IOL Calculation in Vitreoretinal Pathology and Surgery

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Jaime Aramberri

Introduction

Pars plana vitrectomy (PPV) has become a frequent surgery indicated in the treatment of many vitreoretinal pathologies: retinal detachment (RD), epiretinal membrane (ERM), macular hole (MH), vitreous hemorrhage, etc. Cataract surgery will soon be needed in 1–2 years as up to 80% of cases will develop this condition [1]. In the Eurequo database, December 2018, from 1,715,348 reported cataract surgeries, 1.1% had previous PPV [2]. Moreover, the combined cataract and PPV procedure, phacovitrectomy, has proved to be a very safe and effective procedure and is being performed as their primary technique by many vitreoretinal surgeons [3, 4].

These eyes present unique challenges to the IOL calculation process that have to be recognized and corrected especially in this era of high demand of accurate refractive predictions motivated by the good functional outcomes of cataract and PPV surgeries plus the introduction of new EDOF and multifocal IOLs, where success depends directly on an emmetropic refractive result.

J. Aramberri (✉)
Miranza Ókular Clinic, Vitoria-Gasteiz, Spain

Miranza Begitek Clinic,
Donostia-San Sebastian, Spain

Axial Length Measurement

Axial length (AL) measurement is more prone to present some error in eyes with macular pathology and when the vitreous cavity's content differs from the natural vitreous humor. These factors will affect ultrasound (US) and optical measurements differently.

In US biometry, a probe containing a transducer is manually aligned with the eye by the operator and a 10 MHz sound beam is emitted through the globe generating echo spikes at each boundary of media with different acoustic densities: anterior and posterior cornea, anterior and posterior lens capsule and retina. The device measures the time between spikes that limit each eye compartment and multiplies by the US velocity of the medium to calculate the linear distance. The higher the medium material density, the higher the US velocity is. Usual values are 1532 m/s for the anterior and vitreous chambers and 1641 m/s for the cornea and lens [5]. The retinal echo spike is generated by the internal limiting membrane (ILM) which is around 0.2 mm before the photoreceptors (Fig. 68.1). This distance is compensated by the IOL formulas. There are two different techniques, applanation and immersion US biometry, with differences in AL up to 0.2 mm shorter with applanation [6] due most probably to corneal compression and thus not affected by any vitreoretinal condition. However, if any retinal tam-

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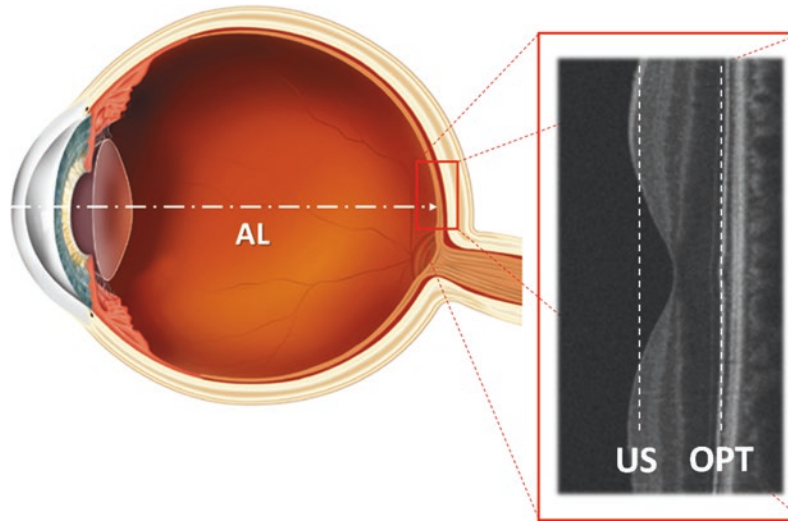

Fig. 68.1 The retinal reflection plane is different for ultrasound (US) and for optical biometry (OPT). Internal limiting membrane for the US and pigment epithelium for the OPT

ponade agent, gas or silicone oil, is in the vitreous cavity the exploring patient position, upright in contact and supine in immersion, might have an effect on the measurement.

In optical biometry, a beam of infrared light is projected into the eye and the reflected light generates an A-scan with spikes at the boundaries of media with different optical densities in the case of Time-domain interferometry (partial coherence interferometry (PCI) and optical low coherence reflectometry (OLCR)) and a B-scan image in the case of Swept Source-OCT (SS-OCT) [7]. The speed of light cannot be measured in the way it is done in the US biometry, but interferometry allows measuring the optical path length (OPL), also called air-distance, that is finally converted to linear distance following this formula:

$$AL = OPL / n \qquad (68.1)$$

where n is the index of refraction of the measured medium.

In the first PCI device, The IOLMaster® (Carl Zeiss-Meditec), the lens position could not be measured and thus segmental biometry could not be done. Another source of difficulty was that the retinal spike was generated in the retinal pigment epithelium (RPE), around 200 μm posterior to the US biometry retinal reference plane. In order to achieve an agreement with the gold standard at that time, the US immersion biometry, the IOLMaster was calibrated to match that technique's measurements with a regression equation [8]:

$$\mathrm{AL} = \left(\mathrm{OPL} / 1.3549 - 1.3033\right) / 0.9571 \qquad (68.2)$$

Since then, this calibration has been the standard in optical biometry. Even with the evolution of new technologies that could finally measure the lens capsular positions allowing segmental biometry, like OLCR and SS-OCT devices, this standard has continued in order to keep the *Status Quo* with formulas and IOL constants developed for the original IOLMaster calibration. Recently, the debate has been opened and there is one SS-OCT biometer, Argos® (Movu), performing segmental biometry where the length of each eye segment is calculated using Eq. 68.1. Obviously, formulas will have to adapt if this becomes a new standard [9].

The optical biometry is clearly superior to US biometry in terms of accuracy and precision: The resolution is two orders of magnitude higher, the repeatability is one order of magnitude higher and the fixation light targeting ensures the visual axis is being measured [7, 10]. The only advantage of US biometry is that all cataracts can be measured, while optical biometry fails in certain cases due to opaque media.

