REVIEW

An overview of phakic intraocular lenses

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Abstract

There are 3 types of phakic intraocular lenses: angle-supported, iris-fixated, and posterior chamber. Implantation of phakic intraocular lenses has been common practice in Europe for the past decade. With the recent approvals by the USA Food and Drug Administration for the Verisyse and Staar lenses, phakic intraocular lens-implantation is expected to increase worldwide. Unlike the power calculation for conventional intraocular lenses using axial length and keratometry, the power of phakic intraocular lenses is calculated from keratometry readings, anterior chamber depth, refractive error, and vertex distance. In this review, different models of phakic intraocular lenses and their indications are addressed. Complications of implanting these lenses include endothelial cell loss, cataract, pigment deposits, iridocyclitis, and vitreoretinal complications. These complications should be noted by surgeons before considering the use of these lenses for refractive correction.

Key words: Lenses, intraocular; Lens implantation, intraocular; Postoperative complications

Introduction

A phakic intraocular lens (PIOL) is an intraocular lens designed for implantation into an eye with phakia. In 1954, Strampelli reported the first implantation of a minus power phakic intraocular lens (PIOL) in the anterior chamber.[1] Thereafter, newer and better designs of PIOLs were developed. There are 3 types of PIOL: the angle-supported/angle-fixated lens (AS PIOL),[2] iris-fixated/iris-claw lens (IF PIOL),[3] and posterior chamber lens (PC PIOL).[4,5] In addition to those used for correcting myopia[3,6-9] and hyperopia,[10-12] certain lenses are used to correct astigmatism[13,14] and presbyopia.[15] The purpose of this article is to review the different PIOLs and the associated complications. The reference articles quoted in this review are collected from a Medline database search using the key word 'phakic intraocular lens' plus 'complications', 'endothelial loss', 'pigment dispersion', 'cataract', 'vitreoretinal complication', 'surgical technique', and 'visual outcome'.

Indications and contraindications

Indications for PIOL implantation are moderate to high myopia or hyperopia. The refraction should be stable so PIOLs are usually indicated for patients older than 20 years. For the implantation of anterior chamber lenses, the anterior chamber depth should be at least 3.0 mm (measured from the inner part of the cornea). The endothelial cell count should be at least $2000/mm^2$ preoperatively. For patients with more than -15.0 D refractive error, bioptics can be considered by adding an additional corneal procedure (usually LASIK).[16,17] Limitations of the Verisyse toric IOL (Advanced Medical Optics, Inc, Santa Ana, USA) are a cylindrical power of up to 7.00 D only and an optical zone of 5.00 mm.[13]

General contraindications for all types of PIOL implantation include ocular conditions such as corneal dystrophy, cataract, history of iritis, glaucoma, pigment dispersion syndrome, pseudoexfoliation of the lens capsule, excess iris convexity, large scotopic pupils, ocular hypertension, contact sports, presbyopic age (in which refractive lens exchange is preferred), and ocular conditions associated with diabetes. Small pupil size is a relative contraindication for posterior chamber lens implantation.[18]

With the development of anterior chamber optical coherence tomography, a new parameter called crystalline lens rise, which is defined by the distance between the anterior pole of the crystalline lens and the horizontal plane joining the opposite iridocorneal recesses, has been proposed.[19] This parameter is used to predict the chance of developing pigment dispersion after AS PIOL implantation. The safety level has been suggested to be <600 μm.

Power calculations for phakic intraocular lens

The formula used for the power calculation for PIOL is based on vergence equations: the object vergence is equal to the refractive index of the object medium divided by the object distance (L = n/l). In 1988, van der Heijde et al published a formula to determine the IOL power needed for phakic myopia and aphakia (hyperopia).[20,21] Holladay later included the desired postoperative refraction (DPostRx) in the equation.[22] In both formulae, the following parameters were needed: the expected/effective lens position (ELP; distance from corneal vertex to principal plane of IOL), the net corneal power (K), the preoperative refraction in D (PreRx), and the vertex distance (V) [**Figure 1**]. Usually, the manufacturer calculates the desired power of the lens for the surgeons who provide the parameters. The effective lens position depends on the type of lens and is estimated from the anterior chamber depth, measured from the corneal vertex to the anterior surface of the lens, rather than using the anatomical anterior chamber depth, which is measured from the corneal endothelium to the anterior surface of the lens.

