and ACD were poorly correlated in eyes with AL of 27.5 mm or greater. New generation IOL formulas that address the differences in AL and ACD are warranted for accurate postoperative outcomes.⁽¹²⁾

A study done by Olsen T. showed that every 1.0 mm erroneous measurements of corneal radius, AL and ACD can result in 5.7 D, 2.7D, and 1.5 D of refractive error, respectively. Thus, ACD contributes to residual refractive error a lot more than AL. Olsen showed that contribution to error from ACD, AL, and corneal power is 42, 36, and 22%, respectively.⁽¹³⁾

AIM OF THE WORK

The objective of this study is to investigate the correlation between AL and ACD in short eyes, normal eyes and long eyes.

Chapter 1

THE AXIAL LENGTH MEASUREMENT

The IOL Master

Ocular biometry is essential for IOL power calculation in cataract surgery. The biometric variables that are used for IOL calculation depend on the chosen IOL formula. ^(14, 15)

Previously, applanation ultrasound (A-scan) biometry has been the most commonly used technique for AL measurement. More recently, optical biometers has gained more preference. ⁽¹⁶⁾

The partial coherence interferometry (PCI)-based IOLMaster (Carl Zeiss Meditec AG, Jena, Germany) was introduced in 1999. Then, the Lenstar LS 900 (Haag Streit AG, Bern, Switzerland) using low coherence optical reflectometry (LCOR) technology was introduced in 2008. ⁽¹⁷⁾

Ultrasonography uses mechanical waves to calculate the time needed for a pulse to travel from the cornea to the retina. Sound travels with different speeds as per the media, more in lens and cornea (1641m/s) and less in aqueous and vitreous (1532m/s). ⁽¹⁸⁾

The AL when measured by applanation A-scan ultrasound causes erroneous AL measurement and an undesired

postoperative refractive outcome. This might be attributed to the indentation of the globe and an off-axis measurement of the AL by the transducer particularly important in highly myopic eyes.⁽¹⁹⁾

The IOLMaster includes an automatic keratometer to determine central corneal curvatures as well as a slit-image-based setup to measure anterior chamber depth. The IOLMaster's most important feature, however, is the use of partial coherence interferometry (PCI)—also named laser Doppler interferometry (LDI), optical coherence biometry (OCB), or laser interference biometry (LIB)—to measure AL **(Fig. 1)**.⁽²⁰⁾



Fig. (1): ZEISS IOLMaster 500⁽²¹⁾

All IOLMaster measurements are noncontact procedures, easily performed and well accepted by patients. The instrument's operating software includes databases for IOL and surgeon data and offers IOL power calculations with all popular formulas.⁽²⁰⁾

Measuring AL with Partial Coherence Interferometry

The AL measuring principle of the IOLMaster is based on dual-beam partial coherence interferometry. The term "coherence" describes the physical property of waves having a temporally constant or regularly varying phase difference at every point in space. Coherence is a necessary requirement for interference. Partially coherent light rays can interfere with each other if they meet within their coherence lengths.⁽²⁰⁾

In the IOLMaster, a laser diode emitting partially coherent light (coherence length $\approx 160\mu\text{m}$) in the near infrared (at a wavelength of 780 nm) is part of a Michelson interferometer setup, which (by means of a moving mirror) produces two partial beams of different optical path lengths.

The patient fixates onto the light of the laser diode, thus offering his visual axis to the measuring laser. Both partial beams are reflected at the cornea and at the retina. An interference signal is obtained when the optical path length of the displacement of the moving mirror in the Michelson interferometer is equal to the optical path length between

cornea and retina (i.e. the AL of the eye). The optical path length equals the geometrical length times the (group) refractive index of the medium through which the light travels. The position of the interferometer's moving mirror can be measured very precisely determining the accuracy of the AL measurement with the IOLMaster (Fig. 2).⁽²⁰⁾