Macular Thickening

In the case of macular thickening, US biometry will underestimate optical AL, overestimating IOL power and leading to a myopic result with a magnitude of 0.10–0.70 D as reported [11]. Kovacs et al. described a mean macular thickening of 142 μm and a decrease in AL of 0.20 mm in a series of macular edema and epiretinal membrane (ERM) cases. The observed prediction error was 0.72 D [12]. In a similar study, Sun et al. reported a macular thickening of 129 μm with an AL decrease of 0.13 μm [13]. This problem should not be found in optical biometry as the retinal reflection originates in the pigment epithelium, and therefore, it is not affected by macular thickening. However, there are several reports of similar measurement errors. Falkner-Radler et al. presented a myopic predictive error of 0.37 D in 40 eyes with macular disease. The error was higher in the case of ERM than in the case of macular hole. It was also higher in cases of gas tamponade [14]. Kojima et al. described a plausible reason for AL error with the old IOL Master: 18.9% of cases presented a double peak in the retina, where it seems logical that the anterior peak corresponds to the ILM-ERM and the posterior to the RPE, as the distance showed good correlation with the OCT measured macular thickness [15]. Kitaguchi defined a "hidden double-peak" also with the IOL Master 5.4 in a case with myopic predictive error. The analysis of all the A-scans showed a double-peak in 8 of 20 scans. The distance between peaks was 0.6 mm, and the attributed refractive error was 0.32 D [16]. We have found similar cases of ERM with Lenstar®, Haag Streit, where a double-peak can be identified in the A-scan image. The software can automatically set the retinal gate at the first peak underestimating the AL (Fig. 68.2).

The magnitude of this refractive error is small and will depend on the AL and IOL power: 0.1 mm of AL error will produce 0.35 D of refractive error in the spectacle plane in a short eye (21 mm) while it will only induce 0.15 D error in a long eye (30 mm) (Fig. 68.3). There is some variability in the reported macular thickening in the case of ERM as there is no standard method to measure the OCT image. In a metanalysis by Huang et al. (535 eyes from 8 studies), the macular thinning after vitrectomy ranged between 68.6 μm and 179 μm [17]. Considering an average 123 μm error, the refraction error would be 0.42 D in a 21-mm eye and 0.18 D in a 30-mm eye.

The proposed solution to correct this error is to add the thickened macular value to the measured AL. If there are two clear peaks in the A-scan, the gate that determines the retinal plane should be manually moved to the posterior peak. This value can be checked with a retinal OCT image; as an alternative option, Sun proposes using the macular thickness of the normal eye [13].

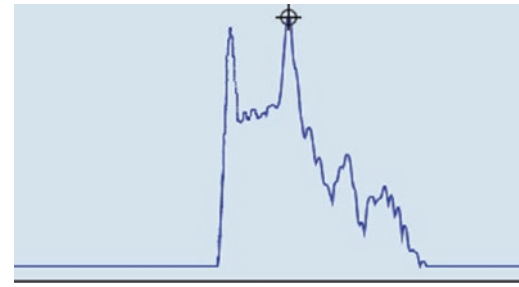

Fig. 68.2 Magnification of the retinal peak. Double-peak produced by ERM. The reference has been manually moved to the posterior peak

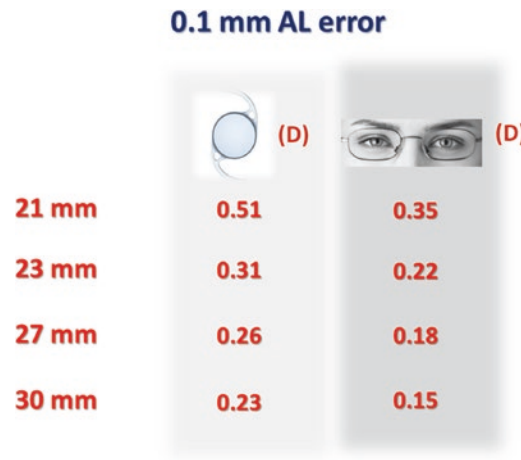

Fig. 68.3 Paraxial calculation of the effect of 0.1 mm AL error in the IOL and spectacle planes for 4 different AL values. IOL position is adapted to the AL and K = 43.5 D

Vounotrypidis et al. compared the IOLMaster 500, PCI, with the IOLMaster 700, SS-OCT, in 79 eyes that underwent phacovitrectomy for macular pathology. The agreement was very good, and there was no difference in the refraction mean prediction error with the Haigis formula. The standard deviation and the mean absolute error were a little lower with the IOLMaster 700 ($p < 0.05$). Curiously, a difference was found in the eyes with ERM and macular hole, while in the eyes with vitreomacular traction syndrome, there was no significant difference [18].

Macula-Off Retinal Detachment

In case of retinal detachment (RD), the macular state will affect the accuracy of the AL measurement. If the macula is detached (macula-off), both the US A-scan and the optic biometry will tend to underestimate the AL (Fig. 68.4). In both cases, the signal reflected from the anteriorly located retinal internal surface will cause this error. With optical biometry, this can occur even with a high signal-to-noise ratio (SNR) as shown by Lege et al. in the first years of the IOLMaster. In a case of macula-off RD, they obtained a measurement with a SNR of 6.5 where the AL was 1.30 mm shorter than the one measured with B-scan US [19]. Optical biometry will more often fail to measure AL and the other biometric parameters than in normal eyes. Even with the new SS-OCT, the failure rate is significant. Liu et al. reported 28.6%, 22.2%, and 14.3% failure rate for AL, anterior chamber depth (ACD), and lens thickness (LT) in 63 eyes with macula-off RD measured with IOLMaster 700 [20].