Holladay's formula works well for all types of lenses. The Staar Company (Monrovia, USA) has its own software for power calculations, but the exact equation was not found in any published articles. Other formulae such as the Olsen-Feingold formula[9,11,12,18,23] have been used for the power calculation of PC PIOLs. The basic concept of this formula is to take account of the relative position of the PIOL to the biometric anterior segment measurements by considering the geometric features, refractive index, and elasticity of the IOL material. Clinically, this formula shows less predictability for myopia than for hyperopia.[23] The accuracy of the power calculations is mainly governed by the accurate measurements of each parameter. Using mathematical models,[24] the parameters affecting the deviation of IOL power from the desired power occurred in the following order: refraction, vertex distance, ELP, keratometry, and refractive index. PIOLs showed high predictability in eyes with preoperative refractive error between +15.0 D to -15.0 D. Thus, accurate measurements of preoperative refraction and the corresponding vertex distance, which may often be neglected in conventional cataract surgery, are important for providing accurate desired postoperative refractions.

$$IOL_e = \frac{1336}{\dfrac{136}{\dfrac{1000}{\dfrac{1000}{PreRx} - V} + K_0} - ELP_0} - \frac{1336}{\dfrac{136}{\dfrac{1000}{\dfrac{1000}{DPostRx} - V} + K_0} - ELP_0}$$

Figure 1. The power determination of phakic intraocular lens using Holladay's formula.[22]
Abbreviations: IOL_e = expected power of the intraocular lens; DPostRx = postoperative refraction; ELP_0 = effective lens position; K_0 = net corneal power; PreRx = preoperative refraction in D; V = vertex distance.

Sizing of phakic intraocular lenses

The original design of the Worst-Fechner biconcave iris claw lens is standardized to 8.5 mm in size, but 7.5-mm or 8.5-mm lenses can now be obtained (Verisyse lens).[3,10,25,26] Other lenses such as angle-fixated and posterior chamber lenses are available in 3 different sizes with a 0.5-mm step. Accurate sizing of PIOLs is important to minimize complications. Limbal white-to-white diameter is usually used to determine the size of the PIOL. The length of anterior chamber PIOLs (AC PIOLs) is approximated by adding 0.5 mm or 1.0 mm to the horizontal white-to-white diameter for myopia or hyperopia according to different lens models.[6,27,28] For PC PIOLs, 0.5 mm or 1.0 mm is added to the horizontal white-to-white diameter for myopia, and 0.5 mm is subtracted for hyperopia.[9,11,29,30] 100 MHz ultrasound biomicroscopy (UBM) and OCT may be helpful for assessing the preoperative and postoperative anatomical conditions.[31-38]

The white-to-white diameter can be measured by various instruments. The usual manual device is a surgical measuring caliper with a scale from 0 to 20.0 mm in 1.0-mm steps. The Holladay-Godwin Cornea Gauge is a hexagonal plate with a half-circle scale from 9.0 mm to 14.0 mm in 0.5-mm increments, and can be held 1.0 mm from the cornea for measurement. Optical devices such as Orbscan II (Orbtek Inc, Salt Lake City, USA) and IOLMaster (Carl Zeiss, Meditec, Jena, Germany) can detect the border between white sclera and the darker iris image. IOLMaster shows the best correlation with the measurements of video images and has the highest reliability.[39]

Angle-supported phakic intraocular lenses

Examples of AS PIOLs include Baikoff ZB (Domilens, Lyon, France), ZB5M (Domilens, Lyon, France), NuVita (Bausch and Lomb Surgical, Irvine, USA),[6,40] ZSAL-4 (Morcher GMBH, Stutgart, Germany),[41] phakic 6H (Ophthalmic Innovations International [OII] Inc, Ontario, USA),[28,42] GBR (IOLTECH, LaRochelle, France)/VIVARTE foldable (CIBA-Vision AG, Embrach, Switzerland),[43] Kelman Duet (Tekia, Irvine, USA),[44] I-CARE lens (Corneal, Paris, France), and Thinlens (ThinOptX, Abingdon, USA) [Figure 2]. The Baikoff lenses are polymethyl methacrylate (PMMA) biconcave lenses that have evolved from the first-generation ZB and second-generation ZB5M to become the third-generation NuVita implant by altering the size and thickness of the optic.[2] The angulation of the haptics have been reduced from 25° to 20°, and the optic edge has been thinned to provide an additional