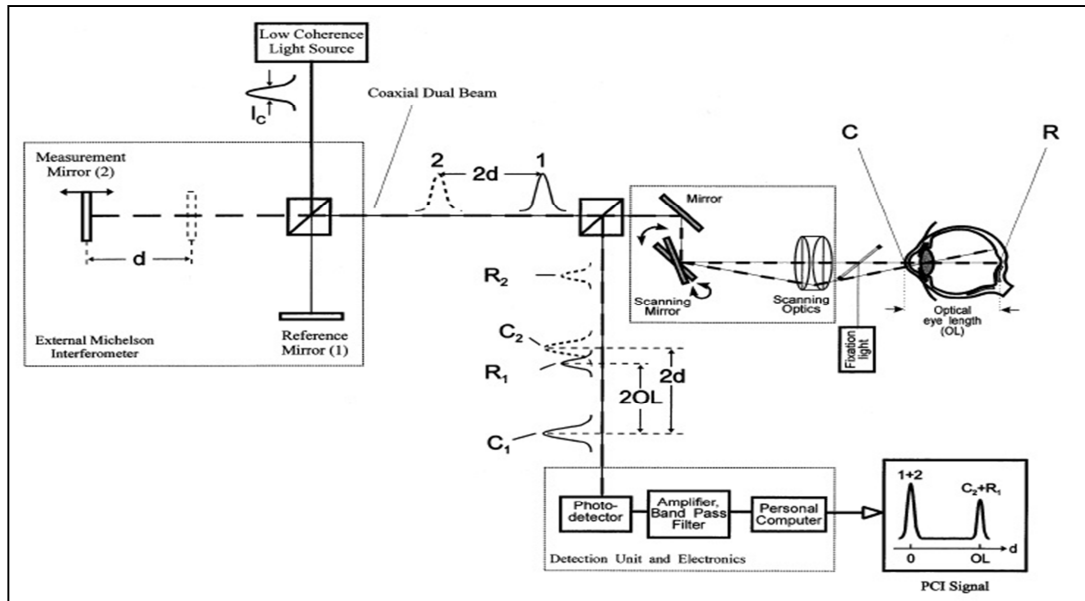


Fig. (2): Sketch of the scanning version of the dual beam partial coherence interferometer.⁽²²⁾

The AL measurement with the IOL master is not affected by the subjective error sources of acoustical A-scan ultrasound biometry. Measurement along the visual axis is ensured as the patient fixates on the light source.⁽²³⁾

It has been suggested that the IOL master is more precise and useful in difficult situations, including high myopia, posterior staphyloma or silicone oil-filled globes.⁽²⁴⁾

However, it will not work in the presence of significant axial opacities. A mature lens, dense posterior subcapsular plaque, vitreous hemorrhage or central corneal scar will preclude any type of meaningful measurement.⁽²⁵⁾

Table (1): Advantages and disadvantages of optical biometers.
(23-25)

Advantages of Optical methods	Disadvantages of Optical methods
Non-contact, hence no cross contamination	Axial opacities of cornea and dense grades on nucleus give inaccurate results.
Ease of use and speed of testing	Needs vision of at least 20/200 for fixation
More accurate in silicone filled eyes and posterior staphylomas	Patients with nytagmus, tremors or lid abnormalities cannot fixate well, hence errors

Table (2): Comparison between IOL master and Lenstar LS 900. ⁽¹⁷⁾

Comparison of technical specifications of new optical biometry devices.		
	IOL Master	Lenstar LS 900
Technology	PCI	LCOR
Source	Semiconductor diode laser (780 nm)	Superluminescent diode laser (820 nm)
Corneal thickness		
Measurement range	N/A	300 – 800 μm
Display resolution	N/A	1 μm
Lens thickness		
Measurement range	N/A	0.5 – 6.5 mm
Display resolution	N/A	0.01 mm
Keratometry		
Measurement range	5 – 10 mm	5 – 10.5 mm
Display resolution	0.01 mm	0.01 mm
Anterior chamber depth		
Measurement range	1.5 – 6.5 mm	1.5 – 5.5 mm
Display resolution	0.01 mm	0.01 mm
Axial length		
Measurement range	14 – 40 mm	14 – 32 mm
Display resolution	0.01 mm	0.01 mm
White-to-white distance		
Measurement range	8 – 16 mm	7 – 16 mm
Display resolution	0.1 mm	0.01 mm

PCI: Partial coherence interferometry
LCOR: Low coherence optical reflectometry

Chapter 2

THE ANTERIOR CHAMBER DEPTH

The anterior chamber of the eye is bounded anteriorly by the inner surface of the cornea, except at its far periphery where it is related to trabecular meshwork. Posteriorly it is bounded by the lens within the pupillary aperture, by the anterior surface of the iris, and peripherally by the anterior face of the ciliary body. The anterior and posterior boundaries meet at the drainage angle of the chamber (**Fig. 3**).⁽²⁶⁾

