Practical Pearls on Biometry and Topography for Comprehensive Ophthalmologist

\[ P = A - 0.9K - 2.5L \]

\[ K = \frac{n - 1}{r} \]

\[ r = 337.5 \]

\[ (P = f(A, K, R_x, pACD)) \]

AIOS ARC CME Series (No 37)
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Practical Pearls on Biometry and Topography for Comprehensive Ophthalmologist

AIOS ARC CME Series (No 37)

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Foreword

It is very gratifying to write the foreword for AIOS ARC CME Series: Practical pearls on Biometry & Topography for comprehensive ophthalmologist by Dr. Amit Porwal and Dr. Jitendra Jethani, under the aegis of Dr. Partha Biswas. At the outset, this CME series is closely aligned to the needs of the comprehensive ophthalmologist, striving to make cataract surgery akin to a refractive procedure. Given its concise and exhaustive nature, this series can be considered as a ‘vade mecum’ for all, from a beginner to a veteran. Although small in dimensions, it is quite remarkable how much is contained within it. With its standardized format and pithy style of writing, information is easily navigated, accessed, and remembered.

Cataract surgery is reaching new frontiers with both surgeons and patients striving for excellence in visual outcome. The post-LVC cataract patient is now routine and is demanding 6/6 and N6. The COVID-19 pandemic has deferred many-a-patient from turning up to the clinic, who ultimately are now turning up as mature cataracts. Hence, accurate biometry in such, now ‘routine’, cases is extremely important, and is elucidated well in this series. Cataract surgery is an ever-evolving procedure, with it being difficult to catch up with recent advancements. So, this compilation is very pertinent in today’s world, where being out-dated is analogical to being misinformed.

The scope of the book continues to impress, with advances in biometry and Topography, rubbing shoulders with newest sections in ophthalmology on artificial intelligence and the Ladas formula for biometry. New trainees may particularly benefit, as each chapter covers the basics and historical aspects. Simplistic language used in this series is there to shepherd us through the gauntlet of confusing terminology in this vast subject.

I am sure that many ophthalmologists will benefit from this CME series.

Dr. Mahipal Singh Sachdev
President, All India Ophthalmological Society
Chairman & Medical Director
Centre For Sight group of Eye Hospitals
Cataract surgery is the most commonly performed refractive surgery today. The last decade has seen a paradigm shift as phacoemulsification, better surgical skills, better machines, and more accurate biometric calculations have transformed cataract surgery from a simple vision-restoring surgery to a highly demanding refractive surgery. As more and more surgeries are being performed on patients having good preoperative best-corrected visual acuity, the expectations of patients have also increased exponentially, and spectacle independence remains a common goal of surgery for surgeons and patients alike.

The past few years has seen a booming industry of premium intraocular lenses (IOLs) such as multifocal IOLs, trifocal IOLs, and toric IOLs, all targeting the patient’s desire for spectacle independence. Femtosecond laser-assisted cataract surgery (FLACS) has also emerged as a promising technology aiming to achieve predictable circular and central capsular opening with perfect IOL overlap to provide better centration. However, all these technologies fail to prevent refractive surprise if the biometry calculations have not been accurate. Hence, the search for the ideal biometry formula remains the holy grail even today.

There have been multiple formulae over the years, and physicians and mathematicians have moved from theoretical to regression formulae, and then back again to theoretical formulae, trying to understand the optics and anatomy of the complex human eye. Modern formulae even incorporate ray tracing aberrometry and artificial intelligence to reduce the prediction error further. But the interrelationship between the various components of the optical system of the eye and its changing dynamics from the phakic to pseudophakic state has been difficult to accurately predict. Moreover, these equations change in a nonlinear way from the hypermetropic to the myopic eye, and in extreme ranges of ametropia, most formulae lose their accuracy.

As a result, till now, the most reliable method was to use different formulae for different range of axial length (AL). However, times are changing, and
modern cataract surgery has set the bar higher than before. Newer generation formulae have been developed, which provide more accurate results over a wide range of ocular parameters.

Special situations such as paediatric cataract, silicon filled eyes, post refractive surgery eyes, co-existing corneal opacities or retinal pathology, are challenging cases which require a different biometry approach.

I congratulate the editors, Dr Amit Porwal & Dr Jitendra Jethani, as well as all the authors, for putting together an excellent CME series discussing both existing protocols and recent advances in biometry for the cataract surgeon.

It is imperative to change with the changing times, and updating newer formulae and protocols into practice has become essential for every ophthalmologist in the country to deliver the best of technology to our patients.

Dr Partha Biswas
Chairman, Scientific Committee, AIOS
Immediate Past Chairman, ARC, AIOS
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With the current advances in management of cataract surgery, the complete surgery actually revolves around the calculation of accurate intraocular lens (IOL) power. With the advances of multifocals, toric IOL, accommodating lenses and the light adjusting lenses, the focus has shifted completely towards the accurate and actual measurement of the optics and refraction and thereby the biometry of the eye.

The calculation has become the most important step in cataract surgery since now it is more of a refractive surgery and refractive rehabilitation rather than the visual rehabilitation. It is therefore very important to be upgraded about biometry for the sake of ultimate results which is satisfying both to the surgeon and the patient.

Before the era of the ultrasonography units, the IOL power was determined using an intelligent guess work approach. But now various formulas have been developed for IOL power calculation.

Guess Work approach have following concepts:
1) IDEM (Ideal emmetropia) lenses
2) Standard lenses
3) Emmetropia lenses

Background

Biometry is the method of applying mathematics to biology. The term was originally used by Whewell initially in the 1800s for calculating life expectancy. The refractive power of the eye primarily depends upon the cornea, the lens, ocular media, and the axial length of the eye. When planning for cataract surgery, in order to achieve the desired post-operative refraction, the required power of the intraocular lens
(IOL) implant can be calculated if the corneal refractive power, media type, and axial length are known. [1]

**History**

Way back in 1949, when the first IOL implantation was attempted by Harold Ridley, the patient ended up with a refractive surprise of nearly 20 diopters. Fyodorov and co-workers [2] first estimated the optical power of an IOL using vergence formulas in 1967. In the 1970s, after availability of accurate A scan, several studies were conducted to establish and publish various theoretical vergence formulas. In the early 1980s, several IDEM (ideal emmetropia) lenses were also attempted, so named as the pre and post refraction from them were similar. On similar lines, standard lenses were also attempted (after Gernet and Zorkendorfer) in 1982.

**Definitions**

**Outcome**

Emmetropia or no refractive error is the ideal outcome sought, in accordance with which maximum biometry is carried out. However, this may not be true in all the cases. In some cases the patient may be kept hypermetropic or myopic postoperatively. The patient secondary to his occupational or social needs may prefer a certain refractive status postoperatively. Some-times, the other eye refractive state has to be considered, as in cases of monovision or anisometropia. This should be kept less than 2 diopters. For monovision, the dominant eye has to be corrected for distance and the nondominant eye can be kept myopic but not more than 1.5 D.

**Refractive State of the Cornea or keratometry (K)**

The measurement of corneal power though not absolutely accurate is based upon the steepness of the cornea. The cornea is assumed to be a perfect spherical optical mirror with a fixed anterior to posterior corneal curvature ratio. The corneal curvature is predicted from this, which is then used to determine the corneal power. The cornea must be assumed to be a perfect sphere, with par-axial optics and the power of the back of the cornea must also be determined. Keratometry may be
difficult or impossible in conditions with irregular or distorted corneal surface. In such cases keratometric reading of opposite eye may be used or can be calculated from corneal topography map.

Changes in K reading; alters the IOL power in a ratio of nearly 1:1. It can be measured either by keratometry or topography but neither measures the actual corneal power directly. The mathematical principle behind the keratometry method is that the central cornea is assumed to be a perfect sphere and acts as a spherical convex mirror. Further the posterior corneal curvature is assumed to be 1.2mm steeper than the anterior; this is especially altered after refractive surgeries due to which increased errors are observed. From the size of the reflected image from the cornea acting as a convex mirror, the radius of curvature is determined, which is then converted to power in diopter or mm.

Radius (r) of curvature (mm) = \( 2u \text{ (mm)} \times \frac{\text{Size of Image}}{\text{Size of Object}} \)

\( u \) = distance of object from principle plane and 

\( D = \frac{(n_2 - n_1)}{r} \)

\( n \) = Refractive index of medium 1 & 2 respectively.

Topographical methods use the Scheimpflug principle via the Pentacam or the Galilei (double Scheimpflug) to measure the anterior and posterior radii of corneal curvature along with the corneal thickness which is then used to measure corneal power in diopters. In a normal phakic eye the average anterior corneal radius of curvature is 7.5mm, which corresponds to 44.44D using keratometric refractive index of 1.3333 (4/3) which was found to be more accurate than the older one used 1.3375. The posterior corneal radius of curvature averages 1.2mm less than the anterior surface radius.

**Axial length (AL)**

Axial length is defined as the distance from the anterior corneal surface to the retinal pigment epithelium. It is the most important factor in biometric calculations. As 1mm error in AL measurement results in approximately 2.35D refractive error in a 23.5mm eye. The error with wrong AL assessment being less in case of longer eyes as compared to shorter eyes. It can be measured using optical
or ultrasound methods, which can further be done by direct contact or immersion. A combination of these measurements prevents errors in AL measurements. Optical methods like IOL master and Lenstar have benefits of non-contact procedures along with greater accuracy. They may inaccurate or difficult to obtain in denser and posterior subcapsular cataracts. Contact ultrasound measurements are likely to have more subjective errors due to corneal compression which can be helped by immersion scans but it has less control over alignment and hence may give varied results. A combination of techniques can give better results in doubtful cases.

A-constant

A-constant, although called a constant is actually highly variable depending upon multiple factors like
a. IOL dependent: type, material, position;
b. Surgeon dependent: technique of incision, placement of incision;
c. K and AL measurement adjustments; or
d. Adjustment for the manner of carrying out biometry.

Once fixed for a particular surgeon, IOL and machine for the scan, it is applied as a constant to the appropriate formula. It approximately varies with a ratio of 1:1 with the IOL power.

Gain

The amplification of the sound waves is done in an ultrasound for the transducer both to reduce the noise and to be able to make sure that enough sound waves reach the transducer. The gain is defined as the electronic amplification factor of the sound waves received by the transducer while doing A scan, it is measured in decibel (dB). Normal setting is around 70% -75%. But it may be increased where high echoes are inadequate (hard cataracts, dense ocular opacities, high myopia). It is decreased when artifacts are seen near the retinal spikes (silicone filled eyes & in pseudophakics).

IOL Formulae for calculation

Formulas for calculation of IOL power have been evolving since their inception. These can be classified on the basis of their derivation
(theoretical, regression analysis or combination) or according to their evolution as per generations. By derivation, theoretical formulas are determined by application of geometrical optics to the schematic and reduced eyes using various constants.

Most of the modern day formulae are based upon the theoretical equation formulated by Fyodorov and its modifications. Here the IOL power is chosen as the variable, which is calculated on the basis of this equation and its derivative

\[ P = \frac{1336}{[AL-ELP]} - \frac{1336}{\{\frac{1000}{\left(\frac{1000}{D_{PostRx}}-V\right)+K}\}-ELP} \]

Where
- Net corneal power (K)
- Axial length (AL)
- IOL power (P)
- Effective lens position (ELP)
- Desired refraction (D_{PostRx})
- Vertex distance (V)

The only variable which cannot be measured pre-operatively is ELP and most of the later day formulae like Holladay, Hoffer Q, SRK/T or Haigis attempt to calculate ELP more accurately.

**Different Formulae For IOL Power Calculation**

Depending upon the basis of their deviation they are grouped under following:

1) Theoretical formulae
2) Regression formulae

Depending upon the time they were evolved they are grouped under following

1) First Generation
2) Second Generation
3) Third Generation
4) Fourth Generation
A. FIRST GENERATION FORMULAE

This is the earliest formulae used for IOL Power calculation.

1) Theoretical formulae

These formulae were based on three variables:
- The Axial Length of eyeball
- K-reading
- The estimated postoperative ACD

1. Binkhorst formula

\[ P = \frac{1336(4r-a)}{(a-d)(4r-d)} \]

Where
- \( P \) = IOL power in diopters
- \( r \) = Corneal radius in millimeters
- \( a \) = AL in millimeters
- \( d \) = assumed postoperative ACD plus corneal thickness

2. Colenbrander-Hoffer formula

\[ P = \frac{1336}{a - d - 0.05} - \frac{1336}{1336 - K - d - 0.05} \]

Where \( K \)= average keratometry in diopters

3. Gill’s formula

\[ P = 129.40 + (-108K) + (-2.79 \times L\text{ eye}) + (0.26 \times CL) + (0.38 \times \text{Ref}) \]

Where
- \( P \) = Desired iol power
- \( K \) = refractive power of cornea in diopters
- \( L\text{ eye} \) = AL in millimeters
- \( LCD \) = distance of apex of anterior corneal surface to apex of IOL in millimeters
- \( \text{Ref} \) = desired postoperative refraction.
4. **Clayman’s formula**

Emmetropizing IOL = 18D  
Emmetropic AL = 24 mm  
Emmetropic average keratometer reading = 42.0D  
1 mm in AL = 3 D of IOL power  
1 D in keratometry = 1 D of IOL power  
If IOL power > 21D, deduct 0.25 for every dioptre > 18.0D  
For example: AL = 21.2 mm; K = 43.0 D  
It leads to 6D hyperopia in length; 1.0D myopia in keratometry  
Hence IOL power = 18 + 6 - 1 = 23.0D

5. **Fyodorov formula**

\[ P = \frac{1336 - LK}{(L - C) - CK / 1336} \]

Where  
\( P \) = implant power for emmetropia  
\( L \) = the axial length in millimeter  
\( K \) = the corneal power in diopters  
\( C \) = the estimated postoperative ACD.