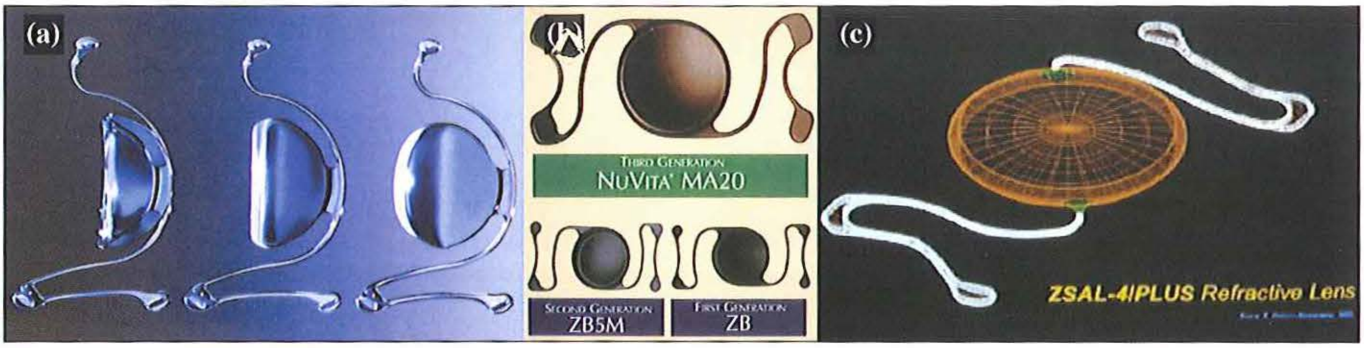

Figure 2. Angle-supported phakic intraocular lenses. (a) Vivarte; (b) NuVita MA; and (c) ZSAL-4. Reproduced courtesy of Dr H Burkhard Dick (Training Verisyse™ Phakic Intraocular Lens) and Advanced Medical Optics, Inc.

0.6 mm of lens-cornea spacing.[45] The modified Kelman Duet has a similar design and the lens is in 2 pieces: a PMMA haptic with a silicone optic.[44] Other lenses include the ZSAL and Phakic 6 lenses. The first-generation ZSAL-1 lens was convex-concave and this has evolved to plano-concave for the fourth-generation ZSAL-4 or ZSAL-4/plus. The phakic 6 and 6H lenses are biconcave PMMA lenses that are also modified from the Baikoff lenses. Foldable AS PIOLs such as the GBR/VIVARTE[43] have now been introduced to decrease the size of the corneo-scleral incision.[28,46]

Surgical technique

The implantation of an AS PIOL can be performed under general, peribulbar, or retrobulbar anesthesia, depending on a patient's needs and the surgeon's preference. The recommended anesthesia is peribulbar. Topical anesthesia can be used but the surgery may be more painful and complications may result. Baikoff et al suggested that the operation be performed with the eyes in tight miosis using pilocarpine.[6]

A 6- or 7-mm incision is made in the lateral nasal or temporal cornea parallel to the iris plane and the anterior chamber is filled with a viscoelastic substance. The implant, held with pincers or forceps, is introduced with a circular movement following the scleral curve and envelops the curve of the pupil. The distal loops or the leading haptic should be fitted into the iridocorneal angle without causing any pupil distortion. Once the leading haptic is properly positioned, additional viscoelastic is added as needed, and the trailing haptic is then placed in the iridocorneal angle on the opposite side of the eye. Pupillary block is common with non-patent iridectomies with AC PIOLs.[6,47] Iridectomies should be performed on all eyes. In case of 360° posterior synechiae, iridectomy allows aqueous circulation. To obtain small, patent iridectomies, pigment vacuum iridectomy by removing the pigment layer of the iris using vacuum aspiration with a 25-gauge cannula after removing the stromal layer by surgical excision has been suggested.[48] The surgery is completed after exchanging viscoelastics with balanced salt solution (BSS) and wound closure with 2 to 5 interrupted 10-0 nylon sutures.

Visual results, outcomes, and complications

Studies have been conducted to evaluate the safety, effectiveness, predictability, and stability of AC PIOLs. The AS PIOLs and PC PIOLs showed similar predictabilities.[49-51] Complications such as corneal endothelial loss, damage to the iridocorneal angle and glaucoma, pupil ovalization (**Figure 3**), IOL rotation, cataract formation, chronic low-grade iritis, and retinal detachment have been reported.[6,28,31,49,51-53] AS PIOLs appeared to be well tolerated by the corneal endothelium, with a low rate of other complications, in a 7-year study.[54] However, pupil ovalization is a common complication with this type of lens (5.9%). Moreover, halos and glare are the most annoying visual disturbance after AS PIOL implantation (27.8%).[6] However, lenses with a larger optical zone (ZSAL-4 compared with ZB5M/ZB5MF) have significantly lower halo incidence ($p < 0.05$).

In a review of AS PIOLs, the endothelial cell loss after implantation ranged from 16% to 19% at 1 year and from 20% to 28% after 2 years for the Baikoff ZB lens. The endothelial cell loss ranged from 4.5% to 5.5% at 1 year, from 5.6% to 6.8% at 2 years and from 5.5% to 7.5% at 3 years for the ZB5M phakic IOL. Ultrasound biomicroscopy was used to examine the position of the footplates, the anatomy of the angle, and the anatomic relationships of AC PIOLs.[55] The ZSAL-4 AS PIOL was found to have space between the IOL and the endothelium greater than other AS PIOLs; the intermittent contact between the IOL edge and the mid-peripheral cornea may be responsible for the endothelial damage with this lens.[56]