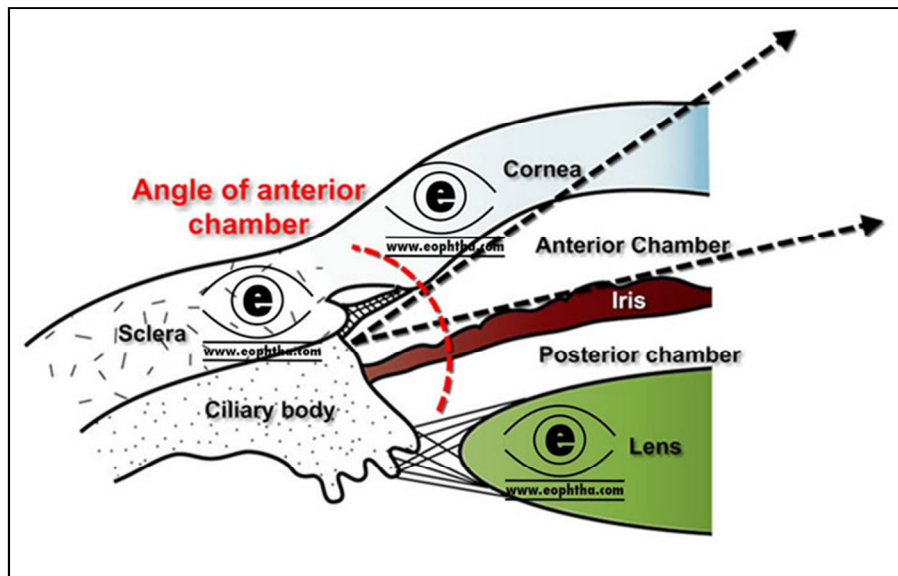


Fig. (3): The boundaries of the anterior chamber of the eye.⁽²⁷⁾

The anterior chamber communicates with the extracellular spaces of the iris, ciliary body and trabecular

meshwork and, through the pupillary aperture, with the posterior chamber of the eye. ⁽²⁶⁾

Anterior chamber volume is in the region of 220 μ L, the average depth is 3.15 (range 2.6-4.4) mm and it is not affected by gender. Chamber diameter varies from 11.3 to 12.4 mm. ACD decreases by 0.01 mm per year of life. ⁽²⁶⁾

ACD is diminished slightly during accommodation, partly by increased anterior lens curvature, and partly by forward translocation of the lens. ⁽²⁶⁾

ACD is measured from the central anterior corneal epithelium to the anterior crystalline lens capsule. ⁽²⁸⁾

The term anatomic external ACD describes the distance from the anterior corneal vertex to the anterior vertex of the crystalline lens. The anatomic internal ACD is measured from the posterior vertex of the cornea to the anterior crystalline lens vertex and does not include the central corneal thickness; ACD used in IOL calculations is the anatomic external ACD. ⁽²⁹⁾

Significance of ACD measurement

Selection of IOL formula

The accuracy of IOL formulas differ according to the ACD even in eyes with the same AL and K. The Hoffer Q formula is preferred over other formulae in short eyes with an ACD shallower than 2.5 mm. In short and normal eyes with an

ACD < 2.5 mm the Haigis formula might underestimate ELP. The Haigis formula is the preferred choice in eyes with an AL ≥ 24.5 mm and an ACD ≥ 3.5 mm.⁽³⁰⁾ Studies showed that the differences between the predicted refractive errors of the Hoffer Q and Haigis formulae increased as ACD decreased in short eyes.^(31, 32)

Risk of Angle Closure Glaucoma

There is a well described association between a shallow anterior chamber and primary angle closure glaucoma (PACG) and it has been suggested that measurement of ACD may have potential in screening for PACG.^(33, 34)

When compared to gonioscopy, only ACD measurement provided an adequate mix of sensitivity and specificity. Shallower AC depth, shorter axial globe length, greater than 2D of hyperopia, high grades of nuclear sclerotic cataract and an increased cup-to-disc ratio were significantly correlated with a diagnosis of PACG (**Fig. 4**).⁽³³⁾

The Van Herick's technique is a commonly used qualitative method of assessing the size of the anterior chamber angle (ACA) correlating it with the risk of angle closure. Whereby, it involves comparing the depth of the peripheral anterior chamber to the thickness of the cornea, when a narrow beam is shone within the limbus at a 60° angle. The anterior chamber drainage angle is then graded as a ratio between the

peripheral anterior chamber depth and corneal thickness (AC: C ratio) to provide the Van Herick's result. ^{(35), (36)}

Table (3): Van Herick's grading of the anterior chamber angle. ⁽³⁷⁾

Ratio	Angle Closure	Angle Grade
1:1	Open Angle	VH grade 4
1:1/2	Open angle	VH grade 3
1:1/4	Narrow angle	VH grade 2
1: <1/4	Angle Closure likely	VH grade 1