The most reliable method in such cases is the vector-A/B-scan US biometry. A horizontal B-scan is taken imaging simultaneously the cornea, anterior and posterior lens capsules, and the optic nerve. Then, a vector is overlaid intersecting the central cornea, lens, and macular area. With this technique, Abou-Shousha et al. reported similar measurements to postoperative (PO) IOLMaster numbers in 100 eyes. The mean difference with preoperative applanation vector-A/B-scan US biometry was 0.08 mm. On the other hand, both preoperative A-scan US biometry and IOLMaster biometry measured a shorter AL; 0.82 mm with the former and 0.79 mm with the latter. Depending on the AL used for the IOL power calculation, the PO refraction would have been within ±1.00 D of prediction in 50% of cases with US A-scan, 57% with the IOLMaster, and 83% with applanation vector-A/B-scan US biometry [21]. Rahman

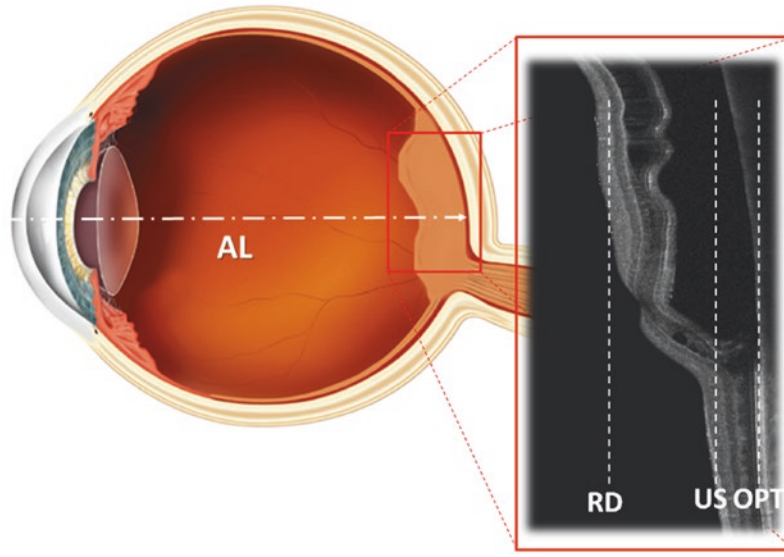

Fig. 68.4 Both US and PCI will measure a shorter AL if the detached retinal signal is used as reference for the retinal plane

et al. reported similar results in 54 cases of macula-off RD where the optical biometry with the IOLMaster (v.5.4) underestimated the AL value by 0.98 ± 1.55 mm as compared to US biometry. They noticed some correlation between bullous RD and a higher level of AL underestimation [22]. In 2016, Rahman et al. proposed a solution by selecting a more posterior peak in the IOLMaster display. With this method, they achieved equaling the preoperative measurement to the PO measurement with a mean difference of 0.049 ± 0.144 mm in 13 eyes [23].

If immersion US is done in supine position, the error might be smaller as the retina sinks closer to its natural position by gravity. This probably explains the lack of difference, 0.03 ± 0.63 mm, between preop and PO measurements reported by Pongsachareonnont et al. in 16 cases of macula-off RD with immersion US biometry, while the IOLMaster presented a difference of 0.98 ± 1.02 mm [24].

Another option is to use the AL of the fellow-eye if there is refractive symmetry. El-Khayat et al. reported a refraction prediction error of −0.01 ± 1.09 D in contrast to the actually measured AL with a value of −1.22 ± 2.32 D. In the first group, 71.4% of eyes where within ±1.00 D of error while in the second group, this was 58.5% [25].

Scleral Buckling

Although PPV is the most common technique for the treatment of RD, scleral buckling with scleral implants is still a popular procedure with a high success rate, especially in developing countries due to a lower cost. The indentation of the eye wall layers beneath the retinal break, and the drainage of subretinal fluid will close the defect and reduce the vitreoretinal traction, leading to the resolution of the RD. This anatomical modification will change several biometric parameters affecting refraction: The encircling circumferential buckling will elongate the eyeball with an AL increase between 0.44 and 1.20 mm in the short term. This variability can be explained by differences in surgical techniques and analyzed population samples [26, 27]. Lee et al. reported a long-term AL increase, 26.05 ± 11.39 months follow-up, of 1.28 mm in low myopes and 1.40 mm in high myopes. An AL threshold value of 26.5 mm was used to define these two groups [26]. Albanese et al. studied 34 eyes phakic eyes with a mean follow-up of 50.9 ± 21.9 months reporting an AL increase of 0.83 mm (95% CI 0.72–0.95). The myopic shift was 1.35 D. The fellow eye experienced an AL increase of 0.08 mm (95% CI 0.00–0.16) in the same period of time [28].

The optical effect of this AL increase will depend on the AL of the eye: 1 mm will change refraction around 2.60 D in an average eye (AL = 23.75 mm), 3.5 D in a short eye (AL = 21.00 mm), and 1.5 D in a long eye (AL = 30.00 mm).

The ACD will decrease after scleral buckling surgery with some variability in the magnitude: from 0.09 to 0.52 mm. It has been argued that this change can be attributed to the anterior movement of the iris-lens diaphragm due to some choroidal effusion [27]. It is not clear if this will have any effect on the IOL position after cataract surgery.

Astigmatism is reported to increase after this surgery, especially if radial buckles are in use [29]. The induced astigmatism seems to be much variable, probably depending on the size and position of the scleral implant. The effect decreases through the first PO year. This should be considered if a toric IOL is planned shortly after retinal surgery.

Vitrectomized Eyes

After vitrectomy, the vitreous cavity is filled with aqueous humor. This will not affect US biometry as US speed seems to be similar in both elements. The water content of the vitreous humor is very high, with a value around 1532 m/s [30], and hence, there is no need to adjust this parameter for the vitreous compartment using US. However, light speed could experience some difference: it is not clear if there is a change in the index of refraction of vitreous after vitrectomy, but if the

IOLMaster calibration works under the assumption of equal indices and the actual index decreases after vitrectomy, there might be an error in the optical biometry measurement of the vitreous segment which is around 70% of the total length. The AL will be underestimated because the biometer is not aware of this index of refraction difference. More research is needed to clarify this point. This error will add to the model error as later explained below.

Silicone Oil

The use of silicone oil as tamponade agent has expanded from the initial indication of complex RD (such as RD with proliferative vitreoretinopathy and diabetic tractional RD) to other retinal conditions like macular hole, myopic foveoschisis, optic disk pit, uveitis, etc. [31]. There are various silicone oils with different physicochemical properties (Table 68.1): The most frequently used ones are polydimethylsiloxanes (PDMS), that float within the vitreous cavity as they are lighter than water (specific gravity 0.97 g/cm^3). The reported index of refraction is 1.4.

Cataracts are frequently developed after vitrectomy with silicone oil endotamponade, and therefore, biometry must be performed after they are used. The presence of this material will affect this measurement as both US and light speed are different from the vitreous humor.