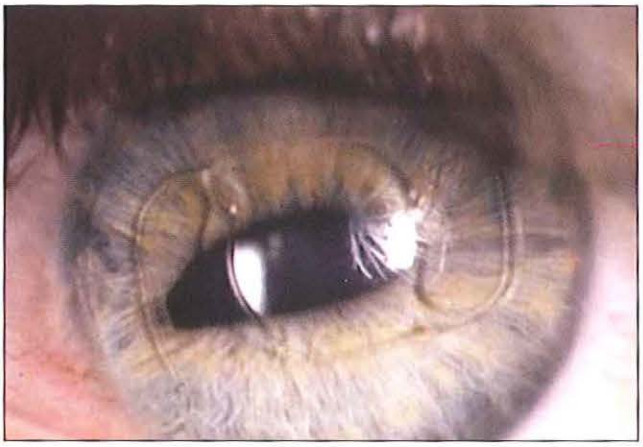

Figure 3. Pupil ovalization in an eye with an angle-supported phakic intraocular lens. Reproduced courtesy of Dr H Burkhard Dick (Training Verisyse™ Phakic Intraocular Lens) and Advanced Medical Optics, Inc.

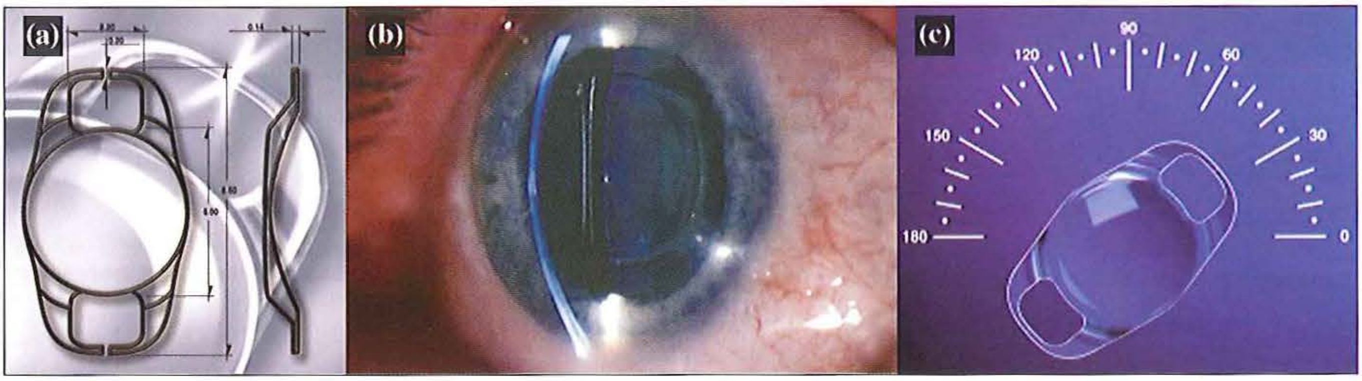

Figure 4. Iris-claw phakic intraocular lenses. (a) Verisyse lens; (b) lens in situ; and (c) toric lens. Reproduced courtesy of Dr H Burkhard Dick (Training Verisyse™ Phakic Intraocular Lens) and Advanced Medical Optics, Inc.

Vitreoretinal complications can occur after AC PIOL implantation. In a retrospective study of the incidence of retinal disease following refractive surgery,[57] 294 eyes corrected by AC PIOL were reviewed. Epiretinal membrane appeared in 1 patient 19 months after AC PIOL implantation. The incidences of retinal detachment and choroidal neovascularization (CNV) were 4.08% and 2.38%, respectively. Implantation of AS PIOLs to correct myopia in patients with keratoconus stage I to II have been reported. Short-term clinical results were acceptable, but astigmatism could not be corrected by wound incision.[52]

Iris-fixated phakic intraocular lenses

The initial design of IF PIOLs was biconcave[3,58,59] but this was later modified to a large convex-concave optic to decrease corneal endothelial damage, glare, and halos.[60] In 1998, the name of the Worst-Fechner IOL was changed to the Artisan lens (Ophtec, The Netherlands) although the design remained unchanged.[26,29] The lens is also known as the Verisyse (**Figures 4a and b**).[61] As well as correcting myopia, the lens can be used to correct hyperopia and astigmatism (**Figure 4c**).[26,61,62] The Verisyse (Artisan) myopic lens (size range, -5.0 to -20.0 D) is a 5- or 6-mm concave-convex optic with an 8.5-mm wide elliptical carrier, which is used to grip the outer edge of the iris for lens fixation. The Verisyse lens is the first PIOL to receive USA Food and Drug Administration (FDA) approval.