2. **Regression formulae**

**SRK-I formula**

Regression analysis using the actual post-operative results of implant power as a function of the variables of corneal power and axial length were derived. Sanders, Retzlaff and Kraff developed the SRK formula which was widely used. Though now replaced with the newer generation formula, it is still useful for understanding the relation of the variables and A-constant to the IOL Power (P).

\[ P = A - 0.9K - 2.5AL \]

Where  
\( P \) = Power of the IOL in diopters  
\( A \) = A constant  
\( K \) = Average keratometry value in diopters  
\( AL \) = axial length in mm
This is rarely used to calculate IOL power manually where other tools are not available, but should be avoided whenever possible.

It is based on regression analysis of the actual postoperative results of implant power as a function of the variables of corneal power and AL. It was introduced by Sanders, Retzlaff and Kraff, based on the regression analysis, taking into account the retrospective computer analysis of a large number of postoperative refractions. This formula performs well with AL between 22.0 and 24.5mm. Regression formula tends to predict too small value in short eyes and too large a value in long eyes, because of this SRK-I formula has been modified twice.

B. SECOND GENERATION FORMULAE

1. Theoretical formula

**Modified Binkhorst formulae**

Binkhorst in 1981 improved the prediction of effective lens position by using a single variable predictor, the AL, as a scaling factor for effective lens position and presented a formula to better predict ACD.

2. Regression formula

**SRK-II formula**

It is same as the SRK-I formula but the A-constant is modified on the basis of the AL as follows

- If L is <20mm A +3.0
- If L is 20.00-20.99 A +2.0
- If L is 21.00-21.99 A +1.0
- If L is 22.00-24.50 A
- If L is >24.50 A-0.5
Modified SRK II formulae

In this formula A constant is modified as given:

- If L is < 20mm  A+1.5
- If L is 20-21mm  A+1.0
- If L is 21-22mm  A+0.5
- If L is 22-24.5mm  A
- If L is 24.5-26mm  A-1.0
- If L is >26mm  A-1.5

C. THIRD-GENERATION FORMULAE

Most of these formulae are a hybrid of both theoretical and regression formulae.

Holladay-1 formula

This formula was based on geometric relationship of the anterior segment. Soon this formula was modified and use an empirically derived constant which is then added to the ACD estimate.

Holladay-II formula

It is considered more accurate because of its enhanced ability to predict the position of the implants.

Hoffer’s Q formula

This formula is best for short eyes.

Haigis formula

D. FOURTH-GENERATION FORMULAE

Holladay-II formula

Holladay consultant IOL programme

Refractive formula

It is described by Holladay to calculate IOL power for aphakic, ametropic, pseudophakic and PRLs. In this formula AL measurement
is not required. Following parameters are required for IOL power calculation:

Preoperative refractive power  
Corneal power  
Desired postoperative refraction  
Vertex distance

This formula is not very good for aphakic eyes because it is difficult to measure the vertex distance accurately and thus leads to high errors.

**SRK-T formula**

This formula is empirically optimized for postoperative ACD, retinal thickness and corneal refractive index. This formula is more accurate for extremely long eye (>26mm).

1. Axial Eye Length Measurements (A-Scan Biometry) in Byrne SF, Green RL (eds):  
Introduction

Modern cataract surgery aims to achieve ideal post-operative refractive outcomes. In addition to good operative techniques, intraocular lens quality and healthy retina, a precise calculation of intraocular lens (IOL) power is crucial to achieve good results after cataract surgery. IOL power calculation primarily depends on the axial length, anterior chamber depth, keratometry and lens formulae. Of these factors axial length is considered a key determinant in calculating IOL power.

A (amplitude) scan or ultrasound biometry has been the most commonly used technique to measure the axial length and for calculation of IOL power. Optical biometry using partial coherence interferometry (PCI) introduced almost 2 decades ago and swept-source optical coherence tomography (SS-OCT) introduced recently are gaining preference over A-scan in axial length measurement and IOL power calculation.

A (amplitude) Scan

A-scan uses ultrasound waves of 10-12 MHz frequency. It works on the principle of acoustic impedance. Thin sound beam is emitted from the probe tip, with an echo bouncing back into probe tip as the sound beam strikes each interface. The echoes received back into the probe from these interfaces are converted by biometer to spikes arising from baseline (Figure 1). The greater the difference in the two media at the interface, the stronger the echo and the higher the spike.
Comparison of a Scan with Optical Biometry

Figure 1: A-scan biometry

Techniques

1. **Contact- Applanation Method**
   
   **Hand Held Method**
   
   Contact technique probe is directly placed on the corneal surface (Figure 2).

Figure 2: Contact Technique
2. **Immersion**

The immersion technique is accomplished by placing a small scleral shell between the patient’s lids, filling it with saline, and immersing the probe into the fluid, being careful to avoid contact with cornea (Figure 3).

![Immersion Technique](image)

**Figure 3: Immersion Technique**

**Optical Biometry**

The introduction of optical biometry in late 1900’s revolutionized the precision of IOL power calculation. In 1999, the first automated optical biometry device became available for clinical use – IOLMaster 500 (Carl Zeiss Meditec, Jena, Germany). It is based on the concept of partial coherence interferometry (PCI) and operates as a modified Michelson Interferometer.8

PCI biometry was first developed by Austrian physicist Fercher and Roth who performed the first in vivo AL measurement in 1986. The principle involves a dual beam of infrared (IR) light (780 nm) emitted by a semiconductor laser diode. A signal is produced as a result of
interference between the light reflected from the tear film and that reflected by the retinal pigment epithelium. The photo-detector receives the interference signal to calculate the optical distance (OD) between the corneal surface and retina. This OD is used to derive the other geometrical intraocular distances.8

Accuracy of optical biometry is usually determined by signal-to-noise ratio (SNR). The greater the SNR more accurate is the scan. Scans with SNR ≥ 2.1 are considered more accurate though borderline scans can be considered after taking additional A-scan measurements. Chia TM et al. concluded in a study that borderline scans with SNR 1.6-2.0 are still useful in planning surgery and that additional ultrasound measurements may be useful more as a corroborative tool.9

Currently newer optical biometry devices with advanced technology have evolved to and increase the accuracy of IOL power calculation.8

- Optical low coherence reflectometry (OLCR): LENSTAR LS 900, ALADDIN, GALILEIG6
- Swept-Source OCT (SS-OCT): IOLMASTER 700, EYESTAR 900, ARGOS.
- Fourier-domain OCT: OA2000(TOMEY)

**Advantages Of Optical Biometry Over A-Scan:**8,10

a. Optical biometry uses light waves whereas A-scan uses sound waves for the measurement of axial length. Light waves have shorter wave length than sound waves. Shorter the wave length more precise is the axial length measurement. The accuracy of A-scan is approximately 0.10-0.12 mm as compared to 0.012 for optical biometry. Nakhli FR. Compared the axial length measurement using optical biometry and A scan and found that the difference was statistically significant only in short eyes (p=0.031).10

b. Optical biometry measures the axial length along the visual axis of the eye, whereas A-scan measures axial length along the anatomical axis of the eye. The visual axis and anatomical axis do not coincide. For IOL power calculation it is the visual axis that is
more important than anatomical axis. Thus axial length measured by optical biometry is more accurate.

c. Optical biometry measures axial length from the corneal epithelial till the Bruch’s membrane, whereas A-scan measures axial length from the corneal epithelium till the internal limiting membrane (ILM). Since the A-scan measures only till ILM and since average thickness of retina is 200 µ (distance between ILM and bruch’s membrane) earlier methods of IOL power calculation used to add 200 µ to the measured AL to make up for this difference. However, retinal thickness may vary from 160 to 400 µ. Optical biometer measures the true AL and therefore, no such additional assumptions for retinal thickness needs to be made.

d. A-scan gives erroneous measurements in eyes with high myopia and posterior staphyloma due to ocular misalignment, whereas optical biometry measures along the visual axis ensures patient fixation to light source and precludes this error.

e. Using A-scan biometry in SO filled eyes has several fallacies, such as false longer eyes, presence of multiple fluid interfaces or poor penetration due to sound absorption by oil. Optical biometry has more accuracy and is less deviating in measuring axial length and predicting postoperative refractive error than A-scan.

f. Aydin R et al. compared the anterior chamber depth (ACD), axial length (AL), lens thickness (LT) measurements obtained by optical low coherence reflectometry to that obtained by A-scan in patients with moderate to high hypermetropia. They found that there was a statistically significant difference in the LT measured by the two methods with a p-value of 0.02.11

g. Optical biometry is non-contact as compared to contact technique of A-scan. A rigid A-scan tip can cause indentation between 0.1 and 0.3mm, resulting in error from 0.3 to 1.0 diopter IOL power.

h. Using optical biometer accurate biometry can be performed in pseudophakic, aphakic eyes and eyes with phakic IOLs. Also AL, measurement is less affected by the type of IOL material.
**Drawbacks Of Optical Biometry Over A-Scan:**

a. One major limitation of optical biometry is its inability to measure axial length accurately in dense cataract (posterior subcapsular cataract, mature and hypermature cataract) and media opacities like corneal opacities.

b. Inability to measure in non-fixating eyes (nystagmus, macular degeneration and dystrophies)

c. More expensive

Recent advances in the technology of optical biometry have tried to overcome the limitations. SS-OCT and OLCR have increased the penetration through dense cataract and media opacities. IOLMaster 700, ARGOS and OA2000 (TOMEY) have better penetration through dense cataract.

IOLMaster 700 (Figure 4) has an added advantage of identifying unusual ocular geometry like crystalline lens tilt or decentration. The OCT image provides a fixation check. The fixation check feature alerts the user to a suboptimal scan if the image captured does not show the foveal pit. The fixation check also helps to identify macular pathologies such as macular holes and age-related macular degeneration, though the findings need to be verified with a dedicated retina OCT.

![Figure 4: IOLMaster 700](image-url)
IOLMaster 700 also has telecentric keratometry (distance independent) similar to IOLMaster 500. IOLMaster 700 measures 18 points over the center of cornea with 950nm light as compared to 6 points by IOLMaster 500. Increased number of points and area increases the accuracy of calculation especially in challenging corneas (postrefractive surgery, post keratoplasty, ectatic cornea) and toric IOL’s.

All optical biometers measure only Standard K (anterior corneal power) which can lead to refractive suprises especially in challenging corneas and high astigmatism. Total keratometry (TK) depends on both anterior and posterior cornea. The posterior steepest meridian is almost always vertical. Such alignment generates ATR astigmatism, which partially compensates anterior WTR astigmatism and increases anterior ATR astigmatism..

Measuring only standard K and even corneal astigmatism from Sim K values has shown to overestimate WTA astigmatism by 0.5D and underestimate ATR astigmatism by 0.3D. Savini G et al. published a relevant work which concluded that corneal astigmatism Sim K measurement overestimated WTA by 0.22±0.32D, underestimated ATR astigmatism by 0.21±0.26D.\textsuperscript{12} In post refractive surgery eyes measuring only standard K leads to significant postoperative suprises.

Refractive suprises can be avoided by measuring the posterior corneal power (posterior K) in addition to anterior corneal power and deriving the total corneal power (TK). Posterior K can be measured either by regression method or by direct measurement. IOLMaster 700 gives us the advantage of directly measuring the posterior K and total K. It derives the TK value from the anterior K, posterior K and the central corneal thickness (CCT) values. The TK is lens-constant compatible and thus the existing standard formulae and IOL constant can be applied.

Studies have shown that direct measurement of posterior K or estimating posterior K by regression produces better refractive accuracy as compared to conventional K. Li Wang et al. published a work that showed LASIK, PRK, and RK eyes, the combination of the directly measured TK and the standard Haigis formula produced
refractive prediction accuracy comparable to the regression based Haigis-L and Barrett True-K formulas.\textsuperscript{13}

Optical biometry devices along with axial length and keratometry also measure anterior chamber depth (ACD), white-to-white (WTW), lens thickness (LT), central corneal thickness (CCT), pupil size (PS).

LenstarLS 900, Alladdin and Galilei G6 also give topography scans that can be used for toric intraocular lens implantation. These devices have in-built 4th and 5th generation formulae (Olsen, Barrett’s suit, Haigis suit, shammass) for calculation of IOL power for toric IOL, post keratorefractive surgery eyes and IOL exchange.

**Conclusion**

Optical biometry with its latest technology has become an indispensible tool for refractive cataract surgery. It has gained preference over A-scan as a faster, non-contact, easy to use, patient friendly, more accurate technique to measure axial length and IOL power. Though optical biometry is the gold standard today, measurement in cases of mature, hypermature and dense brown cataract and non-fixating eyes is still a drawback. A-scan is still the preferred technique in such cases where optical biometry fails. It is even advisable to use both A-scan and optical biometry in difficult situations and decide the IOL power comparing the two to have the best postoperative refractive outcomes.

**References**


When planning cataract surgery, one of the most crucial stages for treatment success is choosing the correct intraocular lens (IOL) power. To reach the targeted refraction, the selection must be performed according to the anatomical and optical parameters of the eye. Intraocular lens (IOL) power calculation formulas have evolved since the publication of the Fyodorov formula in 1967 [1, 2]. Nowadays, there are several methods for calculating the IOL power that can be classified in one of the following groups: (1) historical/refraction based, (2) regression, (3) vergence, (4) artificial intelligence, and (5) ray tracing [3]. First two approaches are considered out of date, artificial intelligence is growing in popularity but not in predictability [4], and ray tracing [5, 6] is a promising option that has not still replaced the most used methods based on the vergence formula.
The main difference between vergence formulas is the number of variables used for estimating the effective-thin lens position (ELPo), ranging from two in SRK/T, Hoffer Q, and Holladay I formulas to five or seven in the Barrett Universal II or Holladay II formulas, respectively.\(^7\)

**What is the effective lens position?**

The only parameter that cannot be measured preoperatively is the position where the IOL “settles down” after surgery, which is also known as the effective lens position (ELP). Prediction of this parameter is initially performed by the IOL manufacturer in form of the A-constant. The A-constant is an empirical value and is specific to the design of the IOL. This constant is later refined by statistical optimizations that reflect the variance of the patient’s particular preoperative biometry, and the surgeon’s personal surgical technique is also taken into account. ELP is defined as the effective distance between the anterior surface of the cornea and the lens plane if the lens was infinitely thin.\(^8,9^\) The ELP is considered to be the main limiting factor for refractive predictability after cataract surgery, as the accuracy of AL and corneal power measurements has been widely demonstrated.\(^7\) Improvements in IOL power calculations over the past 30 years are the result of improved predictability of the ELP variable.

Mathematical formulas have been developed for best estimation of ELP, most of which are based on paraxial optics.\(^8,10^\) In these formulas, some ocular parameters are required and the surgeon should know the intended target refraction.\(^8,10^\)

**The Barrett Universal Formula:** The Barrett Universal II is a formula based on Gaussian principles, or ray tracing. It differs, therefore, from conventional formulae in that it takes into account the change in principal planes that occur with different intraocular lens powers. It also changes the calculation depending on whether the optic configuration alters from a biconvex to a meniscus lens, and finally, it recognizes the changing versions that occur when a lens changes from a positive lens to a minus lens. It doesn’t require additional correction.
factors such as axial length transformation or unusual constants for patients with high myopia and very long axial lenses.

It has a unique theoretical model to predict the ELP and this differs quite significantly from what has been used previously. The difference between the Barrett Universal II and earlier formulae is that it takes into account 5 variables. In addition to axial length, keratometry, and optical ACD, the formula takes into account the lens thickness as well as white to white. And in particular, the lens thickness adds additional accuracy to the prediction across all axial length ranges.[11]

The Barrett Formula suite

The Barrett Universal II is the core formula, which is at the heart of all the other formulae. The Barrett Universal II forms the foundation for the Barrett Toric calculator, which is used to predict the required toric lens power in cylinder for patients requiring a toric lens for astigmatism. The Barrett Toric calculator predicts a posterior cornea, which is different for each individual patient. It is based on a theoretical model, which proposed to explain the phenomena of posterior corneal astigmatism and why it tends to be an against-the-rule effect vertically orientated in the majority of patients.

As a theoretical model, it’s quite distinct from other methods of predicting the posterior cornea, which are based on regression and has proved to be more accurate. This posterior cornea will depend on several factors including keratometry, axial length, and even ACD. All these will influence the prediction which is provided The True K formula is a post refractive formula, which can be used for patients who’ve had previous refractive surgery. This includes patients who had previous LASIK or PRK including hyperopic or myopic procedures, as well as patients who have had radial keratotomy. In addition, there is a True K Toric calculator and this is for patients with astigmatism who have had previous laser surgery, because the calculations required for a toric calculation, in this circumstance, are somewhat different.

The Barrett Rx formula is a solution for patients who have had unexpected outcomes following cataract surgery and for these
patients they require information with a rotating a toric lens is a solution or exchanging the lens is preferred, or a piggy back lens may be appropriate in some circumstances. And all these solutions and outcomes are provided by this formula.[12,13]

The Hill-RBF Calculator

- It is an advanced, self-validating method for IOL power selection employing pattern recognition and sophisticated data interpolation. It has been optimized for use with the Haag-Streit LENSTAR, using optical biometry for all axial measurements and high density autokeratometry. It is an ingenious method of generating internal data relationship that look at different combination of data, with 3 key points data - corneal curvature, ACD, Axial length. They determine the set of measurements of the optical power. It is driven by an advanced, self-validating method using pattern recognition based on artificial intelligence and sophisticated data interpolation. Starting with a large number of cases where the biometry and the outcomes are known, the new Hill-RBF Method is a pure data driven IOL calculation approach and therefore it is free of the limitation of lens-position estimation. RBF stands for Radial Basis activation Function starting with a large number of cases where the biometry and the outcomes are known. RBF is capable to find distinct patterns in the apparently random cloud of data-points. The current algorithm is based on outcome data of more than 12,000 eyes, with Lenstar biometry data and the Alcon SN60WL IOL implanted. It works good with biometry data from other optical biometry devices and with other biconvex IOL’s from -5 D to +30D. The Hill-RBF Method performs equally well on all eyes; short, average and long ones, independent of specific anatomical features. The Hill-RBF/Abulafia-Koch Toric Calculator combines two advanced methods for optimal toric results. In it’s preset form, version 2.0 of the Hill-RBF Calculator has been optimized for from +30.00 D to +6.00 D for biconvex IOLs and from +5.00 D to -5.00 D for meniscus design IOL.[14,15]
Olsen formula

In the new Olsen formula, which is available on the Lenstar device and through the website phaco optics.com, the ELP is predicted primarily through a concept called the C constant. With traditional thin-lens IOL power calculation formulas, the optics of the cornea and the IOL are described as single refracting surfaces based on simple first-order approximations. This category of IOL calculation formulas estimates the effective lens position (ELP), a virtual IOL position that is back calculated from the observed refraction after surgery based on the given thin-lens formula. The Olsen formula uses exact ray tracing and thick-lens considerations to account for the true physical dimensions of an eye’s optical system. It uses the same technology employed by physicists to design telescopes and camera lenses. A key feature of the Olsen formula is accurate estimation of the IOL’s physical position using a newly developed concept, the C-constant.\(^{16,17}\) (Figure).

The C-constant can be thought of as a ratio by which the empty capsular bag will encapsulate and fixate an IOL following in-the-bag implantation.\(^6\) This approach predicts the IOL position as a function of preoperative anterior chamber depth and lens thickness. Because this approach works independent of traditional factors such as eye
length, keratometry (K), whiteto-white dimension, IOL power, age, and gender. It can work in any type of eye, including those that have previously undergone refractive surgery. Its only requirements are accurate measurements of anterior chamber depth and lens thickness, both of which are provided by the LENSTAR optical biometer. This formula performs better – for ELP calculation than other thin lens based formulas. It is based on pure optics – they account well in irregular / or scarred cornea, corneal asphericity, IOL Parameters like ant & post curvatures and spherical aberrations. That is why it is very useful in complex corneas where vergence formula are difficult.

**Hoffer H-5**

It is developed by Santa Monica surgeon Kenneth J. Hoffer. The H-5 uses gender and race to change the average mean values in the Holladay-II and Hoffer Q formulas. By using gender and race to alter the predicted IOL power, the formula may be more customizable for a particular patient. The H-5 is licensed to the IOLMaster 700.

**Ladas Formula**

The current theoretical formulae such as Holladay I, SRK/T, and Hoffer Q have been the mainstay in IOL calculations for the past 20 years. These sophisticated formulas are far better than the previous regression formulae, but each has limitations under specific circumstances.

That is why John Ladas, suggests optimizing multiple formulae and choosing the best parts of each of them. He has developed a two-phased approach: the Ladas super surface and Ladas super formula. The idea is to weed out the formulae’s limitations, implement adjustments, and further optimize the values over time using both individual and crowdsourced data.[18,19]

**Applying the Ladas Approach**

It has been described the Ladas approach to IOL calculation. Looked at five formulas (Hoffer Q, Holladay I, Holladay I with Koch adjustment, Haigis, and SRK/T) as mathematical equations with the potential to be graphed on the x-, y-, and z-axes, and rendered them
in three dimensions one by one. By doing so, it could visualize these could be visualized in a manner that it had not seen before. Then it could pick out the best portions of each one and incorporate them into a newly formed, singular Ladas super surface, from which is derived the Ladas super formula.

**Optimizing the Super Formula**

The various optimizations that have already taken place are specific to or dependent on the formula used, so the optimization is only useful to eyes that are suitable for a given formula. It would be ideal to have a formula-independent optimization. We can achieve this by optimizing every millimeter of the Ladas super surface, and thus the Ladas super formula, based on empirical outcome data and by embedding other parameters (such as anterior chamber depth [ACD]) in a specific manner.

Now that we have a shape of the best of what we have so far, we can essentially sculpt and mold this shape into one that yields the most valid values. We do this primarily by comparing predicted and actual results of IOL power. This approach can evolve over time and become a system that never ceases to improve. Crowdsourcing group data means that we could use thousands, or even millions, of data points to achieve unprecedented accuracy.

**Examples**

Here are a few examples of how the super formula offers calculation options for a diversity of eyes. In a standard eye, the super formula interface localizes to the correct region and provides the most accurate IOL power value. The interface takes into account the axial length, keratometry, A-constant, target refraction, and measured ACD, if needed (Figure 1).

In eyes with a short axial length, the slightest change in effective lens position can dramatically change calculation results. We have found that the super formula easily locates the correct region on the super surface and provides the most accurate calculation (Figure 2).
Role and limitations of newer formulas for Biometry

**Figure 1.** A standard eye: axial length 25.34 mm; K1 43.43 D, K2 44.12 D; ACD 3.14 mm; and target refraction plano. Abbreviations: K, keratometry; ACD, anterior chamber depth.

**Figure 2.** A small eye: axial length 22.29 mm; K1 46.34 D, K2 45.05 D; ACD 3.41 mm; and target refraction plano.
IOL power calculations are often inaccurate in eyes with long axial length unless the ophthalmologist applies the Koch adjustment. The super formula automatically takes this adjustment into account.

![Superformula](image)

**Figure 3.** A long eye: axial length 33.93 mm; K1 45.34 D, K2 44.94 D; ACD 2.94; and target refraction plano. Ladas super formula can streamline the selection of the most appropriate IOL formula for a given eye and improve outcomes. By viewing the current IOL formulae as 3-D entities, we can choose the best portions of each public formula to calculate the most appropriate IOL power value for eyes with any axial length, keratometry reading, and ACD.

**Newer IOL Calculation Preferences**

- **Standard cases (Normal Axl):** Barrett Universal 2, Hill RBF v 2.0, Olsen & Holladay 1, SRK/T.
- **High Myopes (25.5 to 27mm):** Holladay 1 with Wang Koch – modification, Barrett Universal 2, Olsen & Hill RBF v2.0 works well.
- **Very long eyes >27mm Axl:** Barrett universal 2 & Hill RBF v2.0
- **Short eyes:** Barrett Universal 2 & Hill RBF comparable.
References


Role and limitations of newer formulas for Biometry


15. The Hill-RBF Calculator in Clinical Practice; ASCRS EyeWorld Corporate Education; ASCRS 2016.


Nowadays, cataract surgeries are not just about cataract removal and IOL insertion, it is becoming more and more closer to refractive surgery. Measurement of corneal power is an integral part of the biometry for calculation of Intraocular Lens (IOL) power. Though not absolutely accurate, it is based upon the steepness of the cornea. The cornea is assumed to have a perfect spherical reflective surface (especially for the purpose of measurement of IOL power). It is now known that cornea doesn’t have a fixed anterior to posterior corneal curvature ratio. The cornea acts as a convex reflecting surface which leads to a virtual image of the target. The corneal curvature is predicted from this, which is then used to determine the corneal power.\(^{(1)}\)

One of the most basic errors in most of the current keratometers is that they do not calculate corneal curvature accurately because of the assumption that cornea is a perfect sphere. The par-axial optics and the power of the back of the cornea would also give important information and should be included in the biometry. It is due to these reasons that computerised videokeratography is now gaining standardization for more accurate results.\(^{(1,2)}\)

Corneal topography can help you accurately place relaxing incisions and predict problems with a patient’s vision postoperatively. According to surgeons corneal topography is indispensable in refractive surgery, but it’s very useful before cataract surgery, as well. This is especially true when a surgeon intends to implant newer intraocular lenses such as multifocal and diffractive-multifocal IOLs, which demand an excellent visual system in order to yield the best results.
Catching the Abnormal

It is important to diagnose and find out irregular corneas before laser surgery, the same applies to cataract surgery as well. It is known that irregular corneas will increase the risk of postop glare halo and reduced quality of vision and are therefore relative contraindications for multifocal IOLs. An irregular cornea will also reduce the efficacy and safety of limbal relaxing incisions.

Keratoconus and other corneal disease

Patients planned for cataract surgery may have subtle forms of keratoconus that could be undetected on routine keratometry and this...
that can affect the outcome of the surgery. Even in patients who do not have apparent astigmatism on optical biometry or manual keratometry, can still have keratoconus that can affect the accuracy of IOL power calculation and effectively the quality of vision. The classic signs, such as inferior corneal steepening with skewed, asymmetric astigmatism and an inferior: superior ratio usually greater than 1.4 D should not be missed. It may not change the surgical decision but would alert that outcome may not be perfect because the patient has some irregular astigmatism. It may be that keratoconus is the limiting factor in his vision, not the cataract.

Figure 1 b. Same patient multiple data analysis showing frank keratoconus and raised indices
Similarly, in a case where topography shows that one of the wings of the 'bow tie' curved towards the side, it could be a sign of an irregular cornea. The corneal topography should be regular and if not then it would be important to assess the pachymetry.

Pellucid marginal degeneration is another rare disease where vertical negative bow ties may be seen. The lower half may be surrounded by a C shaped elevation.

A third irregularity, basement membrane dystrophy (EPMD) isn’t similar to that caused by minor dry eye. The biggest sign is irregular distortion or irregular mires, where there are a lot of side-by-side areas that are very steep and then very flat.

**Prior refractive surgery**

A lot of patients who underwent refractive surgery at a young age forget mentioning that when they are undergoing cataract surgery at a later age. Although a retinal examination does give a clue it is not for moderate myopes where retina may be absolutely normal. Corneal topography provides substantial evidence in case of previous refractive surgery; if it was a myopic procedure, it will be flatter centrally. If it was a hyperopic surgery, it will be more prolate than the typical cornea.”

**Corneal scars**

Although a corneal scar would be evident during a routine slit lamp examination corneal topography gives valuable insight regarding the extent of the scar’s impact on the cornea in terms of irregularities. In a case of pterygium, topography will help you decide whether to do the cataract surgery or remove the pterygium first, in terms of which would give the patient a better vision. In presence of an irregular astigmatism on the topography due to the pterygium, it would be wise to handle pterygium first.”

**Ocular surface/dry eye**

Dry eye can distort topography as well, letting you know that the surface may need to be normalized to get the best vision postop. Sometimes dry eye can be seen more easily on topography than at the slit lamp.
Reading a topography map

When reading a topography map, one has to know the type of map and the diopteric scale that is being analyzed. When analyzing the tangential maps, it is important to understand that they would magnify what is seen on axial maps or sagittal maps. This exacerbation is important when minimal abnormalities may be missed on other maps, they would be perceived in the tangential map. For the scale, we recommend a step of 1 to 1.5 diopters because that would not contract the scale too much at the same time the range won’t be expanded too.

Planning Limbal relaxing incisions (LRIs)

Before planning for placing limbal relaxing incisions, topography needs to be done. The customization is possible only with topography. If the bow tie is asymmetric, the incision in the steeper side would be a little longer than the other side. This would not be possible with a keratometer and its readings.

For skewed astigmatism, if the axes are not perpendicular, the LRIs can’t be on the opposite sides. Infact, if the topography suggests that the astigmatism is irregular, the surgeon would be advised not to do LRIs. The topographers may also give you regional pachymetry like Sirius, which provides useful information with regards to the depth of the LRIs in periphery.

Aspheric IOLs

The newer topographers do give you the spherical aberration (Q value). Since the IOLs like Technis (-0.27 microns of spherical aberration) and Alcon (-0.20 microns of spherical aberration) have negative sphericity to negate the cornea’s positive spherical aberration, it is very important to know whether the cornea has a positive spherical aberration or not. Infact, the spherical aberration of the cornea would let the surgeon select the appropriate IOL for the patient.

Aberrometry and Cataract. Figure

Although internal aberrometry may not help in the IOL power calculation directly, it does contribute in deciding if the patient would be benefitted by a cataract surgery in terms of reducing the patient’s internal aberration. The importance of an aberrometer lies in the fact that it can easily separate the internal and external aberrations which
gives a good idea which particular refractive part is responsible for the visual dysfunction.

Figure 2 a and b. The top image shows high internal aberration in the left eye. The chart shows green bar as higher order internal aberration contributing to the total aberration. The bottom image shows the right eye of the same patient with minimal to no aberrations internally.

References
Myopia is one of the most prevalent eye diseases in the world. Myopia can be school myopia or high myopia. High myopia is associated with the elongation of eye ball (axial length, AL). \cite{1-3}

Myopia is classified into non-pathologic (Simple Myopia) and pathologic myopia. Non-pathologic myopia has usually spherical equivalent $< 6.00$ diopters and onset usually begins during childhood or adolescence while Pathologic myopia is classified as a high myopic refractive error that is progressive and generally presents very early in childhood. It is defined as spherical equivalent $> 6.00$ diopters or axial length $> 26.5 \text{mm}$. \cite{4}

A number of studies have shown that the incidence and progression of cataract among those with high myopia were significantly higher and faster than those with non-myopic eyes. \cite{5-7} Patients with high myopia and cataract often undergo the cataract phacoemulsification. \cite{8} In the present century, cataract surgery is more of a refractive procedure. The accurate calculation of the intraocular lens (IOL) power has become increasingly important along with surgical technique and precision. With the latest advents in formulas used for these calculations, the accuracy of predicting IOL power in emmetropic eyes with an axial length (AL) of 22.0 to 24.5 mm can now be guaranteed. However, due to complex condition of the fundus in high myopic eyes, most existing formulas to predict the IOL power have disappointed in such cases. \cite{9}

Unexpected postoperative hyperopic refractive errors are often seen in these eyes which results in reduction of patient satisfaction with cataract surgery. \cite{10-12} Selecting the formulas with the best predictability becomes crucial in highly myopic patients.
The IOL power calculation formula has been applied for more than 40 years clinically and has been developed to the fourth-generation formula.\textsuperscript{[13, 14]} This evolved into using the keratometry and axial length, first with regression (SRK I and SRK II) and then with theoretical formulae (Holladay 1, SRK/T and Hoffer Q). This has been proved reliable for most eyes, but with more input variables, such as anterior chamber depth, could help predict the effective lens position (ELP) of the IOL more accurately. This factor, determining the precise ELP, is the primary challenge for truly accurate IOL calculations.

The calculation of intraocular lens power (IOL) in high myopic eyes remains a challenge. The potential sources of error in IOL calculation for high myopic eyes include AL measurement, IOL constants used, and IOL power calculation formula employed. In high myopic eyes, due to the presence of posterior staphyloma, partial coherence interferometry (PCI) may be better than conventional ultrasound for measuring the AL\textsuperscript{[14, 15]}. As far as IOL constants are concerned, reports suggest optimized constants greatly improve the predictive refraction outcomes\textsuperscript{[16-18]}. They have also suggested that the Laser Interference Biometry (LIB) constants are more accurate than manufacturer-recommended IOL constants for long eyes\textsuperscript{[19, 20]}. The most studied IOL power calculation formulas the third-generation formulas (Holladay 1, SRK/T, and Hoffer Q) use the keratometry and axial length as the two primary factors for IOL calculations, with other data such as anterior chamber depth, white-to-white, refraction, lens thickness and more to help the ELP determination.

As of late, the newer formulae, the Holladay 2, Haigis, Olsen and Barrett Universal II are found to be more accurate than the third gen formulas because they are more than just single equations. Each of these methods has an approach that is adjusted based on the input parameters of the eye. That’s why these newer formulas are preferred by surgeons worldwide. Especially for patients with very long axial lengths and extreme levels of myopia.

Newer fourth generation formulas (Going beyond the Single Equation)

- Wang-Koch modification to Holladay 1
• Barrett Universal 2
• Hill-RBF method (if parameters are “in bounds”).
• Ladas Super Formula 2.0 with artificial intelligence.
• Olsen Formula

There are currently four approaches in use by surgeons around the world.

1. Target a moderate amount of myopia. (Not recommended.)
2. Adjust the optical biometry axial length as recommended by Wang and Koch in the JCRS. (Recommended)
3. Use the Barrett Universal II formula with optical biometry, which is well suited to this task. (Recommended)
4. Use the Hill-RBF method for IOL from -5 D to +30 D with optical biometry data from sources providing measurements equivalent to the Lenstar (Recommended)

Journal of Cataract and Refractive Surgery paper by Li Wang and Doug Koch at Baylor University have described a method for adjusting the axial length for the high to extreme axial myope when the axial length is carried out by optical biometry. This would apply to both the Lenstar and the IOLMaster, as the approach of both instruments is almost identical at the present time. The adjusted \( AL = 0.83 \times \text{measured AL} + 4.27 \), and then this new value is plugged into Holladay 1 for the IOL power. Theory behind this formulation is that optical biometry may exhibit a systematic error in the measurement of axial length that increases in a linear fashion. This is due to the fact that optical biometry assigns a single, global index of refraction to all eyes, no matter what the axial length, more over vitreous cavity for the high to extreme axial myope dominates the axial measurement and the greater the amount of vitreous, the more its index of refraction contributes to the overall measurement. In this condition, optical biometry will over-estimate the axial length. In other words, the longer the eye, the greater the error.\(^{[22]}\)
Above method is not used for patients with prior refractive surgery as the calculation algorithms have already been optimized for long axial lengths and adding this correction will give a myopic result, so another approach that is gaining in popularity is the use of the Barrett Universal II formula. Here no axial length adjustment is required and standard optical biometry lens constants are used. This is one of the most accurate theoretical formulas currently available. It can be accessed at: http://www.apacrs.org/barrett_universal2/

The new Hill-RBF Method is a fully data base IOL calculation and therefore it is free of the limitation of lens-position estimation. Standard 2nd generation IOL calculation formulae like HofferQ, Holladay or SRK/T estimate the lens position based on axial length and K measurements, assuming that long eyes as well as steep corneas lead to a deep lens position and vice versa. This assumption is the reason why all of these formulae provide weak performance with extreme eyes, because the vast majority of long as well as short eyes show normal anterior chamber dimensions and are not deep or shallow as assumed by the formulae. (Table)

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<tr>
<th>Anterior Segment Size vs. Axial Length</th>
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<td>Anterior Segment Size</td>
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<td>Large Eye Buphthalmos Megalocornea + axial myopia (10%)</td>
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Surgeons have traditionally assumed that short eyes have shallow anterior segments and long eyes have deep anterior segments, but research by Jack Holladay and James Gillis, MD, found that this isn’t the case

(Source: reviewofophthalmology.com/article/in-search-of-the-perfect-iol-formula)

RBF stands for Radial Basis activation Function. It is driven by an advanced, self-validating method using pattern recognition based on artificial intelligence and sophisticated data interpolation. Here, the algorithm is based on outcome data of more than 12,000 eyes,
with Lenstar biometry data and the Alcon SN60WL IOL implanted. It works best with this combination of biometry device and IOL but works also very good with biometry data from other optical biometry devices and with other biconvex IOL’s from -5 D to +30D. The Hill-RBF Method has added its own limitation that allows calculation of the prediction dependability. Reliable calculation results are labelled with “In Bounds”, results that deserve more attention of the surgeon, since the prediction algorithm was not able to determine the desired level of reliability, are labelled “Out of Bounds”. All “Out Bound” calculations informs the surgeon that the respective pattern of biometric measurements is not comparable by the algorithm and it is recommended to use the Olsen and the Barrett formula to confirm the proposed IOL\textsuperscript{[23]}.

To get the most from many of the latest-generation formulas, you also need to have an optical biometer such as the IOLMaster 700 or the Lenstar. The Olsen formula, require a measurement of the lens thickness. In the Olsen formula, which is available on the Lenstar device and through the website phacooptics.com, the ELP is predicted primarily through a concept called the C constant.

Surgeons are trying to improve on the so-called thin-lens method of IOL calculation, which uses the K reading and axial length to try to predict the effective lens position. (Image source: reviewofophthalmology.com).
The Olsen formula uses ray tracing to get the pre-op lens thickness and anterior chamber depth to derive C, which can be thought of as a fraction of the preoperative lens thickness. This C constant is then used to determine where the IOL will come to rest in the eye. (Image courtesy Thomas Olsen, MD.)

The Ladas Super Formula 1.0, which was described first in 2015, took a very similar approach of dividing the eyes based on axial length. When we superimpose the plots of the Ladas and Barrett calculations over a range of axial lengths and corneal powers, we can see that they overlap widely with only small differences for extreme eyes. (figure 1) But both the methods will need to be refined as we learn about effect of the posterior corneal power and perhaps other variables such as gender or genetic background which have been postulated to influence the effective lens position determination. In order to see patterns across thousands of eyes and to evolve, we need a big-data approach.

**Ladas Super Formula 1.0 vs Barrett Universal Formula**

![Figure 1](source: cataractcoach.com)  
*Figure 1*: The original Ladas Super Formula 1.0 (left graph), like the Barrett Universal Formula, has distinct breaks at specific axial lengths indicating a change in the calculation methodology. When we superimpose the Ladas and Barrett formulas (right graph), we can see that they are very similar over a very wide range with some differences for extreme eyes. (Image source: cataractcoach.com)

Artificial intelligence (AI) applied to IOL power determination where we give input variables such as axial length, keratometry, anterior chamber depth, and more which are then weighed appropriately with the hidden inner layers of the AI and the IOL power is predicted that is consistent with the given dataset.
The Ladas Super Formula 2.0 incorporates AI and eliminates the risk of an out-of-bounds result by using the original Ladas Super Formula 1.0 as a framework plus, additional variables can be learned instantly and appropriate adjustments can be made as they relate to the existing variables just like Wang-Koch axial length adjustment.

Here, instead of outright predicting IOL power like the Hill-RBF, Ladas Super Formula 2.0 uses the big data approach to predict the difference or displacement between an existing formula and perfection for a given eye, these adjustments are not random and typically occur on the order of 0.2 diopters. These predicted displacements or adjustments are seamlessly incorporated back into the existing formula. Because the baseline is an already proven formula, the differences is 100 times smaller in magnitude than the standard AI approach that is instead predicting IOL power (0.2 diopters vs. 20 diopters)[24]. Using a massive amount of computing power, a significant displacement from the origin for IOL power was predicted for axial lengths of about 26 mm or longer, varying somewhat with the keratometry as well (figure 2).[24]

**Figure 2:** The artificial intelligence of Ladas Super Formula 2.0 predicts the adjustment needed for long axial lengths. (Image source: cataractcoach.com)
The zone in yellow indicates where the artificial intelligence predicts that an adjustment is needed. This is specifically the type of myopic eyes that benefit by the Wang-Koch axial length adjustment prior to calculation. Source: Uday Devgan, MD

The Ladas Super Formula which can be accessed at www.IOLcalc.com for free.

**Conclusion**

Is One Formula the Best? This is a tricky question to answer. “Everyone who develops a formula says his is the best,” notes Dr. Holladay. “It’s not necessarily that people are biased; it’s that formulas are developed based on a set of data, and the formula is refined until it produces the best outcomes with that dataset. “There aren’t many studies comparing recent formulas such as the Barrett Universal II and Hill-RBF,” Douglas D. Koch, MD, professor of ophthalmology at Baylor College of Medicine in Houston. (Dr. Koch and Li Wang, MD, PhD, created the Wang-Koch modification.) said “The best data I’ve seen was more than 90 percent of eyes within 0.5 D of predicted outcome for the Hill-RBF in normal eyes. I also still find the Holladay I to be an excellent formula, and I now also routinely use the Barrett Universal II. I’ve seen data that suggests that the Barrett Universal II formula does very well in long eyes, but perhaps not quite as well as the Holladay I formula combined with our Wang-Koch modification.

Dr. Devgan (Chief of Ophthalmology at Olive View UCLA Medical Center and Clinical Professor of Ophthalmology at the Jules Stein Eye Institute), says he’s had great success using the Ladas Super Formula that he helped to develop. “We’re able to get 90-plus percent of eyes within half a diopter,” he says. “The older, third-generation formulas usually only get about 70 percent within a half diopter. That’s a big difference. Dr. Koch points out that almost all formulas are subject to two sources of uncertainty: the method the formula used to calculate the ELP, and the accuracy of the measurements you’re putting into the formula like corneal measurements, K-reading and anterior chamber depth. Whichever instrument is being used for measurements, it is important to look for the quality and consistency of the data, topography measurements, all these measurements matters. Dr.
Holladay acknowledges that the accuracy of these measurements may still improve, he points out “The limit isn’t the formula; the limit is the precision of the measurements that we put into the formula. If you look at it from an engineering perspective, the error of the answer is the sum of the squares of the error of each variable that goes into the formula. Our precision limit for the cornea is about 0.25 D; the error for axial length is about 0.1 mm; and the anterior chamber depth and the effective lens position is down to 0.2 or 0.3 mm. Those error limits keep us at about 90 percent of patients within half a diopter of the target outcome.”

Recently few studies are carried out which compare the third gen formula to fourth gen formulas which suggest Barrett Universal II formula is easy to use and comparatively more accurate than the third gen formulas.

Xian fang Rong et al compared the accuracy of the Barrett Universal II, Haigis, and Olsen formulas in calculating intraocular lens (IOL) power in eyes with control (26.0mm to 28.0mm), myopia (28.0mm to 30.0mm) and extreme myopia (30.0 mm or more) and concluded that in eyes with an AL of 28.0 to 30.0 mm, all 3 formulas were accurate. In eyes with AL of 30.0 mm or more, the Barrett Universal II formula was better than the Haigis formula, possibly because there were fewer influencing factors.[25]

Similarly Dong Zhou et al studied the accuracy of the refractive prediction determined by the calculation formulas for different intraocular lens (IOL) powers for high myopia on 217 eyes of 135 patients and concluded that Barrett Universal II formula rendered the lowest predictive error compared with SRK/T, Haigis, Holladay, and Hoffer Q formulas. Thus, Barrett Universal II formula may be regarded as a more reliable formula for high myopia.[26]

Still more studies have to be carried out among fourth generations formulas to get one universal, more accurate and easily accessible formula for calculation of IOL power in high myopic patients. For now, Barrett Universal II formula is the saviour.
References


Intraocular Lens Power Calculation in Short Eyes

Dr. Pradnya Sen, Dr. Amit Mohan, Dr. Elesh Jain, Sadguru Netrachiksalaya, Chitrakoot.

Chapter 6

Introduction

It has been considered that intraocular lens (IOL) calculation formulas are more accurate for eyes with normal axial length, but do not have the same level of postoperative refraction outcome for eyes with short axial length.\[^{[1]}\] Short eyes are commonly defined as axial length less than 22mm.\[^{[2]}\] About 11% of cataract patients have short eyes. Hypermetropia is usually associated with short eyes and presents problem in biometry and IOL power calculation.

Biometry in short eyes

The three factors that determine the lens power estimation: the axial length, the keratometry and the estimated effective lens position (ELP). The axial length measurement is critical in determining the ideal IOL power. A small 1 mm change in the axial length measurement can change the IOL power by 2.5 D in average eyes and even more in shorter eyes.\[^{[3]}\] With ultrasound biometry it is very difficult to obtain good quality of scan in these eyes as they are not well centered with contact ultrasound. With the advent of optical coherence biometry, accurate measurements of the axial length are possible now with less chances of error.

Other sources of error in short eyes are related to the higher probability of having a steep cornea and a shallow anterior chamber depth. In eyes with steeper corneas, we need to use refraction before lens power calculations. Determining exactly the ELP in the short eyes is also a challenge because the anterior chamber depth tends to increase with pseudophakia. Higher optical power of the required IOL also leads to an error in the predicted IOL position. The presence of shallow anterior chamber may lead to more anterior position of IOL.\[^{[4]}\]
The special anatomic characteristics and the high IOL power needed in short eyes might account for the difficulties in achieving precise prediction. An early study suggested that errors of IOL power calculation were attributed to incorrect axial length measurement (54%), postoperative anterior chamber depth estimation (38%) and corneal power evaluation (8%).[5] Additionally, Hoffer found slight errors in ELP were related to unusual postoperative refractive error in short eyes when the IOL power was high.[6] Furthermore, Maclaren suggested that the high IOL power, thick IOL, was also a causative factor affecting postoperative refraction in short eyes.[7]

**Formulas of IOL power calculation**

Intraocular lens (IOL) power selection is a critical factor affecting visual outcome after IOL implantation in short eyes. Many formulas have been developed to achieve a precise prediction of the IOL power.

**First-generation formulas**, such as the Sanders-Retzlaff-Kraff (SRK), are based on a regression study of many eyes, and reasonable for eyes with normal axial length. For eyes with shorter-than-average axial lengths, this formula was not accurate.

**Second generation formula**- the SRK-II is modification of first generation formula. This modification was to alter the A-constant based upon the axial length, and the results were better for short eyes but not ideal.

SRK II formula \( P = A1 - 0.9K - 2.5L \)

\( A1 = \) new constant (\( A1 = A + 3 \) if axial length \( L < 20 \text{mm} \); \( A + 2 \) if \( L \) is 20-21 mm; \( A + 1 \) if \( L \) is 21-22mm)

**Third generation formula** - Moving from regression formulae to more theoretical formulae accuracy of IOL power calculation increased as these third-generation formulae used biometric data to estimate the effective lens position. The commonly used third-generation formulae are Holladay 1, SRK-T and Hoffer Q. Each of these formulae estimates the position of the IOL within the eye with more accurate results in shorter eyes.
Fourth generation formula- The latest fourth generation formulae, use many other biometric parameters like the Haigis requires the anterior chamber depth (ACD); the Holladay 2 requires ACD, white-to-white diameter, lens thickness, age and refraction while the Olsen uses a new C-constant that describes the IOL position as a constant fraction of the lens thickness with good results in hyperopic eyes. New IOL super formula is capable of providing the most accurate calculations of IOL power for an individual eye under all situations[^8].

Review literature on IOL power calculation formula in short eyes

Some of the early studies considered Holladay 2 as one of the most precise IOL formulas for patients with short axial length.[^9,10] Maschos et al suggested Haigis was significantly more precise than Hoffer Q.[^11] Day reported Hoffer Q produced less error than SRK/T[^12] Although, Olsen appears to be more accurate than other fourth generation formulae.[^13]

Wang et al[^14] investigated the accuracy of different IOL power calculation formulas in eyes with short axial length in their meta-analysis of 10 study papers by measuring mean absolute error (MAE). Their results indicate that Haigis is superior to Hoffer Q, SRK/T and SRK II with statistical significance. However, no statistical significant difference between Haigis and Holladay 1 & 2 was identified. In this meta-analysis, Haigis performed better than others because it involved three constants (a0, a1 and a2) and two parameters (ACD and axial length) in predicting the ELP.

In theory, Holladay 2 incorporates more biometric data (lens thickness, age and refraction); ELP will be predicted more precisely leading to more accurate IOL power calculation than other formulas. Holladay 2 produced smallest MAE in comparison with Hoffer Q, Holladay 1 and SRK/T in eyes with short AL.[^9] Carifi et al.[^15] found Holladay 2 produced the smallest MAE among the six formulas in short eyes.

In a recent study done by Gocke et al[^16] to investigate the accuracy of 7 intraocular lens (IOL) calculation formulas (Barrett Universal II,
Intraocular Lens Power Calculation in Short Eyes

Haigis, Hill-RBF, Hoffer Q, Holladay 1, Holladay 2, and Olsen) in predicting refractive outcome in eyes with axial lengths (AL) equal to or less than 22.0 mm. They found Hoffer Q and Holladay 2 formulas produced slightly myopic refractive prediction errors, and the Olsen formula produced hyperopic refractive prediction errors. But there were no statistically significant differences in the median absolute error between the 7 formulas.

To conclude, Haigis formula appears to be more accurate in view of postoperative target refraction in eyes with axial length less than 22.0 mm. However, Hoffer Q can be used as an alternative in these eyes.

References


Introduction

IOL power calculation in children is a unique challenge not only because the pediatric eye is not a small adult eye but also because of the measurement challenges and the changing refraction which takes place more rapidly at a younger age and gradually reduces as the age advances with some children still growing depending on the initial axial length and laterality of the cataract apart from having good visual acuity in the operated eye.

The available formulae at present have been made on the basis of the anatomic features of adult eyes, but the anterior segment of an infant is significantly smaller. The anterior segment of an infant is smaller compared to an adult eye but it is proportionally larger to the posterior segment compared with an adult eye. Eyes with congenital cataract may have greater anatomic variation in anterior segment structures (with variable anterior chamber depth and lens thickness). These structural variations may alter the expected effective lens position, and therefore the effective power and the estimated power. The capsular bag of an infant eye is smaller and will contract earlier, which may result in greater posterior IOL displacement.

Implantation of high-power IOLs (particularly >30 D), often required in infantile eyes, can magnify measurement and calculation errors as well as the errors induced by changes in IOL position. Finally when the calculation is being done regarding the accuracy of the IOL power prediction, by the time the postoperative refraction is obtained, rapid growth of an infant’s eye may result in a myopic shift from the predicted postoperative refraction calculated at the time of surgery.
The idea of implanting a fixed power IOL into an eye which is still growing makes it difficult to choose the perfect or an optimum IOL power for the child. Added to this is the challenge of predictive error in various formulas mainly because they have been meant for adult eyes. The younger the child, more is the difficulty in calculating the final emmetropic refractive status of the pediatric eye at the time of the surgery.

To decide on implanting a particular power of IOL at the calculated (estimated) emmetropic power in children risks significant myopia at ocular maturity.\textsuperscript{1-9} Multiple variable play a role in the final power and the rate of axial growth and hence the rate of refractive growth. This may include the age at which the child is being operated, laterality (one eye or both), amblyopia status (dense or mild), likely compliance with glasses, family history of myopia and also the axial length at the time of surgery.\textsuperscript{9-15}

We could divide the IOL power calculation and the final decision of deciding on the IOL power in children into broad categories

a. Equipment needed
b. Prediction errors and formula used
c. Undercorrection in IOL powers

\textbf{a. Equipment needed}

Since the children may be uncooperative, it is imperative that even if we have assessed the IOL power once, we should go back and reassess and repeat the A scan under anaesthesia especially in children who may be uncooperative or delayed developmental kids. The advantages of using a contact or a immersion A scan has been described in other chapters, however, we prefer to do an immersion A scan in children under anesthesia

A hand held keratometer is a must while calculating the keratometry in children. In the absence of a useful keratometry reading like in traumatic cataracts where central cornea may be affected other eye readings may be taken. In absence of that a reading of 44.00
has been used but we caution the readers to avoid it as much as possible and use a handheld keratometer always.

Figure 1. Shows a handheld keratometer

Portable automated keratometry is a simple keratometric technique that appeared to be as accurate as but with less variability than manual keratometry in determining corneal power for cataract surgery.\textsuperscript{16} Kobashi et al hand held keratometry devices provided excellent repeatability and comparability of corneal powers and corneal astigmatism, suggesting they can be used interchangeably for measurement of these corneal variables in healthy eyes.\textsuperscript{17} The corneal power measurements in fixating versus anesthetized nonfixating children using a Nidek KM-500 handheld keratometer shows that the Nidek KM-500 handheld keratometer provided reliable readings when used intraoperatively on anesthetized nonfixating children and required minimal time to perform.\textsuperscript{18} The axis of rotation would be an issue but the power assessed is fairly reliable.\textsuperscript{15-18} The hand held keratometer, Nidek KM-500 is now not available but other keratometers (Figure 1) are easily available and are fairly accurate and reliable. While using a keratometer, one should be cautious that excessive pressure should not be on the cornea and lids. The lids can be separated with eye speculum or with fingers and have comparable readings with the upright position with relation to keratometry reading.\textsuperscript{19} Multiple measurements are taken and the machine gives the standard deviation of the readings. As mentioned before, using
standard adult K-readings in children should be avoided, as the K-reading changes rapidly during the first year of life.\(^5\)

A scan biometry is another step which is quiet important especially in smaller eyes. As mentioned in the chapter of techniques of A scan, we know that an error in axial length (AL) measurement of 1 mm equates to almost 2.5 D. However, this error compounds to 3.75 D/mm in very short eyes (20 mm).\(^{15}\) Care should be taken while measuring the axial length under anesthesia as the fixation would be absent. Few tips are

i. Immersion A scan should always be preferred over contact A scan under anaesthesia. The difference of the two have been discussed in the previous chapters, needless to say that the indentation is avoided in the immersion A scan

ii. Multiple readings should be taken. The reading with higher Anterior chamber depth should be included in the final measurement

iii. The uprolling of the eye ball/ bell’s phenomenon should be avoided so we should wait till the child is in a higher plane of anesthesia before starting to measure

iv. Measurement of keratometry should be done before the A scan measurements whether contact or immersion A scan is being used

v. The sterility should be maintained during the measurement as most of these measurements are being taken inside the operation theatre.

b. Prediction err ors and formula used

Multiple studies are now available which have compared all the formulas for the predictive value of the IOL powers in children. Starting from Andreo et al\(^{20}\) who reported all the formulas are slightly less accurate in shorter axial lengths. In their study, the Hoffer Q formula had the lowest error (1.4D) and the SRK II had the highest error (1.8 D).\(^{20}\) Similar findings were reported by Neely et al\(^{12}\) whereas Nihalani and Vanderveen et al\(^{10}\) reported Hoffer Q was most effective.
The two Indian studies Kekunayya et al. 11 reported SRK II has the least predictive error (PE) whereas Vasavada et al. 13 reported SRK T and Holladay 2 had the least PE. They further reported that personalising A constants would be helpful although it may still not improve Predictive error. In our own experience of 110 eyes of children (under 5 years of age), we compared SRK II, SRK T, Holladay 1 and Barrett’s universal II formula and we found that Barrett’s formula and SRK T had similar and least predictive error. (unpublished data)

c. Undercorrection in IOL power

As the eye is rapidly growing more so when the child is younger, an undercorrection is a must so that the child doesn’t end up having a high myopic shift in the later years when the axial growth would actually stop.21

Axial length increases rapidly in the first 6 months (0.62 mm/month), then has a relatively slower (infantile phase) growth (0.19 mm/month) till 18 months, followed by a slow (juvenile phase) growth (0.01 mm/month).22 The rate of axial growth may be different in different ethnicities23 and may vary depending upon the initial axial length.14 The rate of axial length growth (RAG) is higher at a younger age and even in pseudophakic children is more rapid in unilateral cases compared to bilateral cases.24,25 Also, the rate of axial growth, reduces with the age. However, the study doesn’t differentiate or mentions the axial length at the time of surgery and whether that affects the RAG.24,25

Multiple ways and methods have been presented and published to undercorrect the IOL power in children.3-5,9,14,26

i. Depending on the age

As the rate of axial growth is higher in the younger age group, the undercorrection needed would be higher.24 An undercorrection of 20% is selected for the age group of children less than 2 years of age, with higher undercorrection when the child is closer to the birth.15 Table 1 summaries the recommendation by Trivedi et al.15,22,26
Table 1. Recommended undercorrections by Trivedi et al (2006)

<table>
<thead>
<tr>
<th>Age at the time of surgery</th>
<th>Undercorrection in diopters (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st year</td>
<td>+12 to +7 D</td>
</tr>
<tr>
<td>1-2 years</td>
<td>+6</td>
</tr>
<tr>
<td>2-4 years</td>
<td>+5</td>
</tr>
<tr>
<td>4 year</td>
<td>+4</td>
</tr>
<tr>
<td>5 year</td>
<td>+3</td>
</tr>
<tr>
<td>6 year</td>
<td>+2</td>
</tr>
<tr>
<td>7 year</td>
<td>+1.5</td>
</tr>
<tr>
<td>8-10 years</td>
<td>+1.0</td>
</tr>
<tr>
<td>10-14 years</td>
<td>+0.5</td>
</tr>
<tr>
<td>14 years</td>
<td>Plano</td>
</tr>
</tbody>
</table>

Undercorrection based on percentage.

An undercorrection based on percentage is also available and used

<table>
<thead>
<tr>
<th>Age in years</th>
<th>Amount of undercorrection (Diopters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 1 year</td>
<td>No IOL</td>
</tr>
<tr>
<td>1-2 years</td>
<td>30% (5-6 D)</td>
</tr>
<tr>
<td>2-3 years</td>
<td>20% (3-4 D)</td>
</tr>
<tr>
<td>3 -5 years</td>
<td>10% (1-2 D)</td>
</tr>
<tr>
<td>Above 5 years</td>
<td>Plano</td>
</tr>
</tbody>
</table>

Rule of Seven

Eneydi et al⁵ suggested “the rule of 7” to undercorrect the IOL power in children. The age of the child would be subtracted from 7 and the resultant number would be the amount of undercorrection to be used. Example: the age of the child is 3 years. Once we subtract 7-3=4, we get +4 diopters as the amount of undercorrection to be done for that particular child.
Sachdeva et al\textsuperscript{27} used Eneydi’s rule of undercorrection\textsuperscript{5} and reported a lower undercorrection for children under 2 years of age as their age group had higher hypermetropia than was expected as per the rule of 7. The number of eyes were 13 in the subgroup of children under 2 years of age. The axial length was not compared to see the differential progression based on axial length.

\textbf{ii. Depending on the unilaterality}

Vasavada et al\textsuperscript{24} reported a large rate of axial growth in unilateral cataract when compared to bilateral cataract. Negalur et al\textsuperscript{25} also suggested a higher axial length elongation in unilateral cataract compared to bilateral cataract cases. This was similar to previous reports by Hussein et al\textsuperscript{28} and another report by Fenn et al\textsuperscript{29} which points towards a higher expected myopic shift in the children with unilateral cataract.

However, despite an expected large growth of the unilateral cataract eye, the undercorrection would be lesser compared to a bilateral cataract.\textsuperscript{15, 26} The reason is obvious to reduce the anisometropia and aniseikonia postoperatively. The treatment of amblyopia is more difficult than the surgery itself. We recommend to not keep the anisometropia more than 2.5 D to 3 D postoperatively. This would be variable depending on the age of the patient as older the child, lesser anisometropia should be targeted.

\textbf{iii Depending on the axial length/ IOL power}

Although little literature is available on the comparison of preoperative axial length and its effect on the axial growth, there have been recommendations that if the IOL power is higher, the undercorrection should be higher as per the calculation of undercorrection by percentages.\textsuperscript{2, 3, 15, 26} A 20\% undercorrection for an axial length of 21.0 mm and an axial length of 19.0 mm would be different. At 3 years of age, undercorrection of 5.7 D is pretty large especially since the eye is hyperopic.
The dictum that the higher IOL power should be undercorrected more may hold good for very young children. However, if the eye is an obvious hyperopic eye/ small eye even at the age of 3-4 years, it is less likely to grow as much as a normal sized eye ball or a myopic eye for that age (say 25.0 mm) would grow. We presented our findings at AIOS 2016 Kolkata (best paper) which clearly demonstrated that the larger eyes would grow at a higher rate of axial growth compared to the smaller eyes for that age.

Even with the Eneydi’s rule of 7 the undercorrection completely depends on the age. We recommend that preoperative axial length should also be considered and the total undercorrection should be increased or decreased depending on whether the eye is myopic or hyperopic before surgery. We believe that this particular dictum of considering preoperative axial length should be taken in consideration along with the age.

iv. Presence of amblyopia

If dense amblyopia is suspected, it would be prudent to leave the eye less hyperopic\(^{15, 26}\) and do a lower undercorrection mainly because of three reasons.
a. The treatment of amblyopia is easier if the power of glasses and anisometropia is low postoperatively. The child faces less aniseikonia and would be more amenable to amblyopia treatment.

b. Although amblyopic eyes are more prone to the axial growth, this myopic shift could be tackled easier with refractive surgery at a later date compared to the hyperopia.

c. If expected compliance to patching or occlusion therapy is low or there is dense amblyopia, it would be wiser to have lower anisometropia as the child also would need addition for near. This would add to the already bulky glasses in cases of unilateral amblyopic cataract patient.

v. Parents and siblings refractive error

It has been noted that if both parents are myopic, 30% to 40% of their children become myopic, whereas if only one of the parents is myopic, 20% to 25% of their offspring will become myopic.15

Zadnik et al suggested that the children born to myopia parents have a higher axial length.30 The chances of children being myopic to parents even if one of them is a myope is high.31-32 When there was at least one highly myopic parent, the odds ratios (ORs) of developing mild or moderate myopia were between 2.5 and 3.7 (95% CI: 1.1–6.5) and the ORs of having high myopia were more than 5.5 (95% CI: 3.2–12.6).32 The siblings had a weaker association with the level of myopia and had no effect on the onset of myopia.30-32 However if neither of the parents is myopic, fewer than 10% of their children will become myopic. The growth anticipation is much higher in a child undergoing pediatric cataract with myopic parents. The Axial growth in such children would be high even after the age of 7 years which is normally a cutoff for undercorrection. These children can be undercorrected depending on the family history and also depending upon the laterality and the axial length presurgery.
vi. IOL Power for secondary IOL implantation in aphakia

The vast majority of children undergoing secondary IOL implantation have had primary posterior capsulotomy and anterior vitrectomy. If adequate peripheral capsular support is present, the IOL is placed into the reopened capsular bag or in the ciliary sulcus. Before measuring the keratometry readings, the child should be asked to discontinue wearing contact lenses if there is a history of using aphakic contact lens as that may affect the actual keratometry readings.

The axial length could be calculated using the A scan in the aphakic mode. The IOL power can then be calculated as it would be for a normal cataract. Here is it important to note that since the refraction is already available, the IOL may be calculated by going the reverse way of adjusting the expected error of refraction as the actual aphakic refraction.

Shenoy et al reported good outcomes with sulcus placed secondary IOLs in children. The mean predictive error was 1.65 Diopter and the IOL power calculation done by IOL master had a better absolute PE than the measurements done under anesthesia. Multiple regression analysis revealed an inverse relationship between age at secondary IOL implantation and mean absolute PE. They also found that SRK II gives more favourable refractive outcomes.

vii. IOL power calculation for iris fixation

Very little literature is available on the retrofixation of iris claw IOLs in children. The A constant varies from 115.0 to 117.2 depending on the IOL manufacture. Bhandari et al reported in a series of 363 pediatric eyes a postoperative outcome of 2.5 D to 4.5 D. In our experience, the iris claw IOLs have a high predictive error apart from the astigmatism postoperatively. We analysed our own cases (26 eyes) and found that the mean PE was 1.86 +/- 2.8 diopters (range -2.0 to 4.5 D) at the end of 2 months. The mean astigmatism was 1.88 +/-0.8 D at the end of 4 months.
viii. IOL Power calculator online

It can be used for IOL power calculation in both primary and secondary IOL implantation. It needs the child’s age, A constant of the intended IOL to be implanted, AL and K values. Desired post-operative refraction can also be entered to get the optimum IOL power value.

The pediatric IOL calculator can be downloaded from the AAPOS website: http://www.aapos.org/proinfo/downloads.html

d. How to do the undercorrection

Once the amount of undercorrection is decided, it is important to understand that this is not to be directly subtracted from the amount of IOL power that has been calculated. It is very important to put the expected refractive error in the machine or the biometry formula as shown in the Figure 3-5, the amount of difference and postoperative surprise that can occur because of this.

Figure 3 a. Shows the normal IOL power calculation for a child as +22.0 D in the right eye and +23.0 D in the left eye
Figure 3  b. Same patient, when an expected refraction of 4.0 is put the power is +16 in the right eye and +17.0 in the left eye. It is important to understand that a direct subtraction of 4.0 from the power of 22.0 would be +18.0D and not +16.0 D

Figure 4  a. Calculating an IOL power in a myopic eye. The IOL power is +9.5 in the right eye and +9.0 in the left eye
Figure 4 b. The undercorrection done is 5 D for the power of +9.0 D in the right eye and for +9.5 D in the left eye. The resultant power is +2.5 in the right eye and not +5 and +1.5 in the left eye and not +4.5 D as would result from the direct substraction.

Figure 5 a. Calculating IOL power in a small eye. The IOL power of right eye is +35.0 D and the left eye is +34.5 D
Figure 5 b. The undercorrection once fed as the estimated power outcome gives a power of +28.0 for an expected error of +5.0 D in the right eye and +27.5 D in the left eye. The normal reduction from the original power would give +30 and +29.5 D which would lead to post operative surprises and predictive error.

Let’s summarise these examples in a table to understand better. Any direct reduction and getting it from the biometric formula would lead to a different IOL power. It is imperative to feed the expected error of refraction into the machine and implant the IOL power accordingly. (Table 2)

<table>
<thead>
<tr>
<th>Eye</th>
<th>Axial length</th>
<th>IOL power</th>
<th>Expected refraction</th>
<th>Direct reduction</th>
<th>Biometric formula</th>
<th>Expected surprise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Right</td>
<td>22.32</td>
<td>22</td>
<td>4</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>Left</td>
<td>22.22</td>
<td>23</td>
<td>4</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>Right</td>
<td>26.23</td>
<td>9.5</td>
<td>5</td>
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<td>34.5</td>
<td>5</td>
<td>29.5</td>
<td>27.5</td>
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</tbody>
</table>

Table 2. Shows the difference in outcome of the IOL power if calculated directly from the power and when reading is taken from the biometric calculator in the machine.
References


Development of cataract is one of the most common and expected complications after vitrectomy and the incidence ranges from 12.5% to 80% of eyes\textsuperscript{1-5} depending upon various factors including age, preexisting sclerosis, co morbidities like diabetes and silicone oil injection.\textsuperscript{5-7} The number of vitreoretinal surgeries are rising each year and hence a significant increase in the volume of vitrectomized patients, who in their vitrectomized state pose a challenge to the cataract surgeon.

Due to predictability and advancements in techniques for pars plana vitrectomy and phacoemulsification, more and more surgeons are inclined to remove the cataract and implant intraocular lens (IOL) at the time of silicon oil removal in one procedure.\textsuperscript{8} This is mainly to reduce the number of surgeries needed.

**Silicone Oil and its implications on biometry**

Before moving on to the measurement techniques, it is important to understand the Silicone oil and its implications on axial length measurements by ultrasound of an eye in which the vitreous cavity has been filled with silicone oil. It is common to have pitfalls, especially if the silicone oil has become emulsified.

There are presently two viscosities of silicone oil in use 1,000 cts. silicone oil and 5000 cts.

The 1,000 cts silicone oil slows sound waves to a little more than half the speed (980 m/sec) of normal vitreous and can attenuate the
returning sound wave during ultrasonography. The 5,000 cts silicone oil has higher density and it slows sound waves to approximately 1,040 m/sec.\textsuperscript{9-10}

As far as conventional acoustic biometry is concerned, the speed of sound travelling in SO is significantly slower than in vitreous cavity of phakic eyes; thus rendering a falsely longer axial length (AXL) of SO filled eyes if no correction factor is used.\textsuperscript{8-11}

Multiple studies have suggested that optical biometers are much more predictable compared to the ultrasound biometry.\textsuperscript{8-13} The axial length calculation has been a difficult and complex task until partial coherence interferometry or optical biometers came in use.

The low velocity within the silicone oil causes an erroneous measurement of vitreous cavity depth (VCD). The formula to correct AL in any silicone oil filled vitreous is:

1. \( VCD_{1532} = AL - (ACD + \text{Lens Thickness}) \)
2. \( VCD_{\text{corrected}} = VCD_{1532} \times (1/1532) \times 980 \text{ m/s} \) (or 1040 m/s depending on viscosity of silicone oil used.)
3. \( AL_{\text{corrected}} = VCD_{\text{corrected}} + ACD + \text{Lens Thickness} \)

\((1532\) is the average velocity of sound in aqueous and vitreous)

Each component of the eye had to be individually measured (usually at 1,532 m/sec) and the true axial length calculated using the velocity conversion equation (\( TAL = Vc / Vm \times AAL \)) for the lens thickness and the vitreous cavity. The conversion factor of 0.71 multiplied by the measured axial length has been reported to correct for the apparent increase in axial length induced by silicone oil of viscosity 1300 CST.\textsuperscript{14}

In contrast, using partial coherence interferometry to measure eyes containing silicone oil in the vitreous cavity with the optical Biometer is relatively easy. Under the menu heading, one has to select either “Silicone Filled Eye” or “Silicone Filled Eye – Aphakic” depending upon the status of the eye. Tayaab and his colleagues showed that mean preoperative AXL measured with IOL master was 0.04 \(+/-\) 0.29 mm than post operative measurements after removal of silicone oil from the eyes.\textsuperscript{8}
In absence of an optical Biometer, prior to IOL placement, have the retina specialist first remove the silicone oil. The axial length is then measured in the usual way and intraocular lens power can then be calculated.

**Measuring Axial length**

If the oil filled in the eye is either emulsified or is incomplete, it would move around. In supine position, the silicone oil will rest on the retina while the liquefied vitreous will layer on top of it. This gives rise to multiple retinal echoes which causes difficulty in getting an appropriate axial length measurement.

If the measurements are made while patient is placed supine (as in immersion technique) the ultrasound waves will cross two mediums first the liquefied vitreous and then the silicone oil filled area, this would make it extremely difficult to understand and measure the vitreous cavity depth reliably.

Therefore it is advisable to make the patient sit upright and then perform the biometry. This would make only a single medium in the center though which the ultrasonic waves would pass. In cases of eyes filled with gas or perfluorocarbons, ultrasound echoes are blocked.

In certain eyes it is impossible to obtain the axial length. The following options may then be considered:

(a) Measure axial length of the fellow eye (provided the patient is not one-eyed) (unreliable)

(b) CT-scan image can be used to measure axial length in eyes with incomplete silicone oil fill (high error possible) and

(c) The final option would be to consider the use of standard power IOL.

None of these options would be ideal but it would be as a last resort and not a standard practice. It would be actually advisable to remove the silicone oil and then again calculate the IOL power and then go ahead with the surgery.
Adjustments to intraocular lens power

The index of refraction of silicone oil (1.405) is higher than that of the vitreous gel. Since the index is higher it makes the overall refraction hyperopic by acting as a minus IOL. The more curvature or power incorporated in the posterior surface of the lens, the greater is the postoperative error. If the silicone oil is to be retained in the vitreous cavity at the time of IOL implantation the surgeon should consider adding 3-8 D to the calculated IOL power, depending on lens shape to achieve emmetropia.

Holladay, and others, have recommended that biconvex intraocular lenses should not be placed in patients who have silicone oil in the vitreous cavity. Instead, these patients should have a PMMA convex-plano lens, with the plano side oriented so it is facing towards the vitreous cavity and preferably over an intact posterior capsule. Eyes with the posterior meniscus IOLs experience the smallest change. Thus when silicone oil is filling the vitreous cavity the rule of thumb to arrive at the necessary IOL power is as follows:

(a) Use convexo-plano IOL to minimize effect of silicone oil (add 3 to the calculated IOL power).

(b) If using a biconvex lens, add 6 D to the calculated power.

(c) When silicone oil removal is performed 2-5 D of induced myopia should be expected.

PMMA lenses are a first choice, and silicone lenses should be avoided. A silicone IOL should be avoided in an eye that has undergone prior vitrectomy. Also one piece plate haptic design lenses and lenses with small and ovoid optics should be avoided. Silicone oil can interact with the posterior surface of the IOL in patients with a posterior capsular rent impairing visual acuity as well as fundus visualization both intra and postoperatively. Postoperatively, these patients complain of defective vision and presence of rainbows or haloes around light. Silicone oil adhesion to IOL surface is maximum with the silicone IOL15-16.
The additional power that must be added to the original IOL calculation for a convex plano IOL (with the plano side facing towards the vitreous cavity) is determined by the following relationship, as described in 1995 by Patel and confirmed by Meldrum\textsuperscript{17}.

\[ \text{Additional IOL power (diopters)} = \left( \frac{N_s - N_v}{A_L - A_C} \right) \times 1,000 \]

where:

- \( N_s \) = refractive index of silicone oil (1.4034)
- \( N_v \) = refractive index of vitreous (1.336)
- \( A_L \) = axial length in mm
- \( A_C \) = anterior chamber depth in mm.

For an eye of average dimensions, and with the vitreous cavity filled with silicone oil, the additional power needed for a convex-plano PMMA intraocular lens is typically between +3.0 D to +3.5 D.

**Combined Phacovitrectomy IOL power considerations**

Due to advancement and better microsurgical techniques, the surgeons now prefer a phacovitrectomy which further reduces the number of surgeries. Here the post-operative surprise may be in order depending upon the use of buckle, use of oil and other factors including macular involvement in retinal detachment surgery preoperatively.

Masashi et al\textsuperscript{12} suggested that the mean postoperative predictive error in cases of incipient RD of the superior side and with macula involvement was -1.08 ± 1.32 diopters as measured by IOL master and -1.23 ± 1.39 diopters as measured by A-scan.

Shiraki et al\textsuperscript{13} reported a myopic shift post surgery in patients undergoing phacoavitrectomy for Rhegmatogenous retinal detachment (RRD) and with ERM. The myopic shift was significant up to 0.6 D in patients with RRD. They suggested in addition of +0.5 D to prevent postoperative refractive surprise in patients to prevent such a surprise. They suggested that this was secondary to change in the effective lens position postoperatively.
References


13. Shiraki N, Wakabayashi T, Sakaguchi H, Nishida K. Optical Biometry-Based...


Corneal refractive surgery [including radial keratotomy (RK), photorefractive keratectomy (PRK) and laser-assisted in situ keratomileusis (LASIK)] is now almost 4-5 decades old surgeries. Better techniques, better machines and better algorithms have made sure the refractive surgeries have become more predictable and more and more younger patients opt for this option to have glass independent vision and life. A lot of patients who got operated few decades back are now coming for cataract surgeries. One of the important reasons to have corneal topographer instead of just a keratometry is that if the patient doesn’t volunteer the information, the topographer can raise a red flag regarding the treated corneas.

Corneal refractive surgeries would modify only the anterior corneal curvature but leave the posterior curvature unchanged, thereby altering the normal anterior/posterior curvature ratio. As the standard keratometry would measure only the anterior corneal curvature, the posterior curvature is extrapolated based on the normal anterior/posterior curvature ratio. However, in a previously treated corneal surface, this extrapolation would not be valid. Hence a good strategy for determining post-LVC (Laser vision correction) keratometry is to directly measure both anterior and posterior corneal curvature and thereby calculate the net corneal power. Patients who had previous refractive surgery should be warned about the potential need for refractive correction after their cataract surgery.

**Error in Effective Lens Position Calculation after Refractive Surgery**

Standard IOL power formulae use the axial length and corneal power
to predict the position of the IOL postoperatively. Refractive surgery changes the corneal power but not the depth of the lens, leading to an error in ELP prediction in the standard formulae.

After RK and myopic LVC, the corneal power is decreased and the ELP estimates become too low. This leads to an underestimation of the IOL power that is required. Overestimation of IOL power occurs after hyperopic LVC. Special methods must be used to reduce this error.

Keratometry Error after Radial Keratotomy (RK)

RK was very popular in our country some two decades back mainly because of the low cost. However, with the advent of better refractive surgical options, RK is now almost obsolete surgery. A large number of patients actually report for cataract surgery in recent years. Radial keratotomy (RK) differs from other LVCs in that it would flatten both the anterior and posterior corneal surfaces. It leaves a small central optical zone. The effective optical zone diameter can be significantly smaller than the measurement zone of standard keratometry depending on the number of incisions and length of the same. Therefore, standard keratometry tends to overestimate the true corneal power.

Also, post cataract surgery the incision would swell up due to edema and occasionally complications like opening up of incision has been seen. The corneal edema would cause a central flattening after cataract surgery. Most of this flattening effect resolves over several months, but a residual hyperopic shift can persist for years. Therefore, in post-RK eyes, the true corneal power can only be estimated by taking into account the small effective optical zone and postoperative hyperopic shift.

A surgeon could also choose to use multiple methods and select the flattest or steepest keratometric values in the case of a postmyopic or posthyperopic eye, respectively. Different methods which can be used

1. Clinical history method
   This was first introduced by Holladay in 1989. Corneal power is calculated by subtracting the change in manifest refraction at the
corneal plane induced by the refractive surgical procedure from the corneal power values obtained before refractive surgery.

K=KPRE-RCC

K: calculated corneal power
KPRE: corneal power before refractive surgery
RCC: change in manifest refraction at the corneal plane

This method theoretically yields the actual corneal power and is easy to calculate if the relevant data are available. Problems with this method include unavailability or inaccuracy of these data and interval changes in the corneal curvature or lens power. Also, clinical history method is not suitable for RK because of unstable corneal power (Post RK cornea typically flattens progressively over many years).

2. **Double-K Formulae**
   In the “double-K” version of IOL formula, the post-refractive surgery corneal power reading is used in the vergence calculation while the pre-refractive surgery corneal power (or an estimate of it) is used in the ELP prediction formula. This reduces the error in post-refractive surgery ELP calculation. Double-K versions of SRK/T, Hoffer Q and Holladay II formulae are available. The double-K Holladay II formula allows both a post-RK and a post-LVC setting.

3. **Hoffer Q Formula**
   The Hoffer Q formula estimates a method of ELP calculation that is less sensitive to corneal power variation. It introduces less error in post-refractive surgery eyes than other single-K formulae. If double-K formulae are not available, the single-K Hoffer-Q formula may be useful.

4. **Haigis-L Formula**
   This formula is part of the built-in software of IOLMaster. Corneal power is calculated by inputting IOL-Master biometry as follows: axial length (AL), anterior chamber depth (ACD), and keratometry (corneal radii).
This formula is a regression formula based on statistics. Accuracy may decrease if the eye is on the edge of normal distribution (high myopic or high hyperopic eyes). It is based on LASIK data and only suitable for post-LVC cases, not post-RK cases.

5. **Masket Formula**

\[ P = PTARG - 0.326 \times RCC - 0.101 \]

PTARG: IOL power calculated by standard IOL formulas

RCC: surgically induced refractive change

This method adjusts the power of the IOL, calculated using the postoperative measured data using the knowledge of the surgically induced refractive change. They recommend using the SRK/T formula for myopic ALs and the Hoffer Q for hyperopic ALs.

6. **Koch and Wang Nomogram Adjustment**

Koch and Wang made separate nomograms for both post myopic and hyperopic refractive surgeries. This nomogram is easy to use by just look up at the axial length of the patient and add or subtract the adjusted IOL power to the IOL power calculated using the SRK/T, Hoffer Q, and Holladay 1 formulas

When there is a wide range of recommendations (typically in cases of refractive surgery for high or extreme dioptric correction), it is wise to hedge in the direction of myopic results.

7. **The C constant**

Olson’s formula uses the concept of C constant. The C constant defines the position of the IOL as a fraction of the capsular bag size. This can be calculated with optical biometry. It depends on the anterior segment parameters and the Anterior chamber depth and lens thickness. It works in all type of eyes including post – LASIK eyes.

8. **Online ASCRS Calculator**

It starts with a welcome screen where we have to accept the terms and conditions. (Fig 1) The calculator has been developed by Wareen Hill, Li Wang and Douglas Koch and is presently version 4.8
IOL Power Calculation Post Corneal Refractive Surgery

**Figure 1.** Showing the welcome screen of ASCRS online calculator

Next it gives three options about what type of surgery was done: Myopic LASIK, Hyperopic LASIK, or RK. Once selected, it moves on to that particular type of procedure done and asks for more details regarding the previous surgery and present details of the eye. (Fig. 2)

**Figure 2.** Showing the screen of the online calculator for IOL power in a patient who had undergone myopic LASIK surgery
Once the details are filled in the software calculates the IOL power using various formulas which would be mentioned in the return sheet that is received on pressing the calculate button. (Fig. 3). It gives average of all the formulae used and also what is the minimum and the maximum IOL power received. The surgeon can use his discretion to decide which power he would use.

**Figure 3.** Screen shot showing the IOL Power calculated by the online software (ASCRS)

**Barrett’s True K formula online calculator**

This is one of the most useful formulae for post refractive and RK eyes. The presence is online and is very similar to the ASCRS online

**Figure 4.** The welcome screen. Patient’s data has to be fed here in the software.
IOL Power Calculation Post Corneal Refractive Surgery

The URL is of Barrett’s true K universal formula. (Figure 4). It asks for all the relevant information starting from the patient details and keratometry, axial length, white to white, anterior chamber depth and lens thickness.

Once the data has been put in the online calculator, universal formula and then calculate has to be pressed to get the final answer and to calculate the IOL power formulae in such cases. The formula would immediately generate the IOL power calculation along with the predictive error (Figure 5)

![Barrett True K Formula - For Prior Myopic or Hyperopic LASIK/PRK/RK](image)

**Figure 5.** The figure shows the result of IOL power calculation post myopic eye based on the ultrasonic findings.

Let's see the IOL power calculation it the Barrett II universal formula without putting the details of myopic LASIK. The difference of IOL power would be significant. The same set of data in terms of biometry have been used except that the previous myopic surgery has been removed. The difference in the IOL power is of around 2.0 D (Figure 6)
Figure 6. Shows the IOL power with the same data with Barrett universal II online calculator with previous history of myopic LASIK surgery done. This shows the amount of error that may be resultant if the surgeon is unaware that the LASIK surgery done before.
Cataract surgery is increasingly becoming a refractive surgery. The outcome of the surgery post-operatively is judged by the patient as the amount of residual refractive error. Therefore, achieving a good and thorough IOL power calculation is becoming imperative in modern day cataract surgery. This means that pre-operative evaluation assumes as much or even more importance than the actual surgical performance. A systematic, thorough and repeatable methodology needs to be followed for each patient.

**Keratometry**

Measuring keratometry should be the first investigation in the pre-operative work up, even before putting a drop of local anesthetic or lubricant. This is because the reading are most accurate when taken on a ‘virgin’ cornea. Manual keratometer remains the gold standard when done by a trained ophthalmologist/optometrist. It is important to appose and align both of the mire (figure 1). It gives us lot of information on the regularity of the cornea; frequent breaking up of the mires is likely to be due an unstable tear film and inability to align the mires may be due to irregular astigmatism. A corneal topography is not mandatory or essential in all cases, however whenever there is a doubt of irregular astigmatism, it is always a good idea to confirm the regularity of the astigmatism with any kind of topography/tomography.
Axial Length

Measuring the axial length accurately is probably the most important part of the IOL power calculation. This is because a 1mm change in axial length can cause up to 3 D of refractive surprise. There are various techniques to measure the axial length (contact, immersion, optical biometry). Contact ultrasound biometry has the maximum potential for error as the amount of pressure applied on the cornea can be variable and excessive indentation of the cornea or vice versa can give equally erroneous readings. Therefore, contact biometry in today's current times is best to be avoided.

Immersion ultrasound biometry is more accurate than contact biometry. It is important to confirm the spikes of the different structures of the eye are appropriately identified to decide the reliability of the readings. (figure 2). Immersion biometry has the advantage of being able to get a reading even in the most dense or white mature cataract which is sometimes not possible even with the most sophisticated modern day optical biometers. It also gives data about the lens thickness and anterior chamber depth. However, it is a tedious procedure to perform, requires a skilled trained technician and the patient to lie supine, and be quite messy to perform sometimes.

Optical biometers have truly revolutionized modern day IOL power calculations. This is because they not only give us a more accurate and repeatable axial length reading, but also give us lot of other data like keratometry, anterior chamber depth, lens thickness, white-to-white corneal diameter, etc. This allows a more accurate IOL power calculation with the newer generation IOL calculation formulas. The most commonly used biometers (eg, Lenstar, IOL master 500, etc) are based on the principle of partial coherence tomography. The major limitation for them is that it is difficult to get a good signal strength reading in cases with dense cataracts, white cataracts or even very dense posterior sub capsular cataracts. The newer generations biometers are now based on the principle of “swept source OCT”, which means they are able to penetrate through almost all grades of
cataracts except for the pure mature white cataracts. Additionally, some of them also give additional information about the posterior corneal curvature.

Whatever technique of measurement is used, it is imperative to compare the readings of both eyes, as it is relatively uncommon to have a significant difference in axial length of 2 eyes. A significant difference between the 2 eyes should alert the surgeon to a possible erroneous reading or possibility of amblyopia in one eye.

Also in cases of high myopia, there is always a possibility of a posterior staphyloma. In the presence of a posterior staphyloma, optical biometers are preferred as they are more likely to obtain the correct avail length, as they measure from the macula, compared to immersion biometry techniques which can give falsely longer axial length readings due to fixation issues and erroneous reading taken from the reflections from the optic nerve.

### IOL Calculation Formula

There are several IOL calculation formulas which are now freely available. Each formula has its strengths and weaknesses and therefore it is sometimes confusing for the clinician to decide as to which IOL calculation formula to use in which eye. Older generation formulas like SRK II should be avoided as far as possible. SRK-T works well particularly for most normal axial length and keratometry, however in extremes of axial length and keratometry it is not the most accurate. 4th generation formulas (Barretts Universal II, Holladay2, Haigis-L, Hill RBF) should be used. And the best part about Barretts Universal II formula and Hill RBF formula is that they are available free online for anyone to access and they have been shown to be very accurate across all Axial Length and Keratometry in several peer reviewed studies. The Barretts formula for Toric IOLs also has an inbuilt algorithm to account for the effect of the posterior corneal curvature. Further, every surgeon induces some astigmatism by performing cataract surgery. Therefore it is imperative for every surgeon to know their Surgically Induced Astigmatism (SIA). By incorporating the SIA and the effect
of the posterior cornea, we get the TOTAL astigmatism that the patient will be left behind after the surgery

**IOL Calculation In Post-Refractive Surgery Eyes**

More and more patients operated for refractive surgery before a couple of decades are now coming up for their cataract surgery, and they are the patients who are most desirable of independence from glasses. The ratio between the anterior corneal curvature and posterior corneal curvature is altered in such eyes, and this varies depending on whether a myopic ablation, hyperopic ablation or Radial Keratotomy was done. The regular IOL calculation formulas don’t work very well. There are special formulas designed to take this into account and should be used (eg: Shammas, Barrett True K, Wong-Koch modification, etc). The easiest place to access this is on the ASCRS website which gives a free access to several special formulas specially designed for post refractive surgery eyes. Inspite of this, some of these patients are bound to have unpredictable refractive outcomes, therefore it is best to counsel these patients for a possible residual refractive error after surgery.

**IOL Calculation in Silicon Oil Filled Eyes**

Due to change in the refractive index of silicon oil, the speed of travel of ultrasound is changed. So if axial length is measured with the normal velocity (1532m/sec), it will lead to a false long axial length reading. Therefore we need to change the velocity of ultrasound to about 1032m/sec to get an accurate axial length measurement. Another issue with raised with silicon oil is that the silicon oil bubble acts as a convex surface, which induces a hyperopia in refraction of approximately 3.00DSph to 5.00DSph. So if the silicon oil is not planned to be removed anytime soon, we add approximately +4.0D to the IOL power measured; eg if the IOL power measured in +22.0D, we would implant a +26.0D. In cases where silicon oil removal is planned simultaneously along with cataract surgery or anytime soon, no change is made to the IOL power calculated. Most modern day immersion machines and optical biometers have a ‘silicon oil filled’ mode which has the reduced velocity settings.
Common Causes for Refractive Surprise after Uneventful Cataract Surgery

1) **Incorrect/Inaccurate Axial length measurement**: This still remains the number one cause. With more and more access and availability of newer generation optical biometers using Swept Source OCT technology, this is likely to reduce in the coming few years.

2) **Astigmatism**: Very little attention is given to the TOTAL Astigmatism that the patient is going to be left behind after cataract surgery. Also, there is a need to use IOL calculation formulas which take into consideration the posterior corneal curvature as well.

3) **In-Appropriate IOL Calculation Formula**

How to Tackle a Refractive Surprise

1) Wait for at least 7 days to confirm the refraction. In special cases like Post RK patients, you may need to wait for at least 4-6 weeks for the refraction to stabilize.

4) Treat the case as a fresh new case, take all measurements again. This is because the keratometry will also have changed after the primary surgery.

5) If the refractive error is acceptable to the patient with glasses, then do not intervene. However, if there is a gross refractive error, early surgical intervention maybe required.

6) **PiggyBack IOL**: Usually very predictable and easy to perform. Limitations include cost of the IOL, and possibility of low grade uveal irritation or glaucoma.

7) **Lasik/PRK**: Can be done for moderate refractive errors. However, it must be kept in mind that corneal refractive surgery will induce some amount of corneal aberrations, and this could be detrimental to the quality of vision particularly if there has been a multifocal IOL that has been implanted.
8) **IOL exchange:** This remains the most practical solution particularly for large refractive surprises. Repeat surgery is generally preferred within the first 4-6 week of the primary surgery before fibrosis sets in following which it could be difficult to safely remove the IOL from the capsular bag. Possibility of zonular damage and posterior capsule rupture needs to be counseled to the patient.

Modern day IOL calculation has come a long way in the last 10-15 years, and the addition of better instruments to get accurate pre-operative measurements and equally accurate IOL calculation formulas have made life very easy us the ophthalmologists. Refractive surprises although uncommon, we must always be on guard to prevent it from happening.

![Figure 1](image)

**Figure 1** : Aligning the mires in manual Keratometry
Figure 2: Look for the spiked in immersion/contact ultrasound
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