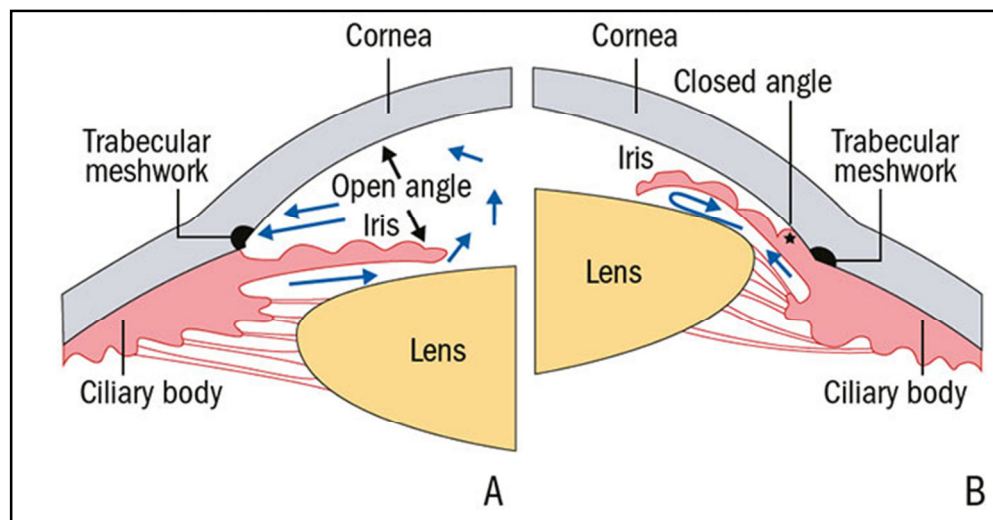


Fig. (4): The anatomical and physiological differences between an open (A) and narrow/closed (B) anterior chamber angle. ⁽³⁸⁾

Application of ACD in Refractive Procedures

ACD measurement is an important factor in phakic IOL implantation. In both high myopia and hyperopia PACL implant is hazardous when the ACD is shallower than 3 mm. In

fact, high power negative IOL may impact on the endothelium because of the proximity of its thick border to the cornea (**Fig. 5**).⁽³⁹⁾

Moreover, referring to the most used formulae, an exact IOL power in phakic cases depends on the accuracy of ACD measurement.^(40, 41)

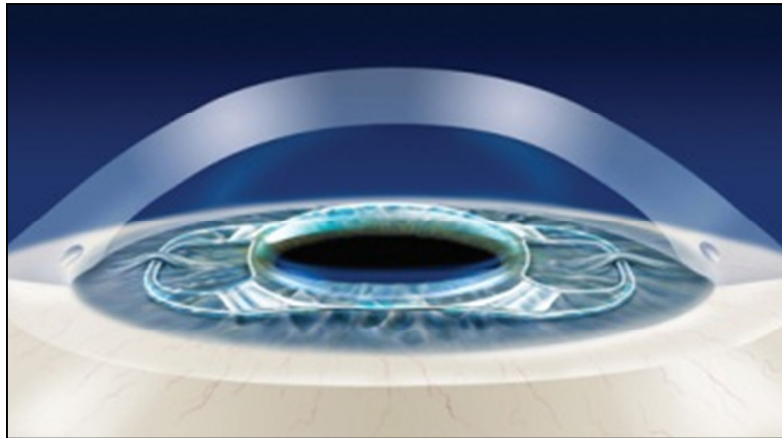


Fig. (5): Phakic IOL in the anterior chamber.⁽⁴²⁾

Shallow anterior chamber is also one of the challenges of phacoemulsification surgery. The corneal endothelium and posterior lens capsule are subject to irreparable damage should the fluidic balance induce anterior chamber instability.⁽⁴³⁾

With a shallow anterior chamber, performing a capsulorrhexis at the beginning of the cataract surgery is difficult due to poor maneuverability and lack of flattening of the anterior lens capsule. In most situations, this can be addressed by injecting viscoelastics at the time of surgery.

Cohesive viscoelastics do a better job of creating and maintaining space. ⁽⁴³⁾

If the anterior segment remains excessively shallow, a limited pars plana anterior vitrectomy can be done to remove volume from the vitreous cavity. This allows the anterior chamber to be further deepened during surgery but may pose additional risks to the retina. ⁽⁴³⁾

Therefore, this technique should be used cautiously. During phacoemulsification, the bottle height can be raised in order to increase the infusion pressure into the anterior chamber, thereby deepening it. ⁽⁴³⁾

Thus, ACD measurement has many applications either clinical as in the assessment of angle closure risk, or surgical as in the selection of IOL formula calculation preoperatively or intraoperatively during phacoemulsification surgery.