The induced error will be higher in US biometry, where the acoustic density of the silicone oil will determines a US speed lower than vitreous: 972–980 m/s in the 1000 cSt and 978.5–1040 m/s in the 5000 cSt silicone oil [33]. If the normal measuring mode is used with the regular 1532 m/s US velocity for the vitreous compartment, the AL will be overestimated. The simplest solution is to adjust the vitreous humor speed correcting the value. If the software cannot be accessed, the corresponding segment can be recalculated with the following formula:

$$\text{VC correct} = \text{VC}(1532) * (\text{US speed SO} / 1532)$$

where VC correct is the correct vitreous chamber length, VC(1532) is the vitreous chamber length measured with the regular US speed, and US speed SO is the US speed of the silicone oil within the eye. E.g. If the measured vitreous length is 22 mm and the silicone oil speed is 980 m/s: VC correct = 22(980/1532) = 14.07 mm.

Sometimes, there are different fluid segments within the vitreous chamber if the anterior vitreous has not been completely removed or if the silicon oil only partially fills the cavity, leaving a so-called retrosilicone space, which will be especially manifest if the biometry is done in supine position. This problem can be overcome by measuring the eye in the upright position, so that the silicone oil occupies the whole antero-posterior axis (Fig. 68.5).

Another issue can be the emulsification of silicone oil that occurs typically with low viscosity oils: Multiple oil drops will generate decreasing echo spikes not allowing the identification of the retinal signal. This adds to the fact that silicone oil sound absorption is high and the signal is attenuated as it travels through the fluid.

Table 68.1 Physico-chemical characteristics of silicone oils

Silicone oil tamponades	Chemical composition	Viscosity (centistoke)	Specific gravity (g/cm^3)	Interfacial tensión (mN/m)	Refractive index
Conventional SO					
1000 cSt SO	100% PDMS	1000	0.97	35	1.4
5000 cSt SO	100% PDMS	5000	0.97	35	1.4
Heavy SO					
Oxane HD	88.1% 5700 cSt	3300	1.02	45	1.4
Densiron 68	Oxane/11.9% RMN-3 69.5% 5000 cSt PDMS/30.5% F_6H_8	1400	1.06	41	1.4

SO silicone oil, *RMN-3* a partially fluorinated olefin, *PDMS* polydimethylsiloxane [32]

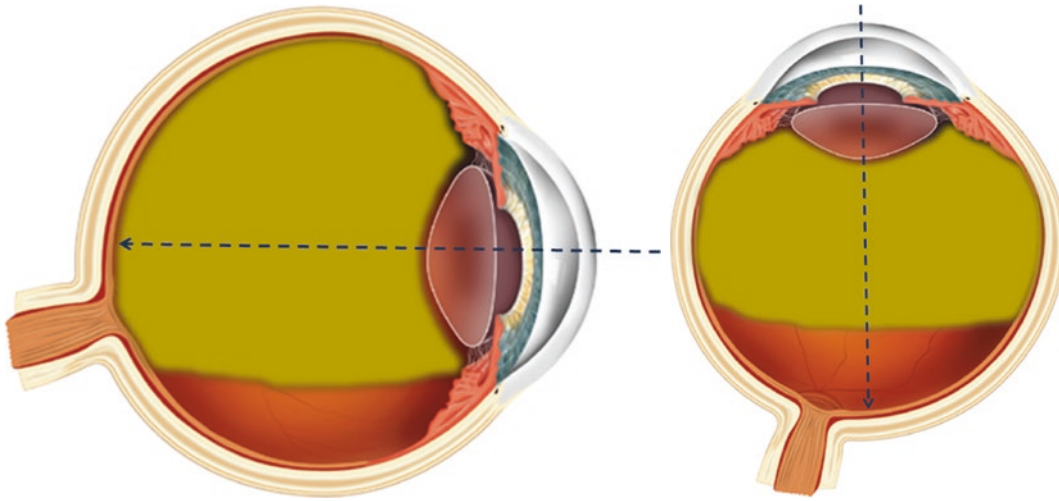

Fig. 68.5 Silicone oil filled eye US biometry: In supine position (left), a retrosilicone space will affect the measurement. This error will be avoided if the measurement is done in the upright position (right)

In a retrospective study, Madanagopalan et al. compared refractive results with US biometry between one group where cataract surgery and silicone oil removal was done the same day and another group where biometry was done after silicone oil removal in a two-step approach. Three months after surgery, the refractive error was higher in the silicone oil biometry group: −1.73 ± 2.04 vs. −0.64 ± 1.59 [34].

Optical biometry is less affected due to the lower relative impact of index of refraction change: from 1.336 to 1.4 (Densiron 68 has 1.387). If AL is measured in the normal phakic mode, the necessary correction is around −0.75 mm.

Since the first IOLMaster, all optical biometers have a silicone oil mode where a correction is applied. Reported results are good with no significant difference before and after silicone oil removal and low refraction prediction error [35, 36]. There might be some differences among different devices. Kulikov et al. found a slight underestimation of AL in shorter eyes (<23.63 mm) and an overestimation in longer eyes (<23.63 mm) when measurements with and without silicone oil were compared using Lenstar 900 and IOLMaster. The former had a difference of 0.09 mm and 0.23 mm in short and long eyes, respectively. The same values were 0.12 mm and 0.28 mm for the IOLMaster [37].

Several studies report higher accuracy with optical biometry than with US biometry. Tayyab et al. compared IOL Master (version 5) and US A-scan before and after silicone oil removal: There was no significant difference with IOL Master while the US biometry showed a mean underestimation of AL of 0.63 mm. Postoperative refractive error was 0.70 ± 0.32 D with IOL Master and 1.55 ± 0.98 D with US biometry [38].

It can be concluded that adjusted optical biometry is quite accurate in these eyes, while adjusted US biometry is more affected by factors that decrease its precision.

It will be interesting to analyze the performance of new Swept Source biometers that measure segmental AL (e.g., Argos) where simply changing the index of refraction of the vitreous chamber should provide more correct measurements.