Surgical technique

For the implantation of the Verisyse lens, a 2-plane, 5- to 6-mm posterior corneal incision can be constructed superiorly with 2 paracenteses at 2 o'clock and 10 o'clock. After an intracameral injection of acetylcholine and viscoelastic material, the lens is introduced and rotated 90° into a horizontal position. The PIOL is fixed by pushing the iris into both claws with a blend-tip enclavation needle; the iris can be also enclavated by special forceps. A peripheral slit iridectomy is performed at 12 o'clock and the viscoelastic material is exchanged with BSS. The wound can be closed with 5 or 6 interrupted 10-0 nylon sutures.[63]

Similar to the spherical Verisyse PIOL, patients undergoing toric implantation (T PIOL) should be prepared with miotic drops to reduce the risk of lens touch. The site of the approach depends on the predetermined implant location and the cylindrical axis as 2 models of lens are available: model A T PIOL has the torus axis identical to the target enclavation axis and model B T PIOL has the enclavation axis 90° to the torus axis. Thus, for eyes with a cylinder axis between 0° and 45° or between 135° and 180°, model A is recommended, while for eyes with a cylinder axis between 45° and 135°, model B is recommended. A clear corneal, limbal, corneoscleral, or scleral wound can be constructed, depending on the surgeon's preference. To decrease the chance of endothelial damage, a 'sandwich technique' is recommended for IF PIOL implantation. This method involves injecting a bolus of a high-viscosity ophthalmic viscosurgical device over the optic after PIOL insertion and before performing enclavation.[64]

Visual results, outcomes, and complications

The iris-claw lenses achieve postoperative refraction within +/-1 D in 60% to 80% of eyes.[8,62,63,65,66] Eyes implanted with the Verisyse lens were studied under UBM. Adequate space was found between the Verisyse hyperopic IOL and the corneal endothelium, angle, and crystalline lens. Haptic indentation of the iris, which can lead to pigment erosion, was observed, thus, possible complications include transient iritis and chronic subclinical inflammation.[67] To decrease the chance of inflammation, shortening the haptics or increasing the lens vault has been suggested.[32,33] Detached enclavations can occur in eyes with the IC PIOL (**Figure 5**). Also, late endothelial damage and corneal decompensation are of concern after IF PIOL implantation. Although no significant endothelial cell loss was found in the 2- to 3-year evaluation of the Verisyse in eyes with myopia,[68-70] a negative correlation between anterior chamber depth and endothelial cell loss was found in eyes with hyperopia.[62] Therefore, it is recommended that eyes indicated for PIOL implantation have a minimum anterior chamber depth of 3.2 mm. Eyes with crystalline lens rise of 600 µm or more have a 67% chance of developing pupillary pigment dispersion. Thus, it is suggested that crystalline lens rise should be used as a selection criterion.[19] Vitreoretinal complications have been found after implantation of an IF PIOL. CNV was found in an eye 3 years after lens implantation.[71] This patient was subsequently treated by photodynamic therapy with visudyne.

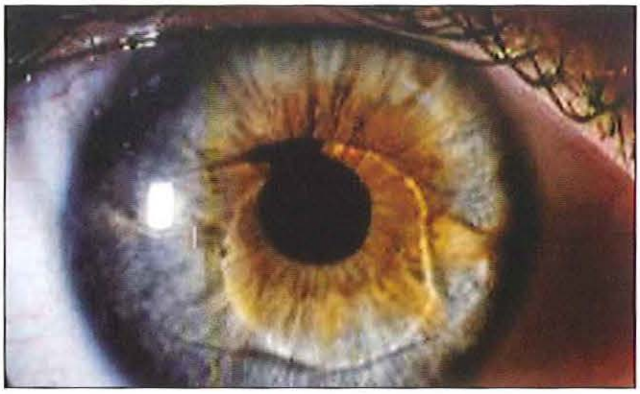

Figure 5. Detached enclavation in an eye with an iris-claw phakic intraocular lens. Reproduced courtesy of Dr H Burkhard Dick (Training Verisyse™ Phakic Intraocular Lens) and Advanced Medical Optics, Inc.

Posterior chamber phakic intraocular lens

Examples of PC IOLs are Chiron-Adatomed (Chiron GmbH, Ratingen, Germany), Staar, Phakic Refractive Lens (PRL; CIBA Vision, Duluth, USA), Sticklens (IOLTECH, LaRochelle, France), and Thinlens. The PC PIOLs were first introduced by Fyodorov (Moscow, Russia).[42] The original design was a collar-button optic located in the anterior chamber with haptics behind the iris.[72] Later, Chiron-Adatomed silicon lenses were used. This lens is a single-piece boat-shaped biconcave lens with plano haptics and is made of a silicon elastomer approved by the USA FDA. The optic diameter was originally 4.0 mm but, in 1994, it was changed to 5.5 mm. Haptic thickness has varied between 0.14 and 0.25 mm and ultimately became 0.18 mm. The overall length ranged from 10.5 mm to 12.0 mm with 0.5 mm steps.[73] This implant has become less popular due to a high cataractogenesis rate. Today, the PRL-Medennium silicon lens[74] and the Staar collamer implantable contact lens are more usually used. The Staar lens is a foldable convex-concave lens made of porcine collagen hydroxyethylmethacrylate copolymer (<0.1% collagen).[75] The Staar lens vaults over the anterior lens capsule and provides space for the aqueous.[37] The lens is designed for the surgical correction of moderate to high hyperopia and myopia with a range of correction from +10.00 to -20.00 D. The Staar lens became the second FDA-approved PIOL (**Figure 6**).

Surgical technique

For the implantation of a PC PIOL, a neodymium:YAG laser iridotomy is performed in the upper peripheral iris at least 2 weeks before implantation to allow inflammation to subside.[18] Two iridotomies are placed 90° apart to preclude the possibility of pupil block after IOL insertion. On the day of surgery, maximal mydriasis is required. After preparation, two 0.8-mm paracenteses are placed 90° from the clear corneal tunnel incision to facilitate immediate replacement of aqueous humor. The use of a viscosurgical device protects the surrounding tissues and allows the IOL to be unfolded slowly in a controlled manner. Each footplate is levered into position behind the iris through the pupil with a long spatula, without placing pressure on the crystalline lens. The operation is completed after the removal of the viscoelastic. Postoperatively, steroid/antibiotic combination eye drops are recommended 3 times daily for 1 week.

Visual results, outcomes, and complications

As PC PIOLs are also called prelens IOLs, pigment dispersion, cataract formation (**Figure 7**), and vitreoretinal complications are important issues for these lenses.[30,76] As previously mentioned, the AS PIOLs and PC PIOLs showed similar predictabilities.[49-51]

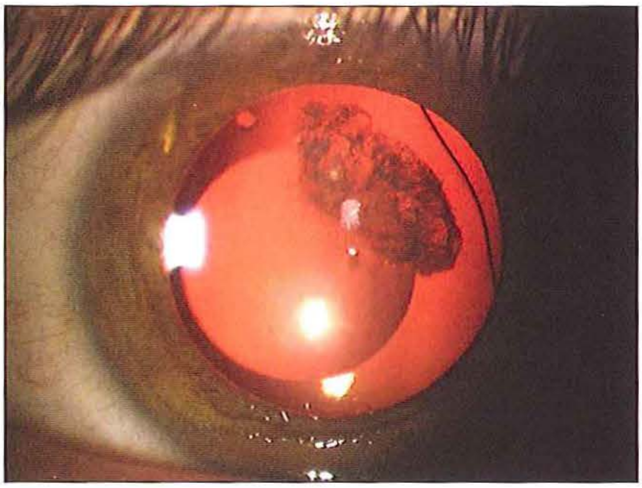

Figure 7. Subcapsular cataract in an eye with a posterior chamber phakic intraocular lens. Reproduced courtesy of STAAR Surgical AG.

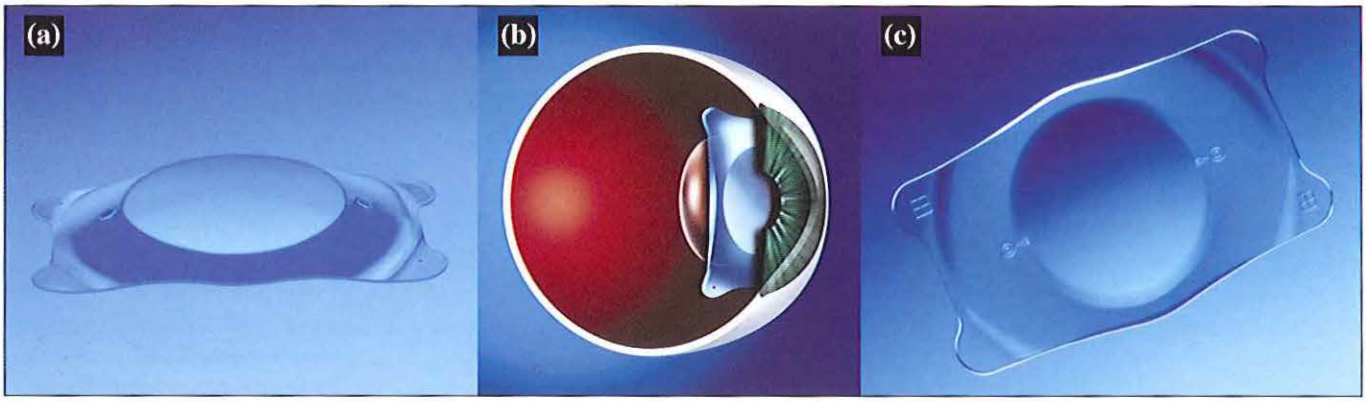

Figure 6. Posterior chamber phakic intraocular lens. (a) Staar lens; (b) Staar lens in situ; and (c) toric lens. Reproduced courtesy of STAAR Surgical AG.

Reports have shown that the chance of cataract formation after implantation of the Chiron Adatomed lens ranges from 17.8% to 33.3% after 6 and 32 months, respectively.[30,45,73] The Staar lens is associated with a 25% to 75% chance of cataract formation within 18 to 32 months, although some reports have shown no cataract formation during follow-up of up to 24 months.[30,76,77] Postoperative atonic pupil has been noted and has sometimes been described as Urrets-Zavalia syndrome.[4,73] This syndrome consists of a transient increase in IOP, iris stromal atrophy, and irreversible paretic mydriasis. Ultrasound biomicroscopy has shown IOL-iris touch, IOL-crystalline lens touch, and anterior chamber shallowing. This raises concerns about pigmentary dispersion, cataractogenesis, and narrow angle glaucoma following PC PIOL implantation.[38,76,78] The so-called 'floating contact lens' has been found to have areas contacting the surrounding tissues and requires a longer time for evaluation. There is a higher incidence of lens decentration and anterior subcapsular cataract with the Adatomed lens than with the Staar lens.[30,79] In the study by Menezo et al,[80] delayed cataract development and cataract type (nuclear) were found in patients with an Ophtec lens and the variables of patient age (older than 40 years) and axial length (>30 mm) may be the prognostic factors.

In patients with the Adatomed and Staar PIOLs, other factors such as lens design, material, and placement probably influenced cataract formation. Cataract formation, IOL

Table 1. Summary of angle-supported phakic intraocular lenses.

Model	Manufacturer	Material	Optic/overall diameter (mm)	Haptic angle	Range (step) [D]	Comments	Outcomes
Baikoff (ZB) First generation	Domilens	Biconcave PMMA	4.5	25°	—	No longer used — endothelial damage	—
Baikoff (ZB5M) Second generation	Domilens	Biconcave PMMA	5.0 (4.0)/12.5, 13.0, 13.5	20°	-7 to -20.0 (1.0)	Pupil ovalisation; halos/glare; 12.3% endothelial cell loss at 2 years; 21.05 to 23.50 photons/ms pigment at 2 years	65% within ±1.00 D at 2 years
Baikoff (Nuvita) Third generation	Bausch and Lomb	Biconcave PMMA	5.0 (4.5)	—	Only minus lens	No longer used; significant endothelial cell loss in the second year	—
ZSAL-1 (1991)	Morcher	Convex-concave PMMA	5.5	15°	—	Failed in eye bank trials	—
ZSAL-2 (1992)	Morcher	PMMA	5.5 (5.0)	17°	—	No longer used	—
ZSAL-3 (1993)	Morcher	PMMA	5.5 (5.0)	18°	—	No longer used	—
ZSAL-4 (1994)	Morcher	Plano-concave PMMA	5.5 (5.0)/ 12.5, 13.0	19°, z-shaped haptic	-6 to -20.0 (1.0)	No longer used; 4.18% endothelial cell loss at 24 months	-0.65 ± 0.65 D, 82.6% within ± 1 D at 2 years
ZSAL-4/plus	Morcher	Plano-concave PMMA	5.8 (5.0-5.3)/ 12.0-13.0	—	-6 to -20.0 (0.5)	Intraocular lens rotation	—
Phakic 6	OII	Biconcave PMMA	6.0 up to -10 D; 5.5 up to -25 D/ 12.0-14.0 (0.5)	—	—	Modified from Baikoff	—
Phakic 6H	OII	Biconcave PMMA	6.0 up to -10 D; 5.5 up to -25 D/ 12.0-14.0 (0.5)	—	—	—	—
Phakic 6H2	OII	Biconcave PMMA	6.0 up to -10 D; 5.5 up to -25 D/ 12.0-14.0 (0.5)	—	-4.0 to -20.0 D, +2.0 to +10.0	Phase II (FDA)	—
GBR/Vivarte	CIBA/ IOLTECH	Biconcave acrylic optic, PMMA haptics, soft acrylic footplates	5.5/12.0, 12.5, 13.0	—	-7.0 to -25.0 (0.5)	3-point angle, foldable, 3.2 mm wound	—
GBR/Vivarte for presbyopia	CIBA/ IOLTECH	Acrylic	5.5	—	-5.0 to +5.0	—	—
Kelman Duet phakic AC	Tekia	PMMA haptic with silicone optic	5.5/12.0, 12.5, 13.0, 13.5	—	-8.0 to -20.0	Few clinical results	—
I-CARE lens (France)	Corneal	Hydrophilic acrylic	5.75/12.0, 12.5, 13.0, 13.5	—	—	Has 4 independent haptics	—
ThinLens	ThinOptX	Acrylic	—	—	—	—	—

Abbreviations: *AC = anterior chamber; OII = Ophthalmic Innovations International; PMMA = polymethyl methacrylate; ms = milliseconds; FDA = Food and Drug Administration.*

dislocation, and severe endothelial cell loss may occur as a late complication of PC PIOL implantation.[81]

Halos and glare can be present after lens implantation. The incidence is more common with PC PIOL than for AS PIOL or IF PIOL implantation. In general, lenses with a larger optical zone result in a lower incidence of halos.[54,82]

CNV has also been found with this type of lens; this occurred in 1 patient 5 weeks after lens implantation and was subsequently treated by photodynamic therapy.[71] Rhegmatogenous retinal detachment (2%) has also been reported in 2% of patients after the implantation of PC PIOL.[83] The designs and specifications of certain lenses as well as the complications are summarized in **Tables 1 to 3**.

Bioptics

Although PIOL implantation shows good predictability clinically,[49-51] LASIK or photorefractive keratectomy are sometimes used to treat residual refractive error;[84-86] the term 'bioptics' is used to describe this kind of surgery.[16,87] Some authors have suggested using 'adjustable refractive surgery' by creating a LASIK flap before PIOL implantation,[88,89] but this technique has become less popular due to the development of higher power PIOLs and the improved technique for surface ablation. The complications of this procedure include pain, halos, endothelial cell loss, recurrent iridocyclitis, transient ocular hypertension, anterior subcapsular opacities, and macular hemorrhage, but these occur with acceptable incidences.[84,86]

Table 2. Summary of iris-fixated phakic intraocular lenses.

Model	Manufacturer	Material	Optic/overall diameter (mm)	Range (step) [D]	Remarks
Artisan/Verisyse	Ophtech / AMO	Concave-convex PMMA	5.0-6.0/7.5, 8.5	-5 to -20	0.78% to 17.41% endothelial cell loss
Artisan 206	Ophtech	Concave-convex PMMA	5.0-6.0/7.5, 8.5	-3.0 to -23.0 (0.5)	—
Artisan 203	Ophtech	PMMA	5.0	+1.0 to +12.0 (0.5)	—
Artisan for Astigmatism	Ophtech	Biconcave PMMA	5.0/8.5	—	A: cylinder on axis, B: cylinder perpendicular to axis
Worst-Fechner	—	Biconcave PMMA	4.0-5.0/8.5	-5.0 to -20.0 (1.0)	17.6% endothelial cell loss, 31.03 to 28.8 pigment photons/ms at 24 months

Abbreviations: *AMO = Advanced Medical Optics, Inc; PMMA = polymethyl methacrylate; ms = milliseconds.*

Table 3. Summary of posterior chamber phakic intraocular lenses.

Model	Manufacturer	Material	Optic/overall diameter (mm)	Range (step) [D]	Remarks	Formula
Adatomed (094M-1)	Chiron	Biconcave Polydimethylsiloxane	5.5/11.5-13.0 x 6.5	-8.0 to -21.0	44.06% anterior subcapsular cataract, 1.46% nucleosclerosis; 54.23% pigment deposits	Van der Heijde/ Holladay
Staar (ICM series)	Staar	Foldable concave-convex collamer, (collagen-polymer, 2-hydroxyethyl methacrylate)	4.5-5.5/12.0-13.0 x 6	-3.0 to -20.0	Sizing: white-to-white minus 0.5 mm; 9.5%-13.04% cataract; 38.10% pigment deposits	Van der Heijde/ Holladay
ICL V4 (ICM)	Staar	Collamer	4.5-5.5/11.5 to 13.0	-3.0 to -20.0	For myopia	Van der Heijde/ Holladay
ICL V4 (ICH)	Staar	Collamer	5.5	+3.0 to +17.0	For hyperopia; sizing according to anterior chamber depth: 2.8-2.9 mm: -0.6 mm, 3.0-3.1:-0.4, 3.2: -0.2, ≥3.2: 0	Van der Heijde/ Holladay
Toric ICL	Staar	Collamer	—	to +6.0	—	Van der Heijde/ Holladay
RPL Medennium (PRL-100, PRL-101)	CIBA	Biconcave silicon	4.5-5.0/10.8 for PRL-100, 11.3 for PRL-101	-3.0 to -20.00 (1.0 for PRL-100, 0.5 for PRL-101)	'Floats' due to hydrophobic; available for white-to-white distance <11.0 mm	Vertex formula: P=ref/ (1-0.012* refraction)
PRL-200	CIBA	Concave-convex silicon	4.5/10.6	+3.0 to +15.0 (0.5)	Maximum hyperopic correction is +11 D	Conversion table
Sticklens	IOLTECH	28% hydrophilic acrylic	6/11.0, 11.5, 12.0	—	—	Van der Heijde/ Holladay
ThinLens	ThinOptX	Hydrophilic acrylic	4.0-6.0	—	—	Van der Heijde/ Holladay

The future of phakic intraocular lenses

Now that there is sufficient experience of PIOL implantation, the designs of the lenses are evolving to fit a smaller wound size and give better outcomes.[31] With the recent acceptance of PIOL implantation in the USA[70] and the development of toric PIOLs,[26,66] PIOL implantation may provide an alternative treatment for patients with high refractive errors.[90] The use of LASIK has been suggested to treat myopia up to -12 D, PC PIOL to treat myopia of -12 to -18 D, and bioptics (PIOL implantation plus corneal surgery) to treat myopia of greater than -18D, with the LASIK procedure performed at least a month after PC PIOL implantation.[87,91] However, longer postoperative evaluation of the complications of these procedures are needed despite the fact that the lenses have been in use for more than a decade.

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