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# Clinically Relevant Biometry

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## Abstract

**Purpose of review—**Obtaining precise post-operative target refraction is of utmost importance in today's modern cataract and refractive surgery. Given the growing number of patients undergoing premium intraocular lens implantations, patient expectation continues to rise. In order to meet heightened patient expectations, it is crucial to pay utmost attention to patient selection, accurate keratometry and biometry readings, as well as to the application of correct intraocular lens power formula with optimized lens constants. This article reviews recent advances in the field of clinical biometry and intraocular lens power calculations.

**Recent findings—**Recently developed low-coherence reflectometry optical biometry is comparable to older ultrasonic biometric and keratometric techniques. In addition, the new IOL Master software upgrade has improved reproducibility and enhanced signal acquisition. Further, the modern lens power formulas currently determine the effective lens position and the shape of the intraocular lens power prediction curve more accurately.

**Summary—**In order to reach target refraction, precise biometric measurements are imperative. Understanding the strengths and limitations of the currently available biometry devices, allows prevention of high variability and inaccuracy, ultimately determining the refractive outcomes.

### Keywords

Biometry; cataract surgery; refractive surgery; keratometry; intraocular lens calculation

## Introduction

Intraocular lens (IOL) power calculation is a crucial step in achieving the desired target refractive outcome, which is a major aim of modern day cataract surgery. Numerous devices and formulas are currently available, allowing accurate determination of the IOL power needed to reach the target refraction.[1–3,4**,5*,6–9,10*,11–16, 17*–18] In order to accomplish target refraction, axial length (AL), anterior chamber depth (ACD), and corneal radii (K1and K2) need to be accurately measured. Moreover, proper choices of IOL power calculation formulas are important, as are the use of accurate IOL constants, depending on the type of IOL and post-operative IOL location. Over the last decade, significant developments have been made, which have led to improvements in the predictability of the refractive outcomes. These include stable in-the-bag IOL placement that ensures stability and more predictable IOL positioning, as well as modifications in IOL power calculation formulas.[1, 2] In addition, recent developments in the biomedical field have led the

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availability of novel devices, such as the laser partial coherence interferometry (PCI) and the low-coherence optical reflectometry (LCOR).[15, 19] To date, A-mode ultrasound biometry had been considered the gold standard for AL and ACD measurement. The PCI-based IOLMaster (Carl Zeiss Meditec AG, Jena, Germany) was introduced in 1999. More recently, a new biometry device, the Lenstar LS 900 (Haag Streit AG, Bern, Switzerland) using LCOR technology was introduced in 2008. Given the heightened patient expectations, it is of utmost importance to accurately predict the correct IOL power. The recent technological developments have stimulated continuous modifications in biometry. This article reviews recent studies and advances in the field of clinical biometry.

## Contact Ultrasound Ocular Biometry

A-mode contact ultrasound ocular biometry has been considered the gold standard for decades. A special crystal embedded in a probe oscillates to generate a high-frequency sound wave that penetrates the eye. This results in a one-dimensional time-amplitude representation of echoes received along the beam path. The distance between the echo spikes recorded on the oscilloscope screen provides an indirect measurement of tissue such as globe length or lens thickness (LT). The height of the spike is indicative of the strength of the tissue sending back the echo. There are two types of A-mode ultrasound biometry available, including contact applanation biometry and immersion biometry. Contact type biometry requires a probe placed on the cornea and is prone to errors due to corneal indentation and off-axis measurements. It also carries risk of transmitting infections. Immersion type biometry requires placing a saline filled scleral shell between the probe and the eye. As no pressure is applied on the eye, corneal indentation is prevented.

## Non-Contact Optical Biometry

Optical biometry for accurate assessment of the AL is increasingly becoming popular, as it is rapid, easy to use, and a contact-free method. The PCI-based IOLMaster uses a 780 nm laser diode infrared light to measure AL (Table 1).[15] The ACD is measured through a lateral slit-illumination with this device, and the anterior corneal curvature is calculated at 6 reference points in a hexagonal pattern at approximately the 2.3 mm optical zone. The new Lenstar LS 900 is LCOR-based and uses a 820 nm superluminescent diode (Table 1).[19] In addition to AL, it measures central corneal thickness (CCT), as well as LT. ACD measurements differ between the IOLMaster and the Lenstar, as Lenstar measures ACD from the corneal endothelium to the anterior lens surface while IOL Master measures ACD from corneal epithelium to the anterior lens surface. The Lenstar also measures crystalline LT and retinal thickness, as well as the size and centricity of the pupil.[19] K readings are calculated by analyzing the anterior corneal curvature at 32 reference points orientated in 2 circles at approximately the 2.30 mm and 1.65 mm optical zones.

These IOL Master and Lenstar LS 900 are in good agreement in terms of mean AL, ACD, and K readings (Table 2).[9, 19–25] The mean difference in AL measurements was only 0.01 mm ± 0.05 (SD) between these two devices (p=0.12). The LCOR-based device measures more parameters than the PCI-based device, including CCT, retinal thickness and pupil diameter. While this is an advantage, measurements with the LCOR-based device take twice as long as those with PCI-based device.[20] Although these optical biometry devices are easy-to-use, their main disadvantage, in our experience, is the failure to provide AL measurements in dense subcapsular cataracts. As they use a laser beam, rather than an ultrasound wave, dense cataracts do not allow the laser beam to reach the retina and reflect accordingly. This issue has previously been reported in several other studies. [19, 25] Thus, we recommend having an A-scan ultrasound biometry device, in order to overcome this obstacle.

## Refractive Power Measurement of the Cornea

Measuring corneal power is always puzzling, as neither manual nor automated keratometers can directly measure the “true” corneal power. Instead, the cornea is assumed to be an spherocylinder with a fixed anterior to posterior corneal curvature. A very fundamental problem in the design of manual and automated keratometers is that they do not provide sufficient information to determine corneal shape accurately. A well-lit target is placed in front of the cornea, which acts as a convex mirror and produces a virtual image of the target. The corneal radius of curvature may then be predictable from this, provided several statements are valid (the cornea is presumed to be spherical; paraxial optics is assumed; the power of the back corneal surface is estimated). Nonetheless, the obtained results are very diminutive. While in most healthy eyes corneal power is relatively easily calculated,[26**] eyes with prior refractive surgery pose a particular challenge. With the change in anterior and posterior corneal curvature in these eyes, the corneal refractive index (n=1.3375) is no longer accurate. Thus, the corneal power is underestimated in these eyes due to corneal flattening, which in turn leads to overestimation of corneal power and a hyperopic refraction after cataract surgery.[26,27]

Computerized videokeratography may be superior to manual keratometers in assessing corneal power in post-refractive surgical eyes. Holladay et al.[27] evaluated the accuracy of central corneal power measurements by Scheimpflug imaging (Pentacam) for eyes that had undergone refractive surgery. They used historical method to compute the theoretical postoperative keratometry (K)-reading, which was then compared to the measured equivalent K-reading (EKR) from the Pentacam. The mean prediction error for the pilot group was −0.06 ± 0.56 diopters (D). Using the 4.5-mm zone determined in the pilot group, the EKR value for the test group of 41 radial keratotomy eyes had a mean prediction error of −0.04 ± 0.94 D (range: −1.84 to ± 2.27 D). They concluded that Scheimpflug imaging with the Pentacam provides an alternative method of measuring the central corneal power in eyes that previously received corneal refractive surgery. In another study by Tang et al.,[28] accuracy of Pentacam EKR readings was found to be inaccurate in virgin corneas as well as in those with a history of laser in-situ keratomiluesis (LASIK), photorefractive keratectomy (PRK), or radial keratotomy (RK). The Pentacam power measurements were consistently steeper than the true corneal power. Kim et al. used true net corneal power of the Pentacam system to provide keratometry readings in eyes, who had previously undergone refractive surgery.[29] The mean deviation from the desired postoperative cataract refractive outcome was 0.47 ± 0.56 D. Jin et al. calculated corneal power by using Gaussian optics formula in post-refractive surgery eyes.[30] Using this calculated K for IOL power calculation in post-refractive cases yielded mean absolute prediction errors of 0.58 ± 0.52 D (Haigis), 0.59 ± 0.49 D (double-K Hoffer Q), and 0.58 ± 0.47 D (double-K SRK/T). Arce et al.[31] applied the method developed by Sonego-Krone et al.[32] using the Orbscan II in eyes with previous myopic and hyperopic refractive surgery. The corneal power in this study represents the average of all points obtained from the Orbscan II total mean-maps within the central 2-mm diameter as measured directly from corneas with previous refractive surgery. The overall difference between the calculated and achieved refraction (0.12 ± 0.93 D, P=0.27) was 1.00 D in 77% of eyes and 2.00 D in 96% of eyes. They concluded that keratometer readings could be performed with reasonable accuracy using the Orbscan II central 2-mm total-mean power in eyes with previous corneal refractive surgery. However, this method yielded better outcomes in eyes with previous RK, myopic LASIK, and myopic PRK, as compared to eyes with hyperopic LASIK or RK with LASIK. In addition, the average power from the central 4-mm zone of the total-optical map also reflected accurately the refractive change after myopic LASIK.[32]

Reduced accuracy of IOL calculations after corneal refractive surgery is a clinical problem of growing importance. There are several methods in the literature to evaluate the corneal power after refractive surgery, including the clinical history method (vertex corrected to the corneal plane), the contact lens over-refraction method, and the Aramberri double-K method, the Latkany Flat-K. Although these methods offer better accuracy in postrefractive surgery eyes, pre- and post-operative K values and/or refraction are still required before cataract surgery, which is time consuming to perform. To save time, Wang et al.[33**] developed an Internet-based IOL power calculator for eyes with previous LASIK, PRK, or RK. Methods using pre-LASIK/PRK keratometry (K) and surgically induced change in refraction, methods using surgically induced change in refraction, and methods using no previous data were evaluated. They found that methods using only surgically-induced changes in refraction, resulted in superior outcomes as compared to methods using pre-LASIK/PRK K values and surgically induced change in refraction. In a recent study by McCarthy et al.[34**] methods of IOL power calculation after myopic laser refractive surgery were compared in a large, multi-surgeon study. The top 5 corneal power adjustment techniques and formula combinations were the Masket with the Hoffer Q formula, the Shammas.cd with the Shammas-PL formula, the Haigis-L, the Clinical History Method with the Hoffer Q, and the Latkany Flat-K with the SRK/T. They concluded that, by using these methods, 70% to 85% of eyes could achieve visual outcomes within 1.0 D of target refraction.

Taken together, it has been widely suggested that it is logical to use several different methods in determining corneal power rather than trusting simply on any one method alone.

## Anterior Chamber Depth Measurement

Most of the modern IOL power formulas depend on ACD measurements in order to increase the accuracy of the IOL power prediction curve. Hence, accurate measurements are crucial to lessen the possibility of undesirable refractive outcomes. All modern biometry devices, as well as slit-scanning videokeratography (Orbscan), Scheimpflug imaging (Pentacam), and anterior segment optical coherence tomography (AS-OCT) are capable of measuring ACD.

There are several studies, which compared ACD measurements between various biometry devices (Table 2).[20, 22, 35–38] Salouti et al.[22] compared ACD readings obtained by Lenstar LS 900, IOLMaster, and A-mode biometry. The ACD measurements obtained by IOLMaster were slightly smaller than those obtained with other devices, demonstrating 3.14 ± 0.40 mm (range: 2.30 to 4.27mm) with A-mode biometry; 3.07 ± 0.42 mm (range: 2.10 to 4.16mm) with IOLMaster; 3.17 ± 0.42 mm (range: 2.19 to 4.51mm) with Lenstar. However these differences were not statistically significant (P= 0.09). The mean difference was 0.07 ± 0.19 mm between A-mode biometry and IOLMaster; −0.03 ± 0.24 mm between A-mode biometry and Lenstar, and −0.10 ± 0.26 mm between IOLMaster and Lenstar. It was found that Lenstar LS 900 consistently gave slightly higher ACD readings, although not clinically significant, compared with those of the IOLMaster. This finding is similar to other studies in which a similar difference was found.[9, 19, 24] Chen et al.[20] compared ACD measurement performed by IOLMaster with the present gold standard A-mode biometry. They found that mean ACD reading was 3.13 ± 0.58 mm (range: 2.26–5.14 mm) with IOLMaster and 3.12 ± 0.49 mm (range: 2.27–4.10 mm) with A-mode biometry. There was a very small difference of 0.00 ± 0.05 mm between these two devices. One of the limitations of that study is that although they included Lenstar LS 900 in their study, they did not include mean ACD readings obtained by this device in their analyses. Salouti et al.[38] reported a mean difference of 0.32mm and 0.30mm between Orbscan-Galilei (dual Scheimpflug system; Zimmer Ophthalmics, Port, Switzerland) and Orbscan-Pentacam, respectively. However, this difference was only 0.02 mm between Pentacam and Galilei.

These data indicate that Orbscan gives consistently higher measurements for anterior chamber depth compared with Galilei and Pentacam. Therefore, they are not interchangeable in every clinical situation. It is important to note that the ACD measuring module of the IOLMaster should not be used to determine the ACD in a pseudophakic eye, as the evaluation software is only designed for phakic eyes. The evaluation algorithms expect scattered light from the crystalline lens, while IOLs essentially produce strong reflections, which will be interpreted erroneously. Pseudophakic ACDs will thus give results, which are faulty and unreliable, as is described in the IOLMaster user manual.[8]

## Axial Length Measurement

Differences in axial length measurements have a substantial influence on the final calculated IOL power. There are numerous studies comparing IOL Master and Lenstar LS900 with A-mode biometry (Table 2).[9, 18, 20–24, 39] In a recent study by Jasvinder et al. [23] a strong inter-method agreement (only 0.01 mm AL difference) was found between IOLMaster and Lenstar in phakic eyes. There was a mean difference of 0.04 mm between Lenstar-immersion biometry and 0.188 mm between Lenstar-A-mode contact biometry. A similar difference was found in mean AL readings between devices in a recent study by Salouti et al.[22] with good agreement. Montes-Mico et al.[39] reported that measurements between IOLMaster, Lenstar, and immersion biometry were highly correlated for axial length (R=0.99) in cataract patients. There was no statistically significant difference between devices in terms of mean AL values.

## Intraocular Lens Power Calculation

Though there are significant improvements in biometry devices in terms of technological developments, there is still an ongoing debate about which IOL power calculation formula best predicts actual post-operative refraction. There is not a single formula, which is suitable for all eyes. Therefore, it is important to know the strengths and weaknesses of the modern IOL power calculation formulas widely used in ophthalmic practice, in order to choose the most appropriate and accurate one that fits to a particular patient. The latest third-generation formulas are Hoffer Q, Holladay, and SRK/T. They all use thin-lens formulas, which reduces IOLs to thin lenses of infinite thickness with only one effective lens plane (ELP). What differentiates these formulas is the method by which the ELP is predicted. In a recent study, Aristodemou et al.[4**] calculated hypothetical prediction errors on prospectively collected data using optimized Hoffer Q, Holladay 1, and SRK/T formulas. The Hoffer Q performed best for ALs from 20.00 to 20.99 mm, the Hoffer Q and Holladay 1 for ALs from 21.00 to 21.49 mm, and the SRK/T for ALs of 27.00 mm or longer. Jin et al.[3] compared the accuracy of the thin-lens and ray-tracing formulas in IOL power calculations in normal and post-refractive surgery eyes. They concluded that thin-lens formulas were as accurate as the ray-tracing method in IOL power calculations in these eyes. However, their MAE values were considerably higher than those found in recent studies using optical biometry.[1] Olsen attributed these high MAEs to the incorrect use of the algorithm for the ACD prediction, which today is regarded as the major source of error in IOL power calculation.[40] The only ACD formula that has been based on ACD measurements using the IOLMaster is the Haigis formula. The Haigis-L formula is quite different from these two variable formulas mentioned above in that it uses three different constants and a measured ACD, in order to more accurately determine the ELP. It doesn’t require corneal power values in the calculation formula; hence, errors in measuring K values are avoided. However, the main pitfall is that the constants must be originated by a regression analysis.

The individual steps of the SRK/T formula were examined with reference to a database of biometry and refractive outcomes in 11.189 eyes by Sheard et al.[5*] They observed a

nonphysiologic behavior in the calculation of corrected axial length and corneal height. They developed the T2 formula using a regression formula for corneal height derived from the development subset and they concluded that any surgeon who uses the SRK/T formula could switch to using the T2 formula and improve refractive outcomes by 10%.

## Conclusion

Modern technology has significantly improved our ability to accurately measure ocular biometrical parameters. Hence, today, we are more confident fulfilling patient expectations. However, it is still very important to pay attention to appropriate patient selection, accurate keratometry and biometry, and right IOL power formula selection. Eventually, the highest variable parameter is going to establish the outcome. In order to increase accuracy in ocular biometry practice, one must have sought the following realizations: properly calibrated instrument and an experienced operator, repeating measurements, using optical biometry rather than contact biometry, using last generation IOL formulas and tailoring the IOL constants accordingly, evaluating refractive outcomes regularly, and following modern up-to-date surgical techniques such as good sizing in capsulorhexis. By following each step carefully in pre-, intra-, and post-operative algorithms, understanding strengths and weaknesses during all these steps, successful outcomes are achievable.

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**Key points**

- Ocular biometry is one of the most important steps before cataract surgery.
- Non-contact optical biometry is easy-to-use, accurate, and a highly reproducible method.
- Ophthalmologists should know the strengths and weaknesses of each device.
- Choosing the right IOL power calculation formula for patients who had previous corneal refractive surgery is still debated.

**Table 1**

Comparison of technical specifications of new optical biometry devices.

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

PCI: Partial coherence interferometry

LCOR: Low coherence optical reflectometry

**Table 2**

Table showing mean differences in terms of mean Axial Length, Anterior Chamber Depth, Keratometry and Intraocular Lens Power and limits of agreement between biometry devices.

| | **Mean differences and limits of agreement (LoA) between biometry devices** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Axial length (mm)** | **LoA** | **ACD** | **LoA** | **Keratometry (D)** | **LoA** | **IOL Power (D)** | **LoA** |
| Jasvinder et al.[23] LCOR-PCI | 0.01 ± 0.03 | −0.04 to 0.07 | N/A | N/A | −0.11 ± 0.18 | −0.45 to 0.59 | 0.07 ± 0.26 | −0.44 to 0.24 |
| Hoffer et al.[21]LCOR-PCI* | 0.026 | −0.05 to 0.10 | 0.128 | −0.12 to 0.38 | −0.107 | −0.46 to 0.25 | | |
| Hoffer et al.[21]LCOR-PCI** | 0.023 | −0.05 to 0.099 | 0.146 | −0.33 to 0.63 | −0.121 | −0.54 to 0.30 | | |
| Salouti et al.[22]US-PCI | −0.01±0.09 | −0.18 to 0.16 | 0.07±0.19 | −0.29 to 0.44 | −0.05±0.27 (Javal vs. PCI) | −0.58 to 0.48 (Javal vs. PCI) | −0.01±0.33 (SRK/T) | −0.66 to 0.64 (SRK/T) |
| Salouti et al.[22]US-LCOR | 0.002±0.07 | −0.14 to 0.14 | −0.03±0.24 | −0.50 to 0.44 | 0.61±0.30 (Javal vs. LCOR) | 0.01 to 1.20 (Javal vs. LCOR) | 0.10±0.40 (SRK/T) | −0.68 to 0.88 (SRK/T) |
| Salouti et al.[22]PCI-LCOR | 0.01±0.07 | −0.12 to 0.14 | −0.10±0.26 | −0.60 to 0.40 | 0.65±0.27 (PCI vs. LCOR) | 0.07 to 1.20 (PCI vs. LCOR) | 0.11±0.40 (SRK/T) | −0.67 to 0.89 (SRK/T) |
| Chenat al.[20] | 0.01±0.05 | −0.09 to 0.11 | N/A | N/A | −0.08±0.15 | N/A | N/A | N/A |

*Cataract eyes,

**Clear lenses

PCI: Partial coherence interferometry, LCOR: Low coherence optical reflectometry

LoA: 95% limits of agreement

ACD: Anterior chamber depth