In order to avoid all these biometry inaccuracies, it is highly recommended that any eye undergoing PPV has measurements done before the surgery. It must be taken into account if the pathology itself can lead to a mismeasurement, e.g., macula-off RD, or if any other procedure that can alter the AL is performed, e.g., scleral

buckling. The AL of the fellow eye can be used as a reference only if there is refraction and biometry symmetry. Another alternative is to perform intraoperative biometry (e.g., ORA system) once the silicone oil has been removed. Finally, delaying the IOL implantation can always be considered until reliable measurements can be obtained.

Bad Fixation and Macular Screening

The IOLMaster 700® has a unique feature among all biometers. It displays a 1 mm horizontal cross-sectional scan of the macular region where the foveal pit can be identified. It uses a wavelength of 1055 nm and has a scan depth of 44 mm and a scan width of 6 mm. Its resolution in tissue is 22 μm, and its measurement speed is 2000 A-scans per second [39]. This macular scan helps identifying the fixation status of the eye even in cases of low visual acuity due to retinal pathology.

Another benefit is the possibility of detecting unknown macular pathologies at the time of biometry. Even if the resolution of the image is much lower than in conventional retinal OCTs, foveal anatomy is usually recognized (Fig. 68.6).

Hirnshall et al. studied 125 eyes by three examiners and reported a moderate sensitivity (0.42–0.68) and high specificity (0.89–0.98) in the detection of macular pathologies. The interobserver reproducibility was 78.3–86.7%. Some diseases like mild-moderate macular atrophy or ERM were more difficult to detect than others probably due to the low resolution of the image [40]. Tognetto et al. studied 1089 eyes by seven examiners. In the detection of macular pathology, the mean sensitivity was 0.81 and the mean specificity 0.84. The positive predictive value was 0.78, and the negative predictive value was 0.86. Similarly to the previous study, the detection rate was higher for the macular hole and other pathologies involving retinal inner layer and lower for geographic atrophies, small drusen, and pigmented epithelium detachments [41].

The conclusion is that it is a valuable tool for macular screening but it cannot substitute for macular FD-OCT that performs better and provides information from a wider macular area.

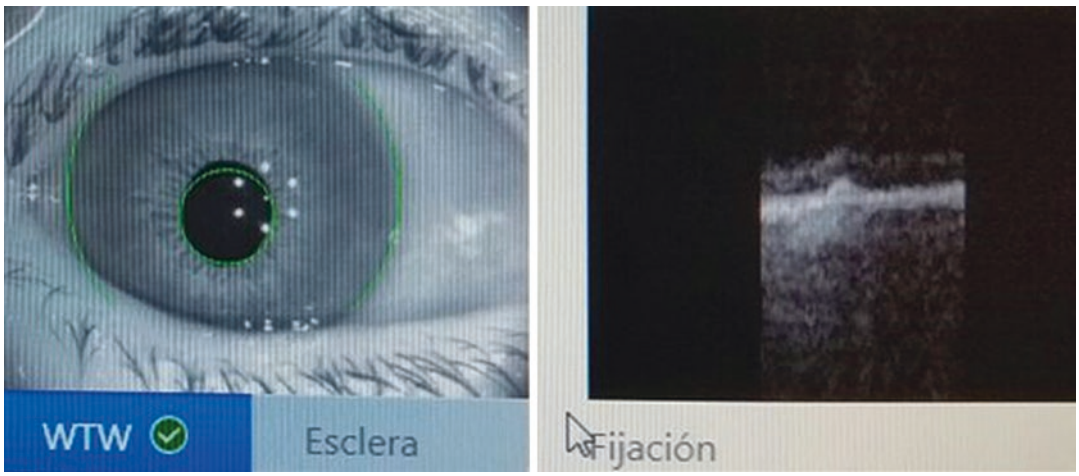

Fig. 68.6 Macular scar with IOLMaster 700 SS-OCT biometer

Vitreous Humor Optics

The vitreous humor is composed of 98–99% water and a framework of collagen fibers and hyaluronic acid. Hitzenberger calculated the group refractive index of these media from the dispersion values of water: 1.3459 and 1.3445 (for λ = 780 nm). There is some variability in the scientific literature about measurements of actual values with reported differences up to 0.009 [42].

All IOL power calculation formulas are pseudophakic eye models. Most of them are thin lens vergence formulas and some are thick lens exact raytracing models. But all of them assume that the index of refraction of vitreous and aqueous humors are equal (usually 1.336). This is also what can be found in the best known schematic eyes (Table 68.2) [43]. All of them show a very small difference between these two values (around 0.001).

Table 68.2 Refractive index of ocular humors in schematic eyes [43]

	Aqueous humor	Vitreous humor
Gullstrand exact #1	1.336	1.336
Le Grand	1.3374	1.336
Navarro	1.3374	1.336
Liou-Brennan	1.336	1.336

If the vitreous/aqueous index of refraction ratio of the vitrectomized eye is different from the model (formula), there will be a consequent error in the calculation. This will depend mainly on the IOL power and to a lesser extent, on its shape. If the index of refraction decreases, the optical effective power increases with a myopic shift in refraction. This might explain some of the refractive changes found after vitrectomy but more research is needed to clarify this point.

In Fig. 68.7, there is a plot of the refraction shift on the spectacle plane as a function of IOL power for a 0.005 change of vitreous index of refraction. The calculation was done for a biconvex IOL (Acrysof® SA60AT model).

This might be the explanation for the myopic refractive shift that has been reported in pseudophakic eyes undergoing vitrectomy. Sharma reported 0.85 D myopic shift in 25 RD eyes [44]. Hamoudi found 0.26 D myopic change in 28 eyes with ERM. ACD change was not analyzed in either of these studies [45]. Byrne studied 84 eyes and reported a myopic shift of 0.45 D. This was higher than 0.50 D in 52% of eyes. The ACD was unchanged [46]. Other potential factors of myopic shift, e.g., AL increase, were not investigated.

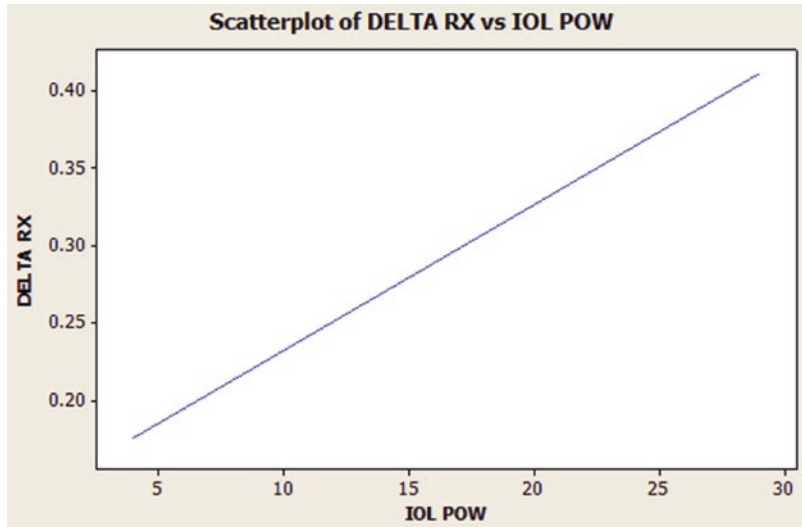

Fig. 68.7 Refraction shift as a function of IOL power for a vitreous index of refraction change of 0.005 with a biconvex IOL. Paraxial calculation. K = 43.5, corneal anterior/posterior ratio = 1.21; n cornea = 1.376; n aqueous = 1.336

Silicone Oil and Refraction

In certain complicated cases, the silicone oil will not be removed from the eye and the induced refractive effect must be taken into account to achieve the desired refractive target. The increased index of refraction within the vitreous segment will affect the IOL-vitreous interface refraction, producing a decrease in the IOL effective power leading to a hyperopic spectacle plane refraction in which magnitude depends on the IOL index of refraction, IOL shape, and IOL power. The main factor is the IOL shape: The more convex the posterior surface is, the higher the refractive shift will be. McCartney et al. calculated this effect theoretically on different IOL shapes. For a biconvex IOL, the effect was around 5.50 D. On the contrary, a meniscus IOL had a negligible refractive change (Table 68.3) [47]. In Fig. 68.8, the refractive change as a function of IOL power is plotted for a silicone oil with the index of refraction value of 1.4 . The calculations are done by paraxial raytracing for a biconvex IOL (Acrysof® SA60AT).

Grinbaum reported a mean PO hyperopia of 4 D, with a wide 4.40 D range in a series of eight cases [48]. Fang et al. studied 27 eyes with a mean AL of 25.84 ± 3.28 mm. The silicone oil induced a refractive shift of 3.90 ± 1.74D, which was correlated with IOL power and with ACD [49]. Song et al. reported a myopic shift of −4.51 ± 1.79 D when the silicone oil was removed from the eyes of 26 eyes [50].

The refractive target will depend on the power and shape of the IOL that will be implanted. It must be remembered than for 0.35 D spectacle plane refraction change, approximately 0.50 D of labeled IOL power change is needed. For example, if 4.5 D of hyperopia are expected, the amount needed to be added to the calculated IOL for emmetropia is 6.43 D.

An alternative that minimizes this source of error is to implant a meniscus or a convex-plano IOL to minimize the induced refractive change.

Table 68.3 Refractions produced by different IOL shapes and powers [46]

	IOL power	Refraction
Plano Convex	13	6.27
	18	7.93
	23	9.59
Biconvex	13	5.36
	18	5.41
	23	5.45
Convex-Plano	13	2.47
	18	2.70
	23	2.95
Meniscus	13	−0.19
	18	0.06
	23	0.44

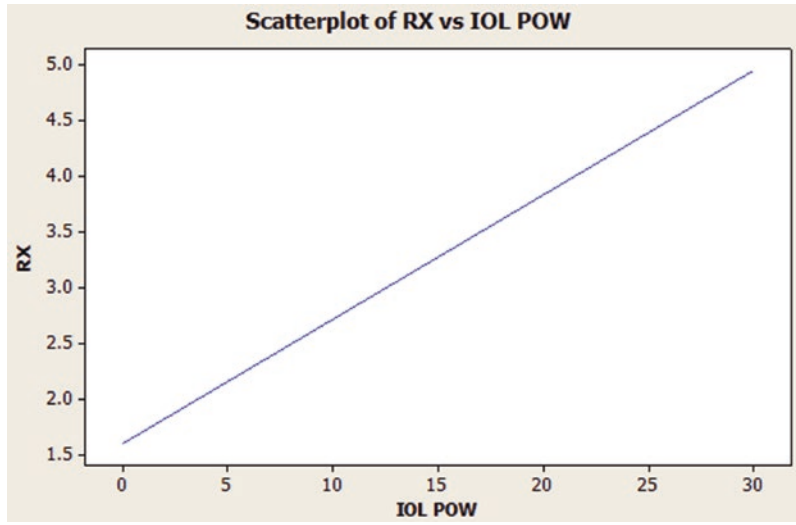

Fig. 68.8 Silicone oil (n = 1.4) induced refractive change is directly proportional to IOL power. Paraxial calculations for a biconvex IOL. K = 43.5 and ELP is adjusted for AXL

IOL Position, Tilt and Centration

The IOL power calculation formulas predict the position of the IOL using different algorithms based on a data series. Linear and non-linear regression functions, and lately machine learning algorithms, have been used to accomplish this task. After vitrectomy, this might be a source of error in refraction prediction, as some differences in IOL position have been reported.

Any change in the axial IOL position within the eye will affect the effective refractive power of the IOL. If the IOL sits posterior to the predicted plane, i.e., deeper in the eye, a hyperopic error will occur while the inverse situation will produce a myopic error. The refractive error magnitude will depend mainly on the ACD error and on the IOL power. Figure 68.9 shows how a small (0.10 mm) and a mid-level (0.50 mm) error will affect the refraction in the IOL plane and in the spectacle plane in eyes of four different ALs.

Many studies have measured this parameter usually comparing a sample undergoing phacovitrectomy and a matched sample of phacoemulsification without vitrectomy as control. Contradictory results have been published: deeper, shallower, and unchanged ACD after vitrectomy. Recently, very accurate SS-OCT devices are probably reporting the most reliable numbers: Three papers using Casia 2 (Tomey) SS-OCT found no significant differences between phacovitrectomy and control groups [51–53]. One study found a shallower ACD in a group that had had gas tamponade [53]. Mijnsbrugge et al. described a deeper ACD after phacovitrectomy in 20 eyes using the IOLMaster 700. This is the only published paper where the control group was composed of the other 20 fellow eyes that underwent phacoemulsification. The difference was 0.16 mm [54].

Even in the papers where there is no difference, it can be seen that in eyes without gas tamponade, there is a trend towards a deeper ACD. It has been proposed that the use of any tamponade after surgery (air, gas, or silicone oil) can alter the zonular fibers and induce an anteriorization of the IOL-bag complex. But more evidence is needed to support this concept and to calculate any predicting function.

IOL tilt and decentration affect the optical performance of the IOL inducing astigmatism and higher-order aberrations [55]. It can be expected that these eyes have a higher incidence due to zonular and IOL instability, the use of

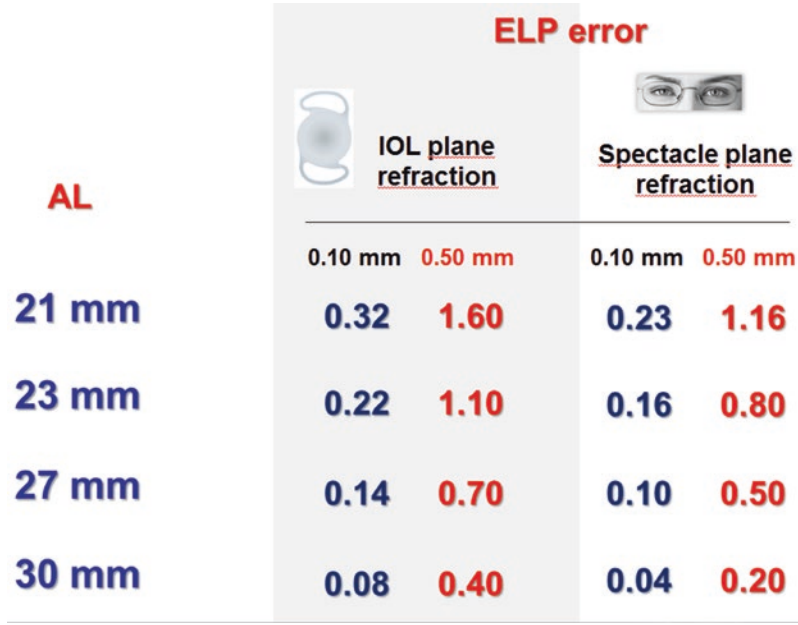

Fig. 68.9 Refractive effect in the IOL plane and the spectacle plane refraction of two different effective lens position (ELP) errors: 0.10 and 0.50 mm. Calculations are done for four different ALs. Paraxial calculations with K = 44 D

endotamponades, and increased capsular fibrosis. This knowledge is valuable in order to calculate the effect on toric IOLs and to help in the selection of the IOL model. Highly aspheric IOLs can induce HOAs if tilt and decentration are significant. Holladay et al. calculated on a theoretical model some threshold values beyond which the performance (in terms of MTF) of an aspheric IOL is affected: 7° for tilt and 0.4 mm for decentration [56].

There are a few papers studying this issue, and again, they yielded contradictory conclusions. Tan et al. found an increase of tilt and decentration when they compared 104 eyes with the previous vitrectomy and 104 eyes without any previous surgery using SS-OCT AS-tomography. Tilt was 5.36° ± 2.50° and 4.54° ± 1.46°, respectively. Decentration was 0.27 ± 0.17 mm and 0.19 ± 0.12 mm. In the vitrectomy group, tilt was >7° in 18.27% of cases vs 5.77% of cases in the control group. In a similar way, decentration >0.4 mm occurred in 21.25% of cases in the vitrectomy group and only in 6.73% of cases in the control group. Ocular aberrometry measured a significantly higher level of HOA in the vitrectomy group: 0.64 ± 0.51 μm vs 0.31 ± 0.17 μm. Risk factors for tilt were silicone oil use in the PPV and a hydrophilic IOL. The only risk factor for decentration was diabetes mellitus [52]. Iwama et al. compared phacovitrectomy cases with (24 eyes) and without (21 eyes) air tamponade, and regular cataract surgery cases (18 eyes). They found a significant higher level of tilt only in the air tamponade group with respect to the normal group. Surgery induced tilt was 1.89° ± 1.32° in this group. In the no-air tamponade and the phacoemulsification groups, these values were 1.54 ± 1.08° and 1.00 ± 0.95°, respectively. Although there were no significant differences in decentration, a higher number of eyes with decentration >0.4 mm in the air tamponade group was reported. They also measured the HOAs with a Hartmann-Shack aberrometer finding that there is no significant differences among groups [57].

However, there are several studies showing non or minimal differences. This was the case with Sato et al. who used similar technologies to compare a group of 60 eyes that underwent phacovitrectomy and 60 eyes of a control group with only phacoemulsification surgery. Three months after surgery, there were no significant differences neither in tilt (4.33° ± 1.47° and 4.84° ± 1.43°, respectively) nor in decentration (0.19 ± 0.12 mm and 0.18 ± 0.09 mm, respectively) [51]. Leisser et al. compared tilt and decentration in two groups that underwent phacovitrectomy using air tamponade in one of them and balanced salt solution in the other. There were no significant differences in either of the variables. Average values were 4.33° ± 1.47° for tilt and for 0.18 ± 0.09 mm decentration. These values look similar to non-vitrectomized eyes [58].

As new SS-OCT tomographers and biometers expand and become the standard of use, more studies will be performed and hopefully all issues related to IOL positioning after PPV will be clearly described.

IOL Calculation in the Vitrectomized Eye

Cataract surgery in a previously vitrectomized eye is technically more challenging due to several anatomical factors produced by the removal of the vitreous and the use of tamponade agents: deep and variable ACD, posterior capsule damage and fluctuations, zonular weakness, and intraoperative miosis, etc.

The IOL power calculation is also more difficult in these eyes: There is a high prevalence of very long eyes with their intrinsic challenges, the IOL position prediction might be affected by the absence of vitreous and the effect of the vitrectomy on the zonular apparatus, the presence of silicone oil can affect the biometric measurements, and finally, the reliability of PO refraction is certainly worse due to the lower visual acuity of these eyes affecting the analysis of outcomes. There are very few papers analyzing these calculations in the last 15 years. Most of them reported some hyperopic shift in the refraction after surgery if the normal IOL constants are used. The most plausible reason is a combination of IOL

position prediction error (the IOL is more posterior than predicted) and a formula error if AL is longer than average.

The newer generation formulas predict the IOL position using four or more variables: In addition to AL and K, they normally get direct information about the anterior segment depth from ACD and LT. Moreover, they have corrected the AL bias related to the IOLMaster calibration method [8]. Many papers have shown a real accuracy improvement over the third-generation formulas [59].

Regarding vitrectomized eyes, Tan et al. studied 111 eyes and found some hyperopic shift with the normal IOL constants in all formulas (Barrett UII, EVO, Ladas, Haigis, SRK/T, Hoffer Q and Holladay 1) except the Kane formula that had a mean PE of only 0.09 D. Haigis had the highest hyperopic shift (0.46 D) This error was AL related as it was higher in a subgroup with AL > 26 mm. When the IOL constants were optimized, the results of the new formulas were a little better, although there was no statistically significant differences in prediction accuracy among them and Haigis and Hoffer Q. Refractions were within ±0.50 D of prediction in a range of 49.53–60.75%. Formula results from best to worst were EVO, Kane, Haigis, Barrett UII, Hoffer Q, SRK/T, Holladay 1 and Ladas SF. In long eyes (33 eyes with AL > 26 mm), the Wang-Koch AL optimization improved the results of the third-generation formulas, and there was no significant difference among all formulas in the study [60]. Lamson et al. studied 61 eyes and found some hyperopic prediction error for all formulas. IOL constants were not optimized. The standard deviation of all prediction error was similar for all formulas: 0.72–0.82. A small subgroup of eyes calculated with Holladay 1 and SRK/T and the Wang-Koch adjustment showed a nil prediction error. Refractions were within ±0.5D of prediction in a range of 45–60.42%. Formulas from best to worst were Holladay 2, Holladay 1, SRK/T, Barrett UII, RBF and Ladas [61]. In 2009, Lee et al. studied 45 eyes where AL had been measured with US biometry. The calculation formulas were SRK/T for eyes with Al > 25 mm and SRK II. This group had a hyperopic prediction error of +0.40 ± 1.07 D while a control group had +0.19 ± 0.82 D [62].

From these studies, it can be concluded that there is some hyperopic prediction error in the IOL power calculation on vitrectomized eyes that should be considered in the preoperative assessment. There is no clear explanation for this, although a plausible hypothesis is a more posterior IOL location within the eye attributable to the lack of vitreous support and/or higher zonular laxity.

IOL Calculation in Phacovitrectomy

Combined phacoemulsification and PPV (phacovitrectomy) has become a routine procedure for the retinal surgeon. IOL calculation and refractive results have been extensively analyzed in multiple studies where a phacovitrectomy group is compared with a regular phacoemulsification control group. The vast majority of them report either a myopic prediction error [13, 18, 53, 63–66] or a neutral effect with no difference between groups [51, 53, 67–70].

Myopic shift was first related to incorrect AL measurement in certain pathologies like macula off RD, where both the US and the PCI biometry tend to get the retinal signal from the anteriorized vitreoretinal interface underestimating the AL value [19, 21]. This can also occur in macular pucker where the PCI can identify the thick epiretinal membrane as the retina displaying a double peak in the A-scan [15]. This point has been discussed above. However, there are studies with the same pathologies and no myopic shift. Shiraki et al. report no refractive error in a group of 20 ERM eyes and a myopic shift (−0.82 ± 0.64 D) in a group of 22 eyes that had macular hole and RD. They explain the myopic shift by the use of gas tamponade in the second group [53]. Hötte et al. reported similar results in a group of macular pathology, where the eyes that had gas tamponade (macular holes) had a myopic prediction error (−0.31) and those who had not showed nil prediction error (ERM and floaters) [66]. On the contrary, Van der Geest found no prediction error in an analogous sample, macular pathology, with

no difference between gas use or not [68]. Ercan also reported no prediction error in 100 eyes with macular pathology with gas tamponade. Prediction accuracy was very good with 80–84% of eyes with MAE < 0.50 D [67].

Biometry technology analysis does not clarify this controversy: There are studies on both sides with all biometers: US, PCI, and SS-OCT. The same can be said about IOL calculation formulas. Modern formulas with new ELP algorithms and AL bias correction render accurate results in some cases and myopic errors in others: Sato et al. [51] and Shiraki et al. (no gas eyes) [53] found no error with Barrett UII, while Vounotrypidis et al. reported myopic shift with modern formulas, Barrett UII included [63]. In this last study, where only ERM cases were included, the calculation was done after IOL constants were optimized in the phacoemulsification group. With these "normal" IOL constants, there was a myopic predictive error in all formulas: −0.14 to −0.21 D. When the constants were optimized for the phacovitrectomy group, results were similarly accurate for all formulas: 65.6% −73.4% of eyes with MAE < 0.50 D. Formulas from best to worst were Holladay 2, Kane, Haigis, SRK/T, Barrett UII, Hoffer Q, RBF, and Holladay 1. Eyes longer than 27 mm were not included in this study, and this might have biased results in detriment to newer generation formulas.

AL has been related to the degree of myopic error: Jee et al. studied 91 eyes that had surgery for macular hole where AL was measured with PCI. In 73 eyes with AL < 26 mm, the prediction error was lower (−0.43 ± 0.63 D) than in 18 eyes with AL > 26 mm (−1.08 ± 0.87 D) [64]. In US biometry, it has been argued that there is some IOP effect leading to the underestimation of AL: Cho et al. found myopic prediction error (−0.43 ± 0.67 D) in 25 eyes that had macula-on RD and no prediction error in 30 eyes with other pathologies [71].

In conclusion, biometric measurements must be carefully checked in this surgical technique, looking for any incorrect retinal identification in the scan. There might be some myopic refractive error that can only be addressed optimizing the IOL constant for phacovitrectomy eyes. Newer generation formulas will address AL induced bias with outcomes slightly worse than those obtained in normal eyes